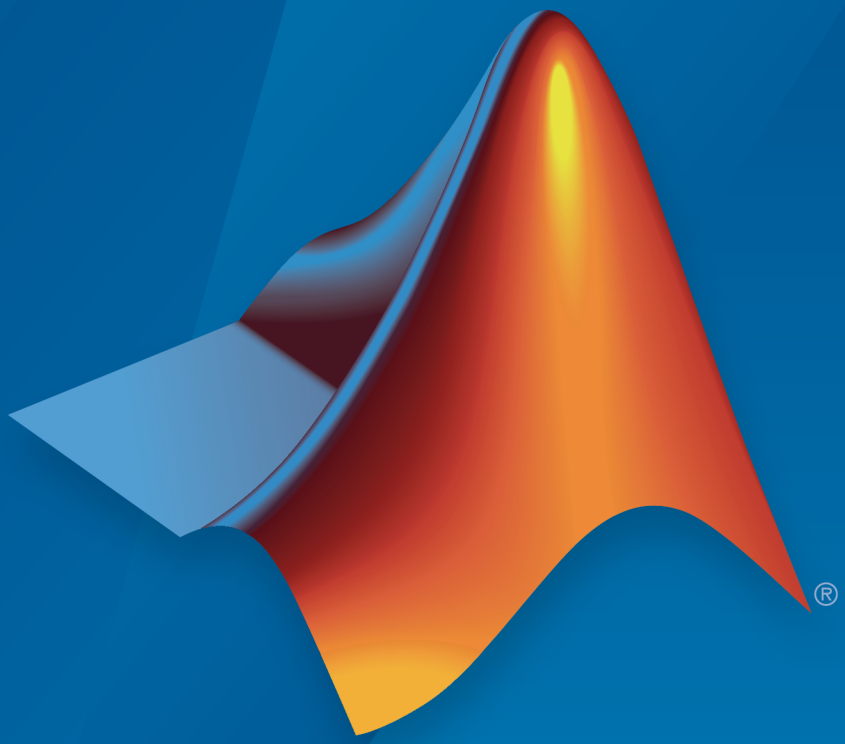
LTE System Toolbox™

Reference



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LTE System Toolbox™ Reference

Revision History

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Contents

List of Abbreviations

A Selected Bibliography

Functions — Alphabetical List

addlteobsolete

Add obsolete LTE Toolbox interface to search path

Syntax

```
addlteobsolete
```

Description

`addlteobsolete` prefixes the directory `matlabroot\toolbox\lte\lteobsolete` to the MATLAB® path, which enables the obsolete LTE Toolbox interface.

Note:

- This interface is provided for backwards compatibility. It will now result in runtime errors indicating which new functions to use.
- You can undo your changes by calling the `rmlteobsolete` function.

Examples

Add Obsolete LTE Toolbox Interface to Search Path

Add the directory associated with the obsolete LTE Toolbox interface to the MATLAB® path.

View the current MATLAB path by calling the `pathtool` function.

```
pathtool
```

The Set Path dialog box appears. Scroll down through the listings to find the LTE System Toolbox™ directories as shown here.

If you see the listing `...\toolbox\lte\lteobsolete`, you do not need to run the `addlteobsolete` function and can exit this example.

Otherwise, click **Close** to close the Set Path dialog box and add the obsolete LTE Toolbox interface to the path by executing the `addlteobsolete` function.

```
addlteobsolete
```

```
Warning: Could not save updated path.
```

To confirm the changes, call the `pathtool` function again.

```
pathtool
```

The Set Path dialog box appears again. Find the LTE System Toolbox directories at the top of the list, as shown here.

The 2nd listing, `...\toolbox\lte\lteobsolete`, shows that you have added the obsolete LTE Toolbox interface to the search path. Click **Close** again to close the Set Path dialog box.

See Also

See Also

`rmlteobsolete`

Introduced in R2014a

lteACKDecode

HARQ-ACK channel decoding

Syntax

```
out = lteACKDecode(chs,in)
```

Description

`out = lteACKDecode(chs,in)` performs the block decoding on soft input data, `in`, assumed to be encoded using the procedure defined for HARQ-ACK in TS 36.212 [1], Section 5.2.2.6 for given PUSCH channel transmission configuration `chs`. The decoded output, `out`, is a vector of length `OACK`, the number of uncoded HARQ-ACK bits transmitted.

Note: If `NBundled` is 0, TDD ACK-NACK descrambling is disabled.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `chs.NLayers` is the total number. See “UL-SCH Parameterization” for further details.

The block decoding is performed separately on each soft input data codeword using a maximum likelihood (ML) approach, assuming that `in` has been demodulated and equalized to best restore the originally transmitted values.

The HARQ-ACK decoder performs different type of block decoding depending upon the number of uncoded HARQ-ACK bits to be recovered (`OACK`). For `OACK` less than 3 bits, the decoder assumes the bits are encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6.

For decoding between 3 and 11 HARQ-ACK bits, the decoder assumes the bits are block encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6.4. For greater than

11 bits, the decoder performs the inverse procedure described in TS 36.212 [1], Section 5.2.2.6.5.

Examples

Decode HARQ-ACK Channel

Show the block decoding of 3 coded HARQ-ACK information bits.

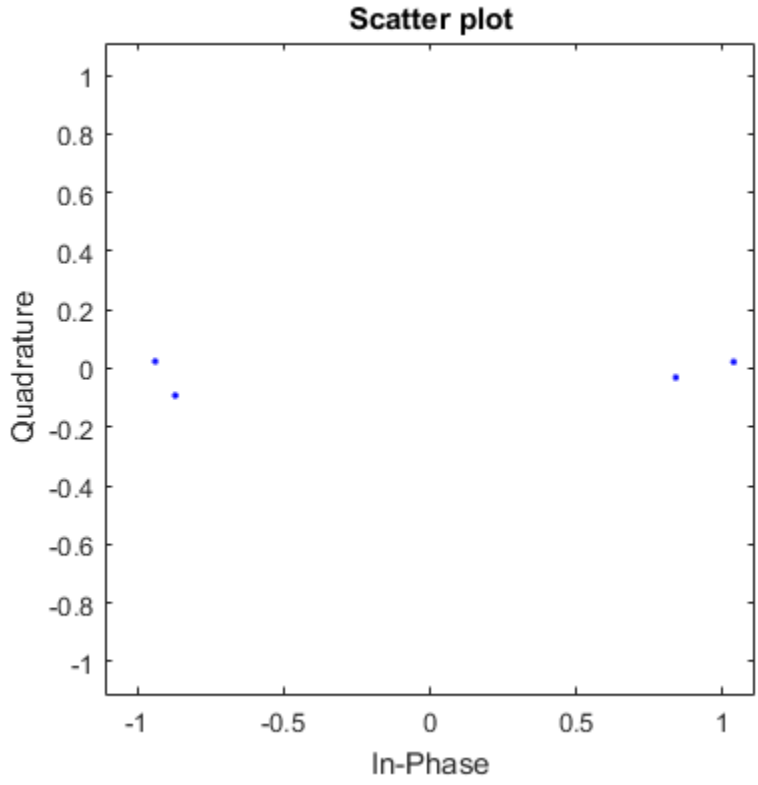
Create input and initialize channel structure. Encode bits and turn logical bits into soft data compatible with log-likelihood ratio check. Use `pskmod` with an initial phase offset of π to align mapping with LTE codebook.

Perform HARQ-ACK bit encoding and modulation.

```
in = [1;0;1];
chs = struct('Modulation','QPSK','QdACK',2,'OACK',length(in));

encodedBits = lteACKEncode(chs,in);
encodedBits = pskmod(double(encodedBits),2,pi());
```

Pass transmitted encoded bits through an AWGN channel with a 20 dB signal-to-noise ratio. Show a `scatterplot` of the noisy received HARQ-ACK softbits.

```
rxBits = awgn(encodedBits,20);
scatterplot(rxBits)
```



Decode the received softbits. Compare the decoded bits with the input bits to show the bits have been recovered with no error.

```
decodedBits = lteACKDecode(chs,rxBits)
isequal(in,decodedBits)
```

```
decodedBits =

     1
     0
     1
```

```
ans =

  logical

   1
```

Input Arguments

chs — PUSCH-specific channel transmission configuration

scalar structure | structure array

PUSCH-specific channel transmission configuration, specified as a structure or a structure array, which contains the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or a cell array of these character vectors	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
`OACK`	Optional	nonnegative scalar integer, 0 (default)	Number of uncoded HARQ-ACK bits. The HARQ-ACK decoder performs different type of block decoding depending upon the number of uncoded HARQ-ACK bits to be recovered (`OACK`). For `OACK` less than 3 bits, the decoder assumes the bits are encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6. For decoding between 3 and 11 HARQ-ACK bits, the decoder assumes the bits are block encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6.4. For greater than 11 bits, the decoder performs the inverse procedure described in TS 36.212 [1], Section 5.2.2.6.5.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.

Parameter Field	Required or Optional	Values	Description
`NBundled`	Optional	0 (default), 1, …, 9	TDD HARQ-ACK bundling scrambling sequence index. When set to 0, the function disables the TDD HARQ-ACK bundling scrambling. Therefore, it is off by default.

`in` — Soft input data

numeric vector

Soft input data, specified as a numeric vector. The input data is assumed to be encoded using the procedure defined for HARQ-ACK in TS 36.212 [1], Section 5.2.2.6.

Output Arguments

`out` — Decoded HARQ-ACK channel

numeric column vector

Decoded HARQ-ACK channel output, returned as an `OACK`-by-1 column vector.

Data Types: `double`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteACKEncode` | `lteCQIDecode` | `lteRIDecode` | `lteUCIDecode` | `lteULSCHDecode` | `lteULSCHDeinterleave`

Introduced in R2014a

lteACKEncode

HARQ-ACK channel encoding

Syntax

```
out = lteACKEncode(chs,in)
```

Description

`out = lteACKEncode(chs,in)` returns the coded HARQ-ACK information bits after performing block coding defined for HARQ-ACK in TS 36.212 [1], Section 5.2.2.6 . The input argument, `in`, is a vector or cell array containing up to 20 HARQ-ACK information bits. The output argument, `out`, is the encoded bits in the same form.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for further details.

Since the HARQ-ACK bits are carried on all defined codewords, a single input results in a cell array of encoded outputs if multiple codewords are parameterized. This allows for easy integration with the other toolbox functions.

The HARQ-ACK coder performs different types of block coding depending upon the number of HARQ-ACK bits in vector `in`. If `in` consists of one element, it uses TS 36.212 [1], Table 5.2.2.6-1. If `in` consists of two elements, it uses TS 36.212 [1], Table 5.2.2.6-2 [1] for encoding. The placeholder bits, x and y in the referenced tables, are represented by –1 and –2, respectively.

Similarly, for between 3 and 11 bits, the HARQ-ACK encoding is performed as described in TS 36.212 [1], Section 5.2.2.6.4. For bits greater than 11, the encoding is performed as described in TS 36.212 [1], Section 5.2.2.6.5.

Examples

Encode HARQ-ACK Channel with one codeword

Encode a HARQ-ACK information bit for one codeword with 16QAM modulation.

```
ackbit = 1;
chs.Modulation = '16QAM';
chs.QdACK = 1;
out1 = lteACKEncode(chs,ackbit)
```

```
Warning: Using default value for parameter field NLayers (1)
Warning: Using default value for parameter field NBundled (0)

out1 =

  4×1 int8 column vector

    1
   -2
   -1
   -1
```

Encode HARQ-ACK Channel with two codewords

Encode a HARQ-ACK information bit for two codewords with differing modulation schemes.

```
ackbit = 1;
chs.Modulation = {'16QAM' '64QAM'};
chs.NLayers = 2;
chs.QdACK = 1;
out2 = lteACKEncode(chs,ackbit)
```

```
out2 =

  1×2 cell array

    [4×1 int8]    [6×1 int8]
```

Input Arguments

`chs` — PUSCH-specific channel transmission configuration

scalar structure | structure array

PUSCH-specific channel transmission configuration, specified as a structure or a structure array, which contains the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`QdACK`	Required	nonnegative scalar integer	Number of coded HARQ-ACK symbols for ACK or NACK (*Q'_ACK*)
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or a cell array of these character vectors	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers, total or per codeword
`NBundled`	Optional	0 (default), 1, …, 9	TDD HARQ-ACK bundling scrambling sequence index. When set to 0, the function disables the TDD HARQ-ACK bundling scrambling. Therefore, it is off by default.

`in` — HARQ-ACK information bits

logical vector of length 1 to 20 | cell array of logical vectors

HARQ-ACK information bits, specified as a logical vector or a cell array of logical vectors. Each vector can have a length of up to 20 information bits.

Data Types: `logical` | `double` | `cell`

Output Arguments

`out` — Encoded HARQ-ACK information bits

integer column vector | cell array of integer column vectors

Encoded HARQ-ACK information bits, returned as either an integer column vector or a cell array of integer column vectors. The encoded bits are in the same form as the input bits. Therefore, if the PUSCH-specific parameter structure, `chs`, defines multiple codewords, `out` is a cell array.

Data Types: `int8` | `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteACKDecode` | `lteCQIEncode` | `lteRIEncode` | `lteUCIEncode` | `lteULSCH` | `lteULSCHInterleave`

Introduced in R2014a

lteBCH

Broadcast channel

Syntax

```
codeblk = lteBCH(enb,trblk)
```

Description

`codeblk = lteBCH(enb,trblk)` returns a vector of BCH transport channel coded bits. The encoding process includes CRC calculation and attachment, convolutional encoding, and rate matching as defined in TS 36.212 [1], Section 5.3.1.

The rate matching internal to the coding results in many repetitions of the coded block. This repetition is deliberate so that part of a received block can be successfully decoded in isolation. Typically, the receiver can recover the BCH bits from the reception of just one frame (¼ of the transmitted block), rather than waiting 40 ms (four frames) for the full block to be received.

Examples

Encode BCH Information Bits

Generate the BCH coded vector of length 1920, corresponding to normal cyclic prefix.

```
enb = struct('CellRefP',1,'CyclicPrefix','Normal');
bchCoded = lteBCH(enb,ones(24,1));
bchCodedSize = size(bchCoded)
```

```
bchCodedSize =

        1920           1
```

Input Arguments

`enb` — eNodeB cell-wide settings

scalar structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

`trblk` — Transport block

numeric vector

Transport block, specified as a numeric vector of length 24 bits. This argument represents the transport block delivered to the BCH every 40 ms.

Output Arguments

`codeblk` — BCH transport channel coded bits

numeric column vector

BCH transport channel coded bits, returned as an integer column vector with 1920 bits for normal cyclic prefix or 1728 bits for extended cyclic prefix.

Data Types: `int8`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCHDecode` | `lteMIB` | `ltePBCH`

Introduced in R2014a

lteBCHDecode

Broadcast channel decoding

Syntax

```
[trblk,cellrefp] = lteBCHDecode(enb,softbits)
```

Description

`[trblk,cellrefp] = lteBCHDecode(enb,softbits)` returns a vector, `trblk`, of the decoded information bits (24 bits). `cellrefp` is the number of cell-specific reference signal antenna ports detected in the CRC mask for given input, `softbits`, and the structure, `enb`. This function performs the inverse of the Broadcast Channel (BCH) processing described in TS 36.212 [1], Section 5.3.1.

Examples

Decode BCH-Encoded Block

Perform BCH coding of one transport block, and BCH decoding of part (one quarter) of the encoded block. In a practical system, this approach would be used to attempt BCH decoding on the one quarter part of the encoded block that is transmitted in the first subframe of each frame.

Create cell-wide configuration structure, initialized to RMC R.4. Perform BCH coding of one transport block.

```
enb = lteRMCDL('R.4');
bchCoded = lteBCH(enb,ones(24,1));
```

Perform BCH decoding of one quarter of the transport block.

```
out = bchCoded(1:length(bchCoded)/4);
[bchDecoded,cellRefP] = lteBCHDecode(enb,out);
bchDecoded(1:10)
```

```
ans =

  10×1 int8 column vector

   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
```

Input Arguments

`enb` — eNodeB cell-wide settings

scalar structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

`softbits` — Soft bits to decode

numeric vector

Soft bits to decode, specified as a numeric vector. This vector can have any length.

The transport block size, 24, is relatively small when compared to the number of coded bits sent in the BCH transmission, 1920 or 1728. For this reason, the rate matching internal to the BCH coding results in many repetitions of the coded block. This decoder allows the input argument `softbits` to be of any length because, successful decoding of coded BCH blocks is often possible using a fraction of the full coded block length.

Output Arguments

`trblk` — Decoded information bits

integer column vector

Decoded information bits, returned as a 24-by-1 integer column vector.

Data Types: `int8`

`cellrefp` — Number of cell-specific reference signal (CRS) antenna ports

0 | 1 | 2 | 4

Number of cell-specific reference signal (CRS) antenna ports detected, returned as a nonnegative scalar integer. Possible values are 0, 1, 2, and 4. If the value is 0, a CRC error has been detected.

Data Types: `uint32`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCH` | `ltePBCHDecode`

Introduced in R2014a

lteCFI

Control format indicator block encoding

Syntax

```
cw = lteCFI(enb)
```

Description

`cw = lteCFI(enb)` returns a 32-element vector, `cw`, that represents the rate 1/16 block encoding of the control format indicator (CFI) value defined in the `CFI` field of the `enb` structure.

The value for CFI can be 1, 2, or 3. This value indicates the time span, in OFDM symbols, of the DCI PDCCH transmission (the control region) in that downlink subframe. For bandwidths in which `NDLRB` is greater than 10 RB, the span of the DCI in OFDM symbols is the same as the actual CFI value. If `NDLRB` is less than or equal to 10 RB, the span is *CFI*+1 symbols.

Examples

Encode CFI Value

Generate the 32-element vector that represents block encoding of a CFI value of 2.

```
cw = lteCFI(struct('CFI',2));
cw(1:10)
```

```
ans =

  10×1 int8 column vector

   1
   0
   1
   1
```

```
0
1
1
0
1
1
```

Input Arguments

enb — eNodeB cell-wide settings

scalar structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (correspondin to a frame).	Control format indicator (CFI) value. In TDD mode, CFI varies per subframe for the RMCs ('R.0', 'R.5', 'R.6', 'R.6-27RB', 'R.12-9RB') The value for CFI can be 1, 2, or 3. This value indicates the time span, in OFDM symbols, of the DCI PDCCH transmission (the control region) in that downlink subframe. For bandwidths in which NDLRB is greater than 10 RB, the span of the DCI in OFDM symbols is the same as the actual CFI value. If NDLRB is less than or equal to 10 RB, the span is *CFI*+1 symbols.

Output Arguments

cw — CFI codeword

integer column vector

CFI codeword, returned as an integer column vector of length 32. This vector represents the 1/16 block encoding of the CFI value defined in structure enb.

Data Types: `int8`

See Also

See Also

`lteCFIDecode` | `ltePCFICH`

Introduced in R2014a

lteCFIDecode

Control format indicator block decoding

Syntax

```
cfi = lteCFIDecode(ibits)
```

Description

`cfi = lteCFIDecode(ibits)` performs the block decoding on soft input data `ibits`, assumed to be encoded using procedure defined in TS 36.212 [1], Section 5.3.4.1. The output, `cfi`, is a scalar representing the control format indicator (CFI) value resulted after performing block decoding on input data. Strictly speaking, `ibits` should be a vector 32 bits long, as per encoded `cfi`. See the `lteCFI` function reference for details. However, this function can decode any size segment of encoded data.

The value for CFI can be 1, 2, or 3. This value indicates the time span, in OFDM symbols, of the DCI PDCCH transmission (the control region) in that downlink subframe. For bandwidths in which `NDLRB` is greater than 10 RB, the span of the DCI in OFDM symbols is the same as the actual CFI value. If `NDLRB` is less than or equal to 10 RB, the span is *CFI*+1 symbols.

Examples

Decode CFI Block

Decode a noisy 32-element vector that represents the block encoding of the control format indicator (CFI) value.

```
cw = double(lteCFI(struct('CFI',2)));
noisycw = cw + 0.4*randn(length(cw),1);
cfi = lteCFIDecode(noisycw)
```

```
cfi =

  int32
```

2

Input Arguments

`ibits` — Soft input data

numeric vector

Soft input data, specified as a numeric vector of length 32. This input data is assumed to be encoded using the procedure defined in TS 36.212 [1], Section 5.3.4.1.

Output Arguments

`cfi` — Control format indicator value

1 | 2 | 3

Control format indicator value, returned as a positive scalar integer. This integer represents the CFI value resulting from performing block decoding on a vector of soft input data, `ibits`.

The value for CFI can be 1, 2, or 3. This value indicates the time span, in OFDM symbols, of the DCI PDCCH transmission (the control region) in that downlink subframe. For bandwidths in which `NDLRB` is greater than 10 RB, the span of the DCI in OFDM symbols is the same as the actual CFI value. If `NDLRB` is less than or equal to 10 RB, the span is *CFI*+1 symbols.

Data Types: `int32`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCFI` | `ltePCFICHDecode`

Introduced in R2014a

lteCQIDecode

Channel quality information channel decoding

Syntax

```
out = lteCQIDecode(chs,in)
```

Description

`out = lteCQIDecode(chs,in)` performs the decoding on soft input data, `in`, assumed to be encoded using the procedure defined for channel quality information (CQI) in TS 36.212, Sections 5.2.2.6 and 5.2.2.6.4 [1] for given channel transmission configuration, `chs`. The decoded output, `out`, is a vector of length `OCQI`, the number of uncoded CQI bits transmitted.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for further details.

The block decoding is performed separately on each soft input data using a maximum likelihood (ML) approach, which assumes that `in` has been demodulated and equalized to best restore the original transmitted values. The length of CQI bits defines the decoding process.

If the number of CQI bits, `OCQI`, is less than or equal to 11, a block decoding is performed to invert the coding procedure defined in TS 36.212, Section 5.2.2.6.4 [1]. If `OCQI` is greater than 11, the CQI bits are recovered by performing rate matching to `OCQI`, tail-biting Viterbi decoding, and 8-bit CRC decoding.

Examples

Decode CQI bits

Decode encoded CQI bits.

Create input stream and initialize channel settings structures for encoding and decoding. Encode CQI bits and turn logical bits into soft data. Decode the CQI bits.

```
cqi = [0; 1; 0; 1; 0; 1];

chsEnc.Modulation = 'QPSK';
chsEnc.QdCQI = 16;
chsEnc.NLayers = 1;

chsDec.NLayers = 1;
chsDec.OCQI = 6;

enc = lteCQIEncode(chsEnc,cqi);
enc = double(enc)-0.5;

rxCqi = lteCQIDecode(chsDec,enc)
```

```
rxCqi =

  6×1 logical array

   0
   1
   0
   1
   0
   1
```

Input Arguments

chs — Channel-specific transmission configuration

scalar structure | structure array

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
OCQI	Optional	nonnegative scalar integer, 0 (default)	Number of uncoded channel quality information (CQI) bits

Parameter Field	Required or Optional	Values	Description
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.

`in` — Encoded soft input data

numeric vector

Encoded soft input data, specified as a numeric vector.

Output Arguments

`out` — Decoded output

logical column vector

Decoded output, returned as a logical column vector of length `OCQI`.

Data Types: `logical`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteACKDecode` | `lteCQIEncode` | `lteRIDecode` | `lteUCIDecode` | `lteULSCHDecode`

Introduced in R2014a

lteCQIEncode

Channel quality information channel encoding

Syntax

```
out = lteCQIEncode(chs,in)
```

Description

`out = lteCQIEncode(chs,in)` returns the encoded channel quality information (CQI) bits after performing channel coding defined for CQI in TS 36.212 [1], Sections 5.2.2.6 and 5.2.2.6.4. `in` should be a vector or cell array containing the CQI bits and `out` is the encoded bits in the same form. `out` is also cell array if the PUSCH-specific parameter structure, `chs`, defines multiple codewords.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for further details.

While the CQI information bits are carried on one codeword only, a single input still results in a cell array of encoded outputs if multiple codewords are parameterized. In this case, the `QdCQI` field should contain a 0 in the position of the unused codeword. This allows for easy integration with the other toolbox functions.

The CQI coder uses two different coding schemes depending upon the number of CQI bits to be coded. If the number of CQI bits are less than or equal to 11, the channel coding of the CQI bits is performed according to TS 36.212 [1], Section 5.2.2.6.4. For CQI bits greater than 11, the coding process includes 8-bit CRC attachment, tail-biting convolutional coding and rate matching to the output length deduced from parameters `QdCQI` and `Modulation`.

Examples

Encode CQI Bits for One Codeword

Generate the coded CQI bits for a single codeword.

Create input stream and initialize channel settings structure. Encode CQI bits.

```
in = [0; 1; 0; 1; 0; 1];
chs1.Modulation = '16QAM';
chs1.QdCQI = 4;
chs1.NLayers = 2;

codedCqi1 = lteCQIEncode(chs1,in)
```

```
codedCqi1 =

  32×1 int8 column vector

   1
   1
   1
   1
   0
   1
   0
   1
   0
   1
   1
   0
   0
   1
   1
   0
   0
   0
   1
   1
   0
   0
   0
   1
```

```
     0
     0
     0
     1
     1
     0
     1
     0
```

Encode CQI Bits for Second of Two Codewords

Generate the coded CQI bits for two codewords with CQI on the second codeword.

Create input stream and initialize channel settings structure. Encode CQI bits. In this case the CQI is on the second codeword. The output is a cell array where the first cell is empty.

```
in = [0; 1; 0; 1; 0; 1];
chs2.Modulation = {'16QAM' '16QAM'};
chs2.QdCQI = [0 4];
chs2.NLayers = 2;

codedCqi2 = lteCQIEncode(chs2,in)
```

```
codedCqi2 =

  1×2 cell array

    [0×1 int8]    [16×1 int8]
```

Input Arguments

chs — Channel-specific transmission configuration

scalar structure | structure array

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`QdCQI`	Required	nonnegative scalar integer	Number of coded channel quality information (CQI) symbols (*Q'_CQI*)
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or a cell array of these character vectors	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.

`in` — CQI input bits

numeric vector | cell array of numeric vectors

CQI input bits, specified as a numeric vector or a cell array of numeric vectors.

Output Arguments

`out` — Encoded CQI output bits

integer vector | cell array of integer vectors

Encoded CQI output bits, returned as an integer vector or a cell array of integer vectors. This argument contains the coded CQI bits after performing channel coding.

Data Types: `int8` | `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteACKEncode` | `lteCQIDecode` | `lteRIEncode` | `lteUCIEncode` | `lteULSCH`

Introduced in R2014a

lteCQISelect

PDSCH channel quality indication calculation

Syntax

```
[cqi,sinrs] = lteCQISelect(enb,chs,hest,noiseest)
```

Description

`[cqi,sinrs] = lteCQISelect(enb,chs,hest,noiseest)` calculates PDSCH CQI (Channel Quality Indication) for the given cell-wide configuration, `enb`, channel configuration, `chs`, channel estimate, `hest`, and receiver noise variance `noiseest`. For more information, see “CQI Selection” on page 1-41.

Examples

Calculate CQI

An empty resource grid for RMC R.13 is populated with cell-specific reference signals symbols. The signal is filtered through the channel, demodulated and the corresponding channel is estimated along with an estimate of noise power spectral density on the reference signal subcarriers. The estimates are used for CQI calculation.

Populate an empty resource grid for RMC R.13 with cell-specific reference signal symbols and modulate the waveform. Add noise to `txWaveform`. Configure an EPA fading channel and filter the signal through this channel.

```
enb = lteRMCDL('R.13');
reGrid = lteResourceGrid(enb);
reGrid(lteCellRSIndices(enb)) = lteCellRS(enb);
[txWaveform,info] = lteOFDMModulate(enb,reGrid);

noise = 0.5*complex(randn(size(txWaveform)),randn(size(txWaveform)));
txWaveform_nz = txWaveform + noise;

chcfg.SamplingRate = info.SamplingRate;
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 4;
```

```
chcfg.DopplerFreq = 5;
chcfg.MIMOCorrelation = 'Low';
chcfg.InitTime = 0;
chcfg.Seed = 1;
rxWaveform = lteFadingChannel(chcfg,txWaveform_nz);
```

Demodulate the received signal. Perform downlink channel estimate and noise power spectral density estimatation on the demodulated signal. Use estimates of channel and noise power spectral density for CQI calculation.

```
rxSubframe = lteOFDMDemodulate(enb,rxWaveform);

cec.FreqWindow = 1;
cec.TimeWindow = 15;
cec.InterpType = 'cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 1;
cec.InterpWindow = 'Centered';
[hest, noiseEst] = lteDLChannelEstimate(enb,cec,rxSubframe);

cqi = lteCQISelect(enb,enb.PDSCH,hest,noiseEst)
```

```
cqi =

     5
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure. The structure contains the following parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})

Parameter Field	Required or Optional	Values	Description
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefi	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
TDDConf	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NSubfra	Required	0 (default), nonnegative scalar integer	Subframe number
The following parameters apply when `chs.TxScheme` is set to `'Port7–14'`			
CSIRefP	Required	1, 2, 4, 8	Array of number of CSI-RS antenna ports
CSIRSCo	Required	Scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRSpe	Optional	`'On'` (default), `'Off'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.

Parameter Field	Required or Optional	Values	Description
`NFrame`	Optional	0 (default), nonnegative scalar integer	Frame number

`chs` — Channel-specific transmission configuration

structure | structure array

Channel-specific transmission configuration, specified as a structure or structure array. The structure contains the following parameter fields:

Parameter Field	Required or Optional	Values	Description
`NLayers`	Required	Integer from 1 to 8	Number of transmission layers.
`CSIMode`	Required	`'PUCCH 1-0'`, `'PUCCH 1-1'`, `'PUSCH 1-2'`, `'PUSCH 3-0'`, `'PUSCH 3-1'`	CSI reporting mode
`TxScheme`	Required	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMu` `'MultiUser` `'Port5'`, `'Port7-8'`, `'Port8'`, `'Port7-14'`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td>SINRs90pc</td><td>Optional</td><td>15 element vector, or function handle</td><td>A vector of 15 SINR values or a function handle to a function of the form f(enb, chs) which returns a vector of 15 SINR values, one for each CQI index 1, ..., 15. These correspond to the lowest SINR for which the throughput of the PDSCH in the CQI/CSI reference resource, for the given configuration and CQI index, is at least 90%. Default is to internally select SINRs based on configuration given in enb and chs, assuming perfect channel estimation and either MMSE equalization or transmit diversity decoding (as appropriate for the transmission scheme) at the receiver.</td></tr>
<tr><td colspan="4">The following parameter applies for 'SpatialMux', 'MultiUser', 'Port5', 'Port7-8', 'Port8', 'Port7–14' transmission schemes.</td></tr>
</table>

Parameter Field	Required or Optiona	Values	Description
PMISet	Require	Integer vector with element values from 0 to 15.	A vector of Precoder Matrix Indications. The vector may contain either a single value (corresponding to single PMI mode) or multiple values (corresponding to multiple or subband PMI mode). For the `'Port7-14'` transmission scheme with eight CSI-RS ports or for CSI reporting with the alternative codebook for four antennas, an additional first value indicates the wideband codebook index, `i1`, and subsequent values indicate the subband codebook indices, `i2`, or the wideband codebook index, `i2`. Valid value range depends on `CellRefP`, `CSIRefP`, `NLayers`, `TxScheme`, and `AltCodebook4Tx`. For more information about setting PMI parameters, see `ltePMIInfo`.
The following parameter applies for `'Port7–14'` transmission scheme with `CSIRefP` equal to 4, or for `'Port7-8'` or `'Port8'` transmission scheme with `CellRefP` equal to 4.			
AltCodel	Require	`'Off'` (default), `'On'`	If set to `'On'`, enables the alternative codebook for CSI reporting with four antennas defined in TS 36.213, Tables 7.2.4-0A to 7.2.4-0D. The default is `'Off'`. (*alternativeCodebookEnabledFor4TX-r12*)
Additionally, one of the following fields must be included. [see note 1]			
NCodewo	Require	1, 2	Number of codewords
Modulat	Require	`'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.

Parameter Field	Required or Optional	Values	Description
[note 1] – Specify the number of codewords directly in the `NCodewords` field. Alternatively, if the `Modulation` field is provided, the number of codewords is established from the number of modulation formats. This value lets you establish the correct number of codewords using the channel transmission configuration structure, `chs`, as provided to `ltePDSCH` function on the transmit side. If present, the `NCodewords` field takes precedence.			

`hest` — Channel estimate

multidimensional array

Channel estimate, specified as a *K*-by-*L*-by-*NRxAnts*-by-*P* array, where:

- *K* is the number of subcarriers.
- *L* is the number of OFDM symbols.
- *NRxAnts* is the number of receive antennas.
- *P* is the number of transmit antennas.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Receiver noise variance

numeric scalar

Receiver noise variance, specified as a numeric scalar. `noiseest` is an estimate of the received noise power spectral density.

Data Types: `double`

Output Arguments

`cqi` — Channel quality information

column vector

Channel quality information, returned as a column vector containing a channel quality information report. Report contents depend on the CSI reporting mode.

Report Mode	Reporting Contents
Single codeword:	
'PUCCH 1-0'	A single wideband CQI index
'PUSCH 3-0'	A single wideband CQI index, followed by a subband differential CQI offset level for each subband.
Two codewords:	
'PUCCH 1-1'	A single wideband CQI index for codeword 0, followed by a spatial differential CQI offset level for codeword 1.
'PUSCH 1-2'	A single wideband CQI index for codeword 0, followed by a single wideband CQI index for codeword 1.
'PUSCH 3-1'	A single wideband CQI index for codeword 0, followed by a subband differential CQI offset level for each subband for codeword 0, followed by a single wideband CQI index for codeword 1, followed by a subband differential CQI offset level for each subband for codeword 1.

Note: CSI reporting modes, are separated into the modes that support one or two codewords, as described by the standard. The CQI select function derives these code words from `chs.NCodewords` or `chs.Modulation`.

`sinrs` — signal-to-interference plus noise ratios

matrix

Signal-to-interference plus noise ratios, in dB, returned as a matrix. Each column of the matrix represents a single codeword. If subband CQI reporting is configured, the SINR for the wideband CQI is in the first row, followed by the `sinrs` for the subband CQIs in subsequent rows. `sinrs` is an optional output.

Definitions

CQI Selection

The function performs the CQI selection by first obtaining SINR (Signal to Interference and Noise Ratio) estimates for a given configuration from `ltePMISelect`. Then the function performs a lookup between those SINR estimates and the CQI index. The lookup tables are precomputed and stored in this function. CQI selection is conditioned on the rank indicated by `chs.NLayers`, except for the `'TxDiversity'` transmission scheme which has a rank of 1. On PUCCH, CQI selection corresponds to Report Type 2 (for reporting Mode1-1) or Report Type 4 (for reporting Mode 1-0). On PUSCH, the reporting is Mode 1-2, Mode 3-0, or Mode 3-1.

A CQI Index is a scalar (0,...,15), indicating the selected value of the CQI index. The CQI index is defined as per TS 36.213. The highest CQI index is selected when a single PDSCH transport block with a modulation scheme and transport block size of CQI index, and occupying a group of downlink physical resource blocks termed the CSI reference resource, can be received with a transport block error probability not exceeding 0.1. If a CQI index of 1 does not satisfy this condition, then the returned CQI index is 0. The CQI reference resource is defined in TS 36.213, Section 7.2.3. The relationship between CQI indices, modulation scheme, and code rate (from which transport block size is derived) is described in TS 36.213, Tables 7.2.3-1 and 7.2.3-2.

A subband differential CQI offset level is the difference between a subband CQI index and the corresponding wideband CQI index.

A spatial differential CQI offset level is the difference between the wideband CQI index for codeword 0 and the wideband CQI index for codeword 1.

Within the 3GPP standard, CQI offsets are reported as *CQI values*. These values are nonnegative integers corresponding to single CQI offset levels or ranges of CQI offset levels (see TS 36.213, Tables 7.2-2 and 7.2.1-2). The CQI offset levels reported here are either the single CQI offset level corresponding to the CQI value reported or the boundary value of the CQI offset level range corresponding to the CQI value reported. For example, a calculated spatial differential CQI offset level of –6 would be reported per the standard as a spatial differential CQI value of 4. This function will return a spatial differential offset level of –4 because the calculated differential CQI offset level exceeds this boundary value, meaning $-6 < -4$ (see TS 36.213, Table 7.2-2).

For transmission schemes using UE-specific beamforming (`'Port 5'`, `'Port 7-8'`, `'Port 8'`, `'Port7-14'`), the performance depends on the beamforming used. For UE-

specific beamforming, the appropriate value of `chs.SINRs90pc` field is provided. If this field is not provided, for single antenna ports, the function uses default `SINRs90pc` values.

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePMISelect` | `lteRISelect`

Introduced in R2014b

lteCRCDecode

Cyclic redundancy check decoding and removal

Syntax

```
[blk,err] = lteCRCDecode(blkcrc,poly)
[blk,err] = lteCRCDecode(blkcrc,poly,mask)
```

Description

`[blk,err] = lteCRCDecode(blkcrc,poly)` checks the input data vector for a CRC error assuming the vector comprises a block of data with the associated CRC bits attached. The data part of the input is returned in vector `blk`. The logical difference (XOR) between the attached CRC and the CRC recalculated across the data part of the input is returned in `uint32` scalar `err`. If `err` is not equal to 0, either an error has occurred or the input CRC has been masked. A logical mask can also be applied directly to `err`. See TS 36.212 [1], Section 5.1.1 for the associated polynomials.

`[blk,err] = lteCRCDecode(blkcrc,poly,mask)` checks the input data vector for a CRC error XOR-ing with the scalar `mask` parameter before it is returned in `err`. The `mask` value is applied to the CRC bits with the most significant bit (MSB) first and the least significant bit (LSB) last.

Examples

Check Data Vector for CRC Error

Check the effect of CRC decoding a block of data with and without a mask.

CRC encode attaching a masked `'24A'`-type CRC to an all-ones vector of length 100.

```
rnti = 8;
blkcrc = lteCRCEncode(ones(100,1),'24A',rnti);
```

CRC decode with the data block without using a mask.

```
[blk1,err1] = lteCRCDecode(blkcrc,'24A');
```

```
err1
```

```
err1 =

  uint32

   8
```

The logical difference between the original CRC and recalculated CRC equals the CRC mask. Since the CRC was been masked, decoding without specifying the mask, returned `err1` = 8, which is the value of `rnti`.

CRC decode using the RNTI as a mask.

```
[blk2,err2] = lteCRCDecode(blkcrc,'24A',rnti);
err2
```

```
err2 =

  uint32

   0
```

The returned output, `err2`, is 0 because the original mask, `rnti`, is XORed with itself.

Input Arguments

`blkcrc` — CRC input data bit vector

numeric column vector

CRC input data bit vector, specified as a numeric column vector. The function checks the input bit vector for a CRC error assuming that the data consists of a block of data with CRC bits attached.

`poly` — CRC polynomial

`'8' | '16' | '24A' | '24B'`

CRC polynomial, specified as `'8'`, `'16'`, `'24A'`, or `'24B'`. See TS 36.212 [1], Section 5.1.1 for the associated polynomials.

`mask` — XOR mask

scalar integer

XOR mask, specified as a scalar integer. The CRC difference is XOR-ed with `mask` before `err` is returned.

Data Types: `double`

Output Arguments

`blk` — Data bit vector

column vector

Data bit vector, returned as a column vector. `blk` is the data-only part of the input `blkcrc`.

Data Types: `int8`

`err` — Logical difference

integer

Logical difference, returned as an integer. `err` is the logical difference between the CRC and CRC recalculated across the data part of the input.

Data Types: `uint32`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCodeBlockDesegment` | `lteConvolutionalDecode` | `lteCRCEncode`

Introduced in R2014a

lteCRCEncode

Cyclic redundancy check calculation and appending

Syntax

```
blkcrc = lteCRCEncode(blk,poly)
blkcrc = lteCRCEncode(blk,poly,mask)
```

Description

`blkcrc = lteCRCEncode(blk,poly)` calculates a cyclic redundancy check (CRC) for the input data vector and returns a copy of the vector with the CRC attached. To support the correct processing of filler bits, negative input bit values are interpreted as logical 0 for the purposes of the CRC calculation. A value of –1 is used to represent filler bits. `lteCRCEncode` calculates the CRC defined by `poly` for the input bit vector `blk` and returns a copy of the input with the CRC appended in vector `blkcrc`. Valid options for the CRC polynomial are `'8'`, `'16'`, `'24A'`, or `'24B'`. See TS 36.212 [1], Section 5.1.1 for the associated polynomials.

`blkcrc = lteCRCEncode(blk,poly,mask)` XOR masks the appended CRC bits with the integral value of `mask`. The `mask` value is applied to the CRC bits with the most significant bit (MSB) first and the least significant bit (LSB) last.

Examples

Calculate and Append CRC

Calculate and append the CRC associated with an all zero vector, which is also zero.

```
crc1 = lteCRCEncode(zeros(100,1),'24A');
crc1(1:10)
```

```
ans =
```

```
  10×1 int8 column vector

   0
   0
   0
   0
   0
   0
   0
   0
   0
   0
```

The result is an all-zeros vector of length 124.

Calculate and Append CRC with MSB First

Mask the CRC bits in an MSB-first order.

Set the XOR mask to 1 to make the appended CRC bits XOR masked from the most significant to least significant bit.

```
mask = 1;
crc2 = lteCRCEncode(zeros(100,1),'24A',mask);
crc2(end-10:end)
```

```
ans =

  11×1 int8 column vector

   0
   0
   0
   0
   0
   0
   0
   0
   0
   0
   1
```

The result is all zeros, except for a single one in last element position.

Input Arguments

`blk` — Data bit vector

numeric column vector

Data bit vector, specified as a numeric column vector.

`poly` — CRC polynomial

`'8' | '16' | '24A' | '24B'`

CRC polynomial, specified as `'8'`, `'16'`, `'24A'`, or `'24B'`. See TS 36.212 [1], Section 5.1.1 for the associated polynomials.

`mask` — XOR mask

integer

XOR mask, specified as an integer. The appended CRC bits are XOR masked from the most significant to least significant bit.

Output Arguments

`blkcrc` — Bit vector with CRC

column vector

Bit vector with CRC, returned as a column vector.

Data Types: `int8`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCodeBlockSegment` | `lteConvolutionalEncode` | `lteCRCDecode`

Introduced in R2014a

lteCSICodebook

Codebook for channel state information reporting

Syntax

```
out = lteCSICodebook(nu,p,idx)
out = lteCSICodebook(nu,p,idx,table)
out = lteCSICodebook(nu,p,i1,i2)
```

Description

`out = lteCSICodebook(nu,p,idx)` returns the precoding matrix associated with channel state information (CSI) reporting as defined in TS 36.213 [1], Section 7.2.4 given the number of layers, `nu`, the number of antennas, `p`, and the codebook index, `idx`. For more information, see "CSI Codebook Reporting" on page 1-53 and `ltePMIInfo`.

`out = lteCSICodebook(nu,p,idx,table)` where `table` specifies the codebook selection table. For more information, see "CSI Codebook Reporting" on page 1-53.

`out = lteCSICodebook(nu,p,i1,i2)` where `i1` and `i2` specify the first and second codebook indices, respectively. This signature was only intended for `p` = 8. This signature may be removed in a future release, instead use `out` = lteCSICodebook(`nu`,`p`,`idx`) with `idx` = [`i1` `i2`].

Examples

Create Codebook Entry for CSI Reporting

This example creates a codebook entry for CSI reporting with 2 layers, 4 antennas, and a codebook index of 3.

```
lteCSICodebook(2,4,3)
```

```
ans =

   0.3536 + 0.0000i   0.0000 + 0.3536i
```

```
   0.0000 - 0.3536i   0.3536 + 0.0000i
  -0.3536 + 0.0000i   0.0000 + 0.3536i
   0.0000 + 0.3536i   0.3536 + 0.0000i
```

Create Alternate Codebook Entry for CSI Reporting

Create an alternative codebook entry for CSI reporting with three layers, and four antennas, using codebook indices provided.

```
lteCSICodebook(3,4,[0 7],'AltCodeBook4Tx')
```

```
ans =

   0.2887 + 0.0000i   0.0000 + 0.2887i  -0.2041 + 0.2041i
   0.2041 - 0.2041i  -0.2041 - 0.2041i   0.0000 - 0.2887i
   0.0000 - 0.2887i   0.2887 + 0.0000i  -0.2041 - 0.2041i
  -0.2041 - 0.2041i  -0.2041 + 0.2041i   0.2887 + 0.0000i
```

The codebook entry [i1 i2] = [0 7] from TS 36.213, Table 7.2.4-0C is used.

Input Arguments

`nu` — Number of transmission layers

1,...,8 | positive scalar integer

Number of transmission layers, specified as an integer from 1 to 8.

`p` — Number of transmission antennas

1 | 2 | 4 | 8 | positive scalar integer

Number of transmission antennas, specified as 1, 2, 4, or 8.

`idx` — Codebook index

0,...,15 | scalar integer | vector with two integers

Codebook index, specified as an integer or vector of two integers from 0 to 15.

- If `p` = 8, `idx` should be a pair of indices `[i1 i2]`.
- If `p` = 4 and `table` = `'AltCodebook4Tx'`, `idx` should be a pair of indices `[i1 i2]`.

- If `p` = 4 and `table` = `'StdCodebook4Tx'`, `idx` should be a single index or a pair with `i1` set to zero.
- If `p` = 1 or `p` = 2, `idx` should be a single index or a pair with `i1` set to zero.

For more information, see "CSI Codebook Reporting" on page 1-53.

Example: [0 3] indicates the codebook indices [`i1 i2`].

`i1` — First codebook index

0 (default),...,15 | scalar integer

First codebook index, specified as an integer from 0 to 15. For more information, see "CSI Codebook Reporting" on page 1-53.

`i2` — Second codebook index

0,...,15 | scalar integer

Second codebook index, specified as an integer from 0 to 15. For more information, see "CSI Codebook Reporting" on page 1-53.

`table` — Codebook selection table

'StdCodebook4Tx' (default) | 'AltCodebook4Tx' | optional

Codebook selection table for four transmission antennas, specified as `'StdCodebook4Tx'` or `'AltCodebook4Tx'`. `table` is optional and only applicable when `p` = 4. For more information, see "CSI Codebook Reporting" on page 1-53.

Data Types: `char`

Output Arguments

`out` — Precoding matrix associated with CSI reporting

complex-valued numeric matrix

Precoding matrix associated with CSI reporting, returned as a complex-valued numeric `p`-by-`nu` matrix, where `p` is the number of transmission antennas, and `nu` is the number of transmission layers. `nu` must always be less than or equal to `p`. For more information, see "CSI Codebook Reporting" on page 1-53.

Data Types: `double`
Complex Number Support: Yes

Definitions

CSI Codebook Reporting

A UE reports the precoding matrix indicator (PMI) according to the feedback modes as described in TS 36.213 [1], Section 7.2.4. `lteCSICodebook` returns the precoding matrix for CSI reporting as a `p`-by-`nu` matrix, where `p` is the number of transmission antennas (CSI-RS or CRS ports) and `nu` is the number of transmission layers (PDSCH transmission layers). `nu` must always be less than or equal to `p`. Inputs to the function are `nu`, `p`, `idx` indicating the codebook indices, and optionally `table` indicating the codebook selection table.

Reference Signal	Codebook	Number of layers, `nu`	`p`	Codebook indices, `idx`[Note 1]		`table`	Transmission scheme
				`i1`	`i2`		
`CSIRefP`	TS 36.213, Table 7.2.4-1	1	8	0–15	0–15	n/a	`'Port7-14'`
	TS 36.213, Table 7.2.4-2	2					
	TS 36.213, Table 7.2.4-3	3		0–3			
	TS 36.213, Table 7.2.4-4	4			0–7		
	TS 36.213, Table 7.2.4-5	5					
	TS 36.213, Table 7.2.4-6	6			0		
	TS 36.213, Table 7.2.4-7	7					

<table>
<tr><th rowspan="2">Reference Signal</th><th rowspan="2">Codebook</th><th rowspan="2">Number of layers, nu</th><th rowspan="2">p</th><th colspan="2">Codebook indices, idx[Note 1]</th><th rowspan="2">table</th><th rowspan="2">Transmission scheme</th></tr>
<tr><th>i1</th><th>i2</th></tr>
<tr><td></td><td>TS 36.213, Table 7.2.4-8</td><td>8</td><td></td><td>0</td><td></td><td></td><td></td></tr>
<tr><td rowspan="7">CellRefP or CSIRefP Note 2</td><td>TS 36.213, Table 7.2.4-0A</td><td>1</td><td rowspan="4">4</td><td rowspan="2">0–15</td><td rowspan="4">0–15</td><td rowspan="5">'AltCode</td><td rowspan="6">'Port7-8' or 'Port7-14' Note 2</td></tr>
<tr><td>TS 36.213, Table 7.2.4-0B</td><td>2</td></tr>
<tr><td>TS 36.213, Table 7.2.4-0C</td><td>3</td><td rowspan="2">0</td></tr>
<tr><td>TS 36.213, Table 7.2.4-0D</td><td>4</td></tr>
<tr><td>TS 36.211, Table 6.3.4.2.3-2</td><td>1–4</td><td>4</td><td rowspan="3">0</td><td>0–15</td><td>'StdCode</td></tr>
<tr><td rowspan="2">TS 36.211, Table 6.3.4.2.3-1</td><td>1</td><td rowspan="2">2</td><td>0–3</td><td rowspan="2">n/a</td></tr>
<tr><td>2</td><td>0–2</td></tr>
<tr><td>Precoding matrix = 1</td><td>1</td><td>1</td><td>0</td><td>any single antenna</td></tr>
</table>

Note 1 —

Preferred format for codebook indices, `idx`, is a two element vector, [`i1 i2`]. A scalar format is accepted when the only available setting for `i1` is zero. For this case, use the applicable scalar input range shown for `i2`.

Note 2—

`CellRefP` for the `'Port7-8'` or `CSIRefP` for the `'Port7-14'`

References

[1] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLPrecode` | `ltePDSCH` | `ltePDSCHDecode` | `ltePMIInfo` | `ltePMISelect`

Introduced in R2014a

lteCSIRS

Channel state information reference signal

Syntax

```
sym = lteCSIRS(enb)
sym = lteCSIRS(enb,opts)
```

Description

`sym = lteCSIRS(enb)` returns the channel state information reference signal (CSI-RS) symbols for transmission in a single subframe on up to eight antenna ports (p = 15,...,22). See "lteCSIRS Processing" on page 1-61.

`sym = lteCSIRS(enb,opts)` enables control of the contents and format of the returned symbols through a cell array of options, `opts`.

Examples

Create CSI-RS Symbols and Combine with Resource Grid

Generate CSI-RS symbols and combine them with a 10 MHz, release 8, port 0 PDSCH subframe resource grid.

Initialize a reference channel structure. Create a 10 MHz, release 8, port 0 PDSCH configuration parameter structure. Set subframe number to 1, number of CSI-RS antenna ports to 8, CSI-RS configuration to 0, and CSIRSPeriod to 6.

```
rmc = lteRMCDL('R.2','FDD',1);
rmc.NSubframe = 1;
rmc.CSIRefP = 8;
rmc.CSIRSConfig = 0;
rmc.CSIRSPeriod = 6;
```

The 8 antenna ports are ports 15 to 22. The setting for `CSIRSPeriod` is `Icsi-rs`, which equals [`Tcsi-rs` `Dcsi-rs`]=[10 1].

Create a 3-D resource grid to contain the subframes for all eight CSI-RS ports.

```
rgrid = lteResourceGrid(rmc,rmc.CSIRefP);
```

Write the release 8 port 0 transmission into the first plane of the resource grid.

```
[wave,rgrid(:,:,1)] = lteRMCDLTool(rmc,[1,0,0,1]);
```

Create the CSI-RS symbols for ports 15 to 22. Overwrite all ports included in the port 0 transmission with the actual CSI-RS and unused RE.

```
rgrid(lteCSIRSIndices(rmc,'rs+unused')) = lteCSIRS(rmc,'rs+unused');
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number
`CellRefP` is only used when the *`Indexing format`* option for indexing generation is `'rs+unused'`			
CellRefP	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as:

Parameter Field	Required or Optional	Values	Description
			• 'FDD' for Frequency Division Duplex or • 'TDD' for Time Division Duplex
The following parameters apply when DuplexMode is set to 'TDD'.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
CSIRSPeriod	Optional	'On' (default), 'Off', Icsi-rs (0,...,154), [Tcsi-rs Dcsi-rs]. You can also specify values in a cell array of configurations for each resource. See note 1.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following CSI-RS resource parameters apply only when CSIRSPeriod sets one, or more CSI-RS subframe configurations to any value other than 'Off'. Each parameter length must be equal to the number of CSI-RS resources required.			
CSIRSConfig	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRefP	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
NCSIID	Optional	Nonnegative scalar integer	CSI-RS scrambling identity. If this field is not present, then NCellID is used as the identity.

Parameter Field	Required or Optional	Values	Description
ZeroPowerCSIRSPer	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource. See note 1.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is only required if one, or more of the above zero power subframe configurations are set to any value other than `'Off'`.			
ZeroPowerCSIR	Required	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists. [1]

Parameter Field	Required or Optional	Values	Description
Note: 1 `CSIRSPeriod` and `ZeroPowerCSIRSPeriod` parameters control the downlink subframes in which the different CSI-RS resources are present. Valid settings include: • always `'On'` • always `'Off'` • scalar subframe configuration index `Icsi-rs` from 0 through 154 • explicit subframe periodicity and offset pair `[Tcsi-rs Dcsi-rs]` The subframes containing CSI-RS are located with `NSubframe` and the optional `NFrame` parameters. `NSubframe` can be greater than 10; thus `NSubframe` = 11 is equivalent to setting `NSubframe` to 1 and `NFrame` to 1. For more information, see TS 36.211 [1], Section 6.10.5.3.			

`opts` — Symbol generation options
character vector | cell array of character vectors

Options to control the content and format of the returned symbols, specified as a character vector or a cell array of character vectors. Values for `opts` include:

Option	Values	Description
Symbol style	`'ind'` (default), `'mat'`	Style for returning CSI-RS symbols, specified as one of the following options. • `'ind'` — returns the CSI-RS symbols as a column vector (default) • `'mat'` — returns the CSI-RS symbols as a matrix, where each column contains symbols for an individual port and CSI-RS configuration. To form a matrix, a column can contain duplicate entries.
Symbol format	`'rsonly'` (default), `'rs +unused'`	Format for the returned symbols, specified as one of the following options. • `'rsonly'` — returns only defined CSI-RS symbols (default), both zero and non-zero

Option	Values	Description
		• `'rs+unused'` — also includes zeros for the resource element (RE) locations that should be unused because they are reserved for CSI-RS on another port.

Note: Returned symbols specify the CSI-RS resource values within an N-by-M-by-antennas array. The number of antennas is `max(CSIRefP)` or if zero power CSI-RS are also defined number of antennas is `max(max(CSIRefP),4)`. For the `'rs+unused'` option, the number of antennas used to define the empty REs (either because they are zero power or they are unused in another port) is `max(max(CSIRefP),CellRefP)`.

Example: `'rs+unused'`

Data Types: `char | cell`

Output Arguments

`sym` — CSI-RS symbols

column vector (default) | matrix

CSI-RS symbols for transmission in a single subframe on up to eight antenna ports, returned as a column vector or matrix of concatenated CSI-RS symbol sequences for each of the `enb.CSIRefP` ports based on the cell-wide parameter settings. The length of `sym` is the number of resource elements. See "lteCSIRS Processing" on page 1-61.

Data Types: `double`
Complex Number Support: Yes

Definitions

lteCSIRS Processing

The `lteCSIRS` function supports the creation of multiple non-zero power CSI-RS resources and zero power CSI-RS.

By default the output symbols are returned as a column vector and are ordered as they should be mapped into the resource elements along with lteCSIRSIndices. If, according to the CSI-RS resource subframe configurations and duplex mode, there are no CSI-RS

scheduled in the subframe, then the output is empty. Optionally the returned symbols can also include zeros representing the resource elements which should be unused since they are reserved for CSI-RS symbols in one or more of the other ports. On assignment into a populated subframe grid, these zeros create empty resource elements for both Release 8, and Release 10 and 11 compatibility. When multiple non-zero power resources and zero power CSI-RS are output, the zero power CSI-RS symbols are first in the concatenated output, followed by the symbols for the ordered set of CSI-RS resources.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCellRS` | `lteCSIRSIndices` | `lteDMRS` | `lteEPDCCHDMRS` | `ltePRBS` | `ltePRS`

Introduced in R2014a

lteCSIRSIndices

CSI-RS resource element indices

Syntax

```
ind = lteCSIRSIndices(enb)
ind = lteCSIRSIndices(enb,opts)
```

Description

`ind = lteCSIRSIndices(enb)` returns the indices of the channel state information reference signal (CSI-RS) resource elements (RE) for the specified subframe. See "lteCSIRSIndices Processing" on page 1-69.

`ind = lteCSIRSIndices(enb,opts)` allows control of the format of the returned indices with a cell array of options, `opts`.

Examples

Generate Column Vector of CSI-RS RE Indices

Generate a column vector of CSI-RS resource element linear indices for ports 15 to 22 of a 10 MHz downlink subframe 0 resource grid.

Create a 10 MHz, downlink, subframe 0 configuration parameter structure. Set the number of antenna ports to 8, the CSI-RS configuration to 0, and `Icsi-rs` to 5.

```
rmc = lteRMCDL('R.2');
rmc.CSIRefP = 8;
rmc.CSIRSConfig = 0;
rmc.CSIRSPeriod = 5;
```

The 8 antenna ports are ports 15 to 22. The variable `Icsi-rs` = 5 is equivalent to a `[Tcsi-rs Dcsi-rs]` setting of `[10 0]`.

```
csirs1 = lteCSIRSIndices(rmc);
csirs1(1:5)
```

```
ans =

  5×1 uint32 column vector

   3010
   3022
   3034
   3046
   3058
```

Generate Matrix of CSI-RS RE Indices

This example shows how to generate a matrix of CSI-RS RE linear indices for ports 15 to 22 of a 10 MHz downlink subframe 0 resource grid.

Create a 10 MHz, downlink, subframe 0 configuration parameter structure. Set the number of antenna ports to 8, the CSI-RS configuration to 0, and `Icsi-rs` to 5.

```
rmc = lteRMCDL('R.2');
rmc.CSIRefP = 8;
rmc.CSIRSConfig = 0;
rmc.CSIRSPeriod = 5;
```

Generate a matrix of linear indices with eight columns.

```
csirs2 = lteCSIRSIndices(rmc,'mat');
size(csirs2)
```

```
ans =

    88     8
```

Generate Used and Unused CSI-RS RE Indices

This example shows how to generate both used and unused CSI-RS RE linear indices for ports 15 to 22 of a 10 MHz downlink subframe 0 resource grid.

Create a 10 MHz, downlink, subframe 0 configuration parameter structure. Set the number of antenna ports to 8, the CSI-RS configuration to 0, and `Icsi-rs` to 5.

```
rmc = lteRMCDL('R.2');
rmc.CSIRefP = 8;
rmc.CSIRSConfig = 0;
```

```
rmc.CSIRSPeriod = 5;
```

The 8 antenna ports are ports 15 to 22. The variable `Icsi-rs` = 5 is equivalent to a `[Tcsi-rs Dcsi-rs]` setting of `[10 0]`.

Generate both used and unused CSI-RS RE in all ports.

```
csirs3 = lteCSIRSIndices(rmc,'rs+unused');
csirs3(1:5)
```

```
ans =

  5×1 uint32 column vector

   3010
   3022
   3034
   3046
   3058
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number
`CellRefP` is only used when the *`Indexing format`* option for indexing generation is `'rs+unused'`			

Parameter Field	Required or Optional	Values	Description
CellRefP	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefix	Optional	'Normal' (default), 'Extended'	Cyclic prefix length
DuplexMode	Optional	'FDD' (default), 'TDD'	Duplexing mode, specified as: • 'FDD' for Frequency Division Duplex or • 'TDD' for Time Division Duplex
The following apply when DuplexMode is set to 'TDD'.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
CSIRSPeriod	Optional	'On' (default), 'Off', Icsi-rs (0,...,154), [Tcsi-rs Dcsi-rs]. You can also specify values in a cell array of configurations for each resource. See note 1.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following CSI-RS resource parameters apply only when CSIRSPeriod sets one, or more CSI-RS subframe configurations to any value other than 'Off'. Each parameter length must be equal to the number of CSI-RS resources required.			
CSIRSConfig	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRefP	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports

Parameter Field	Required or Optional	Values	Description
ZeroPowerCSIRSPer	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource. See note 1	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is required only if one, or more of the other zero power subframe configurations are set to any value other than `'Off'`.			
ZeroPowerCSIR	Required	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

Parameter Field	Required or Optional	Values	Description
Note: 1 The `CSIRSPeriod` and `ZeroPowerCSIRSPeriod` parameters control the downlink subframes in which the different CSI-RS resources are present. Valid settings include: • Always `'On'` • Always `'Off'` • Scalar subframe configuration index `Icsi-rs` from 0 through 154 • Explicit subframe periodicity and offset pair `[Tcsi-rs Dcsi-rs]` To locate the subframes containing CSI-RS, use the `NSubframe` parameter and the optional `NFrame` parameter. `NSubframe` can be greater than 10. Thus `NSubframe` = 11 is equivalent to setting `NSubframe` to 1 and `NFrame` to 1. For more information, see TS 36.211 [1], Section 6.10.5.3.			

`opts` — Index generation options
character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'mat'`, `'sub'`	Style for the returned indices, specified as one of the following options. • `'ind'` — returns the indices as an N_{RE}-by-1 vector (default) • `'mat'` — returns the indices as a matrix. If not precoded, each column contains indices for an individual layer/port. If precoded, each column contains symbols for a transmit antenna. To form a matrix, a column can contain duplicate entries. • `'sub'` — returns the indices as an N_{RE}-by-3 matrix. in `[subcarrier, symbol, antenna]` subscript row style. N_{RE} is the number of resource elements.

Option	Values	Description
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing format	`'rsonly'` (default), `'rs+unused'`	Format for the returned locations, specified as one of the following options. • `'rsonly'` — returns only defined CSI-RS locations (default), both zero and non-zero • `'rs+unused'` — also includes zeros for the resource element (RE) locations that should be unused because they are reserved for CSI-RS on another port.

Note: Returned indices specify the CSI-RS resource values within an N-by-M-by-antennas array. Where the number of antennas is `max(CSIRefP)` or if zero power CSI-RS are also defined number of antennas is `max(max(CSIRefP),4)`. In the case of the 'rs+unused' option, the number of antennas used to define the empty REs (either because they are zero power or they are unused in another port) is `max(max(CSIRefP),CellRefP)`.

Data Types: `char` | `cell`

Output Arguments

`ind` — Channel state information reference signal (CSI-RS) indices

column vector (default) | matrix

Channel state information reference signal (CSI-RS) indices, returned as a vector or matrix. See “lteCSIRSIndices Processing” on page 1-69.

Data Types: `uint32`

Definitions

lteCSIRSIndices Processing

The `lteCSIRSInidices` function supports the creation of multiple non-zero power resources and zero power CSI-RS.

By default the output indices as re returned as a column vector in one-based linear indexing form, that can directly index elements in an *N*-by-*M*-by-*max(CSIRefP)* array. These indices represent the subframe grid across *max(CSIRefP)* antenna ports *(p = 15,...,22)*. Other index representations can also be created as well as whether the output includes the RE that should be empty in a specific port because of CSI-RS transmissions in another port. These indices are ordered as the complex CSI-RS symbols should be mapped and do not include any elements allocated to PBCH, PSS, and SSS. You can define the CSI-RS subframe configuration schedule as required for the CSI-RS resources. If the subframe contains no CSI-RS, then an empty vector is returned. When multiple non-zero power and zero power CSI-RS are returned, the indices for the zero power CSI-RS appear first in the concatenated output, followed by the indices for the ordered set of CSI-RS resources.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteCellRSIndices` | `lteCSIRS` | `lteDMRSIndices` | `ltePRSIndices`

Introduced in R2014a

lteCellRS

Cell-specific reference signal

Syntax

```
sym = lteCellRS(enb)
sym = lteCellRS(enb,ports)
```

Description

`sym = lteCellRS(enb)` returns cell-specific reference signal symbols for cell-wide settings in the `enb` structure. `sym` is a complex-valued column vector containing cell-specific reference signal symbols. Unlike other physical channels and signals, the symbols for multiple antennas are concatenated into a single column rather than returned in a matrix with a column for each antenna. The reason for this behavior is that the number of symbols varies across the antenna ports.

`sym = lteCellRS(enb,ports)` returns cell-specific reference signal symbols for antenna ports specified in the vector, `ports` (0,1,2,3), and cell-wide settings structure, `enb`. In this case, `CellRefP` is ignored if present in `enb` and `ports` is used instead.

Examples

Find Length of Cell-Specific Reference Signals

This example shows different numbers of cell-specific reference signal symbols transmitted at antenna port 0 and 2.

Initialize cell wide parameter structure, `enb`, to RMC R.6

```
enb = lteRMCDL('R.6');
```

Observe the number of cell-specific reference symbols on port 0

```
cellRefPort0 = length(lteCellRS(enb,0))
```

```
cellRefPort0 =
```

```
   200
```

Observe the number of cell-specific reference symbols on port 2

```
cellRefPort2 = length(lteCellRS(enb,2))
```

```
cellRefPort2 =

   100
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

Parameter Field	Required or Optional	Values	Description
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

`ports` — Antenna ports

`0` (default) | `1` | `2` | `3` | numeric vector | optional

Antenna ports, specified as a numeric vector whose elements must be (0, 1, 2, 3).

Output Arguments

`sym` — Cell-specific reference signal symbols

complex-valued numeric column vector

Cell-specific reference signal symbols, returned as a complex-valued numeric column vector. This argument contains cell-specific reference signal symbols for the specified cell-wide settings, `enb`, and optional number of antenna ports, `ports`.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`lteCellRSIndices` | `lteCSIRS` | `lteDMRS` | `lteEPDCCHDMRS` | `ltePRBS` | `ltePRS`

Introduced in R2014a

lteCellRSIndices

CRS resource element indices

Syntax

```
ind = lteCellRSIndices(enb)
ind = lteCellRSIndices(enb,ports)
ind = lteCellRSIndices(enb,ports,opts)
```

Description

`ind = lteCellRSIndices(enb)` returns a column vector of resource element (RE) indices for the cell-specific reference signal (RS), given the cell-wide settings in the `enb` structure. By default, the indices are returned in 1-based linear indexing form that can directly index elements of a 3-D array representing the subframe resource grid for all antenna ports. These indices are ordered as the reference signal modulation symbols should be mapped. Unlike other physical channels and signals, the indices for multiple antennas are concatenated into a single column rather than returned in a matrix with a column for each antenna. The indices for each antenna are concatenated because the number of indices varies across the antenna ports.

`ind = lteCellRSIndices(enb,ports)` returns a column vector of RE indices for antenna ports specified in the vector, `ports` (0,1,2,3), and cell-wide settings structure, `enb`. In this case, `CellRefP` is ignored if present in `enb` and `ports` is used instead.

`ind = lteCellRSIndices(enb,ports,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate Cell-Specific Reference Signal RE Indices

Generate zero-based cell-specific reference signal (CRS) resource element (RE) indices in subscript form for antenna port 2.

```
enb = lteRMCDL('R.0');
enb.NCellID = 10;
```

```
ind = lteCellRSIndices(enb,2,{'0based','sub'});
ind(1:4,:)


ans =

  4×3 uint32 matrix

    4     1     2
   10     1     2
   16     1     2
   22     1     2
```

In this case, each row of the generated matrix has three columns, which represent subcarrier, symbol, and antenna port, respectively.

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or

Parameter Field	Required or Optional	Values	Description
			• `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
`Nsubframe`	Optional	0 (default), nonnegative scalar integer	Subframe number

`ports` — Antenna ports

numeric vector

Antenna ports, specified as a numeric vector whose elements must be (0, 1, 2, 3).

`opts` — Index generation options

character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'sub'`	Style for the returned indices, specified as one of the following options. • `'ind'` — returns the indices in linear index form as a column vector (default) • `'sub'` — returns the indices in `[subcarrier, symbol, antenna]` subscript row style. The number of rows in the output, `ind`, is the number of resource elements (N_{RE}). Thus, `ind` is an N_{RE}-by-3 matrix.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.

Data Types: `char` | `cell`

Output Arguments

`ind` — Cell-specific reference signal RE indices

column vector | numeric matrix

Cell-specific reference signal RE indices, returned as a column vector. Optionally, can be returned as an NRE-by-3 matrix.

Data Types: `uint32`

See Also

See Also

`lteCellRS` | `lteCSIRSIndices` | `lteDMRSIndices` | `ltePRSIndices`

Introduced in R2014a

lteCellSearch

Cell identity search using PSS and SSS

Syntax

```
[cellid,offset,peak] = lteCellSearch(enb,waveform)
[cellid,offset,peak] = lteCellSearch(enb,waveform,alg)
[cellid,offset,peak] = lteCellSearch(enb,waveform,cellids)
```

Description

`[cellid,offset,peak] = lteCellSearch(enb,waveform)` returns the cell identity carried by the PSS and SSS signals in the input waveform, the timing offset to the start of the first frame of the waveform, and the peak correlation magnitude. The cell-wide settings structure, `enb`, defines the link configuration.

`[cellid,offset,peak] = lteCellSearch(enb,waveform,alg)` takes an additional input structure, `alg`, which provides control over the cell search. The input structure, `alg`, contains optional fields to define the SSS detection method, the maximum number of cells to detect, and which cell identities to search.

`[cellid,offset,peak] = lteCellSearch(enb,waveform,cellids)` uses an additional input to constrain the cell search to the list of cell identities specified by in `cellids`.

Note: This syntax will be removed in a future release. Instead use the syntax [`cellid`,`offset`,`peak`] = lteCellSearch(`enb`,`waveform`,`alg`) and set `alg.CellIDs = cellids`.

Examples

Find Cell Identity

Search for the cell identity (in this case 171) of an `R.12` RMC waveform.

Initialize reference channel configuration, `rmc`. Perform cell search on the waveform produced using this configuration.

```
rmc = lteRMCDL('R.12');
rmc.NCellID = 171;
rmc.TotSubframes = 1;

cellID = lteCellSearch(rmc,lteRMCDLTool(rmc,[1;0;0;1]))
```

```
cellID =

   171
```

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Duplexmode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

`waveform` — Time-domain waveform

numeric matrix

Time-domain waveform, specified as a numeric matrix of size *T*-by-*P*. Where *T* is the number of time-domain samples and *P* is the number of receive antennas. The sampling rate of the time domain waveform must be the same as used in the `lteOFDMModulate` function for the specified number of resource blocks `enb.NDLRB`. The number of time domain samples, *T*, must be sufficient to provide at least one subframe for FDD (or 2 for TDD since in TDD mode PSS and SSS lie in adjacent subframes). For the cell search to succeed, the waveform provided must contain the PSS and SSS signals.

Note: `enb.NDLRB` is only required to specify the sampling rate of `waveform`.

Data Types: `double`
Complex Number Support: Yes

`alg` — Cell search algorithm control

structure

Cell search algorithm control, specified as a structure. `alg` accepts these fields defining optional cell search algorithm settings.

Parameter Field	Required or Optional	Values	Description
`SSSDetection`	Optional	`'PreFFT'` (default), `'PostFFT'`.	SSS detection method. [a]
`MaxCellCount`	Optional	Nonnegative scalar integer. (1, ..., 504), default 1.	The number of cell identities to detect. [b]
`CellIDs`	Optional	Vector of nonnegative integers, default vector (0:503).	A vector containing the cell identities to use for the cell search. [c]

a. `'PostFFT'` SSS detection operates in the frequency domain. For `'PostFFT'`:

- OFDM demodulation is performed using the timing estimate from PSS detection,
- the demodulated SSS resource elements are correlated with possible SSS sequences to find the cell identity group,
- and the peak correlation magnitude is the sum of the peak correlation magnitudes from time-domain PSS detection and frequency-domain SSS detection.

b. When `alg.MaxCellCount > 1`, the returned `cellid`, `offset`, and `peak` are vectors, with each element corresponding to one cell.

c. If `alg.CellIDs` is absent, the output vectors are sorted by decreasing correlation peak magnitude, that is, decreasing `peak` value. If `alg.CellIDs` is present and `alg.MaxCellCount = numel(alg.CellIDs)`, the output vectors are in the same order as the cell identities in `alg.CellIDs`. Sorting the peaks enables monitoring of the `peak` output for a predetermined set of cells.

`cellids` — Cell identities

nonnegative scalar integer | vector of nonnegative integers

Cell identities to be used in the cell search, specified as a nonnegative scalar integer or vector of nonnegative integers.

Note: `cellids` and the syntax it is associated with will be removed in a future release. Instead use `alg.CellIDs` and the recommended alternate syntax.

Data Types: `double`

Output Arguments

`cellid` — Cell identity

nonnegative scalar integer | vector of nonnegative integers

Physical layer cell identity, returned as a nonnegative scalar integer or vector of nonnegative integers. `cellid` indicates the detected cell identity. The returned `cellid` is a vector when `alg.MaxCellCount > 1` and more than one cell is detected.

The overall physical layer cell identity is `cellid = (3*`N_{id1}`) + `N_{id2}. PSS conveys the second cell identity number (`N`$_{id2}$`, (0,1,2))` within a cell identity group and is established via time-domain correlation using the `lteDLFrameOffset` function. SSS conveys the first cell identity number (`N`$_{id1}$`, (0,...,167))` and is established in a similar fashion.

Data Types: `double`

`offset` — Timing offset

nonnegative scalar integer | vector of nonnegative integers

Timing offset, returned as a nonnegative scalar integer or vector of nonnegative integers. `offset` indicates the number of samples from the start of the input waveform to the

position in that waveform where the first frame begins. The timing offset is calculated by correlating with the detected PSS and SSS. The returned `offset` is a vector when `alg.MaxCellCount > 1` and more than one cell is detected.

Data Types: `double`

`peak` — Peak magnitude

numeric scalar | vector of numeric values

Peak magnitude of the correlation, returned as a numeric scalar or vector of numeric values, used for cell detection. The returned `peak` is a vector when `alg.MaxCellCount > 1` and more than one cell is detected. The peak correlation magnitude is the sum of the peak correlation magnitudes from PSS and SSS detection. A complete correlation output is available as the output argument, `corr`, from `lteDLFrameOffset`.

See Also

See Also

`lteDLFrameOffset` | `lteFrequencyCorrect` | `lteFrequencyOffset` | `lteOFDMDemodulate`

Introduced in R2014a

lteCodeBlockDesegment

Code block desegmentation and CRC decoding

Syntax

```
[blk,err] = lteCodeBlockDesegment(cbs,blklen)
[blk,err] = lteCodeBlockDesegment(cbs)
```

Description

`[blk,err] = lteCodeBlockDesegment(cbs,blklen)` concatenates the input code block vectors contained in `cbs` into an output vector, `blk`, of length `blklen`. `blklen` is also used to validate the dimensions of the data in `cbs` and to calculate the amount of filler to be removed. If `cbs` is a cell array containing more than one vector, each vector is assumed to have a type-24B CRC attached. This CRC is decoded and stripped from each code block before output concatenation and the CRC error result is placed in the associated element of vector `err`. The length of `err` is the number of code blocks. If `cbs` is a single vector or a cell array containing a single vector, no CRC decoding or stripping is performed and `err` is empty. In all cases, the number of filler bits stripped from the beginning of the (first) code block is calculated from `blklen`. `lteCodeBlockDesegment` performs the inverse of the code block segmentation and CRC appending (see `lteCodeBlockSegment`).

`[blk,err] = lteCodeBlockDesegment(cbs)` no leading filler bits are stripped from the output.

Examples

Desegment Code Block

Perform code block desegmentation and discover when segmentation occurs.

Code block segmentation occurs if the input length is greater than 6144. The input vector of length 6145 is segmented by `lteCodeBlockSegment` into two vectors of length 3072 and 3136.

```
cbs = lteCodeBlockSegment(ones(6145,1));
```

Next, perform desegmentation and CRC removal.

```
[blk,err] = lteCodeBlockDesegment(cbs);
size(blk)
err
```

```
ans =

        6160           1


err =

  1×2 int8 row vector

   0   0
```

The first output, `blk`, is a column vector of length 6160. The second output, `err`, is a column vector of zero values.

Input Arguments

`cbs` — Code block segments

column vector | cell array

Code block segments, specified as a column vector or cell array of column vectors. If `cbs` is a cell array containing more than one vector, each vector is assumed to have a type-24B CRC attached. This CRC is decoded and stripped from each code block before output concatenation and the CRC error result is placed in the associated element of vector `err`. The length of `err` is the number of code blocks. If `cbs` is a single vector or a cell array containing a single vector, no CRC decoding or stripping is performed and `err` is empty. In all cases, the number of filler bits stripped from the beginning of the (first) code block is calculated from `blklen`.

`blklen` — Block length

nonnegative integer

Block length, specified as a nonnegative integer.

Output Arguments

`blk` — Output data block

column vector

Output data block, returned as a column vector. The input code blocks are segmented into a single output data block, `blk`, removing any filler and type-24B CRC bits.

Data Types: `int8`

`err` — Code block CRC decoding errors

column vector | nonnegative integer

Code block CRC decoding errors, returned as a nonnegative integer. The length of `err` is equal to the number of code blocks. If `cbs` is a cell array containing multiple vector elements, `lteCodeBlockDesegment` assumes that each vector has a type-24B CRC attached. The CRC is decoded and stripped from each code block before output concatenation and the CRC error result is placed in the associated element of `err`. If `cbs` is a single vector or a cell array containing a single vector, no CRC decoding or stripping is performed and `err` is empty.

Data Types: `int8`

See Also

See Also

`lteCodeBlockSegment` | `lteCRCDecode` | `lteDLSCHDecode` | `lteTurboDecode` | `lteULSCHDecode`

Introduced in R2014a

lteCodeBlockSegment

Code block segmentation and CRC attachment

Syntax

```
cbs = lteCodeBlockSegment(blk)
```

Description

`cbs = lteCodeBlockSegment(blk)` splits the input data bit vector `blk` into a cell array `cbs` of code block segments, with filler bits and type-24B CRC appended as appropriate, according to the rules of TS 36.212 [1], Section 5.1.2. Code block segmentation occurs in transport blocks, after initial type-24A CRC appending, for turbo encoded transport channels, including DL-SCH, UL-SCH, PCH, and MCH.

The segmentation and padding operation ensures that code blocks entering the turbo coder are no larger than 6144 in length and are all legal turbo code blocks sizes. The LTE turbo coder only supports a finite set of code block sizes. If the input block length is greater than 6144, the input block is split into a cell array of smaller code blocks where each individual block also has a type-24B CRC appended to it. The NULL filler bits, represented by –1 at the output, are prepended to the first code block so that all blocks in the set have acceptable lengths. If the input block length is less than or equal to 6144, no segmentation occurs and no CRC is appended, but the single output code block may have NULL filler bits prepended. The latter case still results in a cell array output containing a single vector.

Examples

Segment Code Block

Perform code block segmentation, providing two vectors with different lengths.

Code block segmentation occurs if the input length is greater than 6144. Provide a vector of length 6144.

```
cbs1 = lteCodeBlockSegment(ones(6144,1))
```

```
cbs1 =

  cell

    [6144×1 int8]
```

No segmentation occurs.

Provide a vector of length 6145.

```
cbs2 = lteCodeBlockSegment(ones(6145,1))

cbs2 =

  1×2 cell array

    [3072×1 int8]    [3136×1 int8]
```

Segmentation occurs for input length greater than 6144.

Input Arguments

`blk` — Data bit vector

column vector

Data bit vector, specified as a column vector.

Output Arguments

`cbs` — Code block segments

cell array of integer column vectors

Code block segments, returned as a cell array with `int8` column vector elements. If the input block length is less than or equal to 6144, `cbs` is a cell array containing a single column vector. If the input block length is greater than 6144, `cbs` is a cell array of multiple column vectors.

Data Types: `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCodeBlockDesegment` | `lteCRCEncode` | `lteDLSCH` | `lteDLSCHInfo` | `lteTurboEncode`

Introduced in R2014a

lteConvolutionalDecode

Convolutional decoding

Syntax

```
output = lteConvolutionalDecode(input)
```

Description

`output = lteConvolutionalDecode(input)` performs convolutional decoding of the input data vector, `input`. The input data is assumed to be soft bit data that has been encoded by a tail-biting convolutional code with constraint length 7, coding rate 1/3, and octal polynomials *G0* =133, *G1* =171 and *G2* =165. Since the code is tail-biting, `output` will be 1/3 of the length of the input. The input data vector is assumed to be structured as three encoded parity streams concatenated block-wise. For example, `input` is `[D0 D1 D2]`, where *D0*, *D1*, and *D2* are the separate parity streams resulting from the original encoding with individual polynomials *G0*, *G1* and *G2*. The decoder uses a soft input *Viterbi* algorithm without any quantization.

Examples

Perform Convolutional Decoding

Convolutionally decode soft bits.

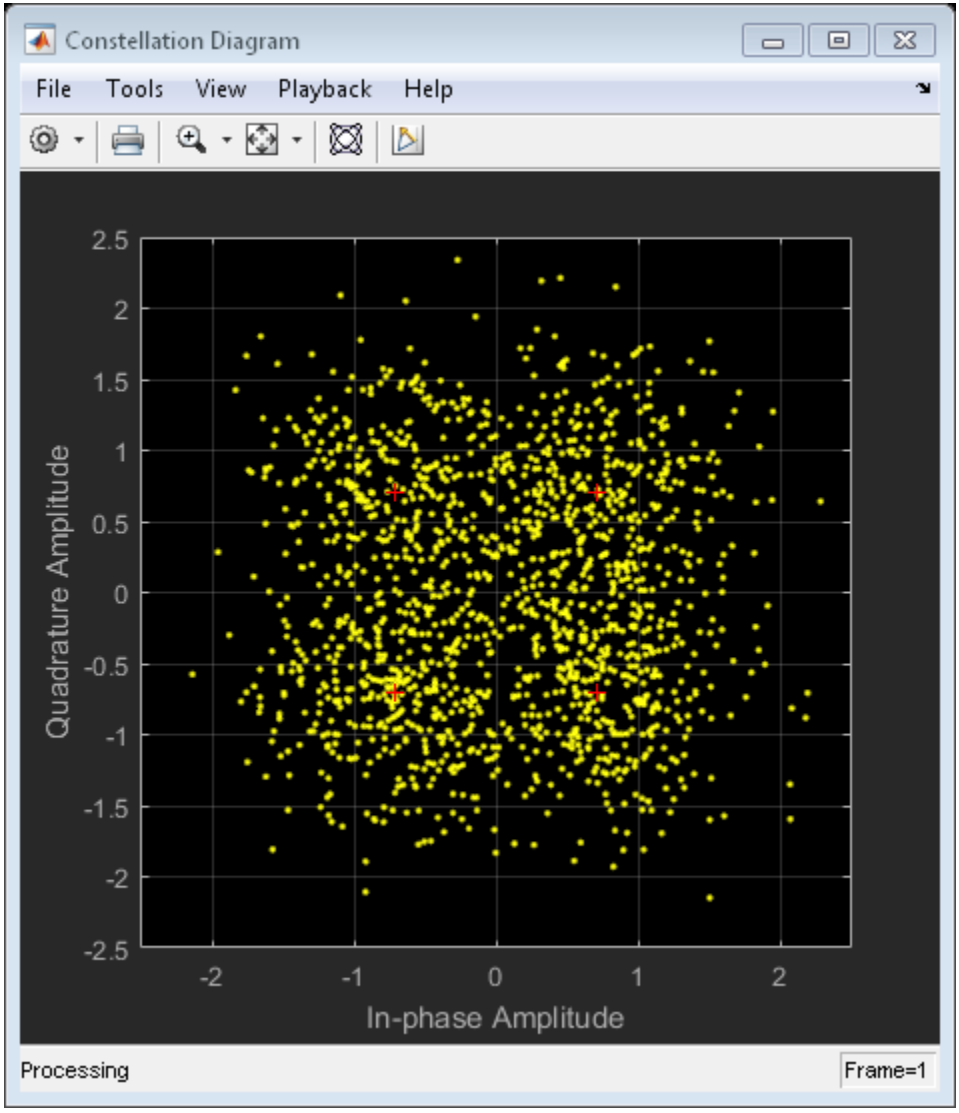
Generate random bits and convolutionally encode them. QPSK modulate the coded bits and add noise to the received symbols.

```
txBits = randi([0 1],1000,1);
codedData = lteConvolutionalEncode(txBits);

txSymbols = lteSymbolModulate(codedData,'QPSK');
noise = 0.5*complex(randn(size(txSymbols)),randn(size(txSymbols)));
rxSymbols = txSymbols + noise;
```

Show `rxSymbols` constellation, setting `txSymbols` as the reference constellation.

```
xylimits = [-2.5 2.5];
```

```
cdScope = comm.ConstellationDiagram('ReferenceConstellation',txSymbols,'XLimits',xylim
cdScope(rxSymbols)
```



Demodulate the noisy symbols to obtain soft bits. Convolutionally decode the soft bits. Display the number of erroneous bits.

```
softBits = lteSymbolDemodulate(rxSymbols,'QPSK','Soft');

rxBits = lteConvolutionalDecode(softBits);

numberErrors = sum(rxBits ~= int8(txBits))


numberErrors =

     0
```

Input Arguments

`input` — Input data

column vector

Input data, specified as a column vector. The data is assumed to be soft bit data encoded by a tail-biting convolutional code with constraint length 7, coding rate 1/3 and octal polynomials *G0*=133, *G1*=171 and *G2*=165.

Output Arguments

`output` — Convolutionally decoded data

column vector

Convolutionally decoded data, specified as a column vector. The decoded data is 1/3 the length of the input `input`.

Data Types: `int8`

See Also

See Also

`lteBCHDecode` | `lteConvolutionalEncode` | `lteCQIDecode` | `lteCRCDecode` | `lteDCIDecode` | `lteRateRecoverConvolutional` | `lteTurboDecode`

Introduced in R2014a

lteConvolutionalEncode

Convolutional encoding

Syntax

```
output = lteConvolutionalEncode(input)
```

Description

`output = lteConvolutionalEncode(input)` returns the result of convolutionally encoding the input data vector `input`. The convolutional code has constraint length 7 and is tail biting with coding rate 1/3 and octal polynomials *G0*=133, *G1*=171 and *G2*=165. Because the code is tail-biting, `output` is three times the length of the input. The three encoded parity streams are concatenated block-wise to form the encoded output that is, `out = [D0 D1 D2]` where `D0`, `D1`, and `D2` are the separate vectors resulting from encoding the input `input` with the individual polynomials G0, G1, and G2.

Examples

Perform Convolutional Encoding

Perform convolutional encoding and compare the length of the input vector to the length of the output vector.

Perform convolutional encoding of a vector of length 100.

```
coded = lteConvolutionalEncode(ones(100,1));
size(coded)
```

```
ans =

   300     1
```

The resulting output is a coded vector of length 300, which is three times the length of the input vector, as expected.

Input Arguments

`input` — Input data vector
column vector

Input data vector, specified as a column vector.

Output Arguments

`output` — Convolutionally encoded data
column vector

Convolutionally encoded data, returned as a column vector. Because the code is tail biting, `output` is three times the length of the input. The three encoded parity streams are concatenated block-wise to form the encoded output that is, `out = [D0 D1 D2]` where `D0`,`D1`, and `D2` are the separate vectors resulting from encoding the input `input` with the individual octal polynomials *G0*=133, *G1*=171, and *G2*=165.

Data Types: `int8`

See Also

See Also
`lteBCH` | `lteConvolutionalDecode` | `lteCRCEncode` | `lteDCIEncode` | `lteRateMatchConvolutional` | `lteTurboEncode`

Introduced in R2014a

lteDCI

Downlink control information format structures and bit payloads

Syntax

```
dciout = lteDCI(enb,dciin)
[dciout,bitsout] = lteDCI(enb,dciin)
[ ___ ] = lteDCI(enb,dciin,opts)
[ ___ ] = lteDCI(enb,chs,dciin,opts)
[ ___ ] = lteDCI(enb,bitsin,opts)
[ ___ ] = lteDCI(enb,chs,bitsin,opts)

[ ___ ] = lteDCI(istr,opts)
```

Description

`dciout = lteDCI(enb,dciin)` returns the `dciout` structure containing a downlink control information (DCI) message given input structures containing the cell-wide settings and the DCI format setting. With this syntax, the messages created have the minimum possible sizes for the cell configuration (link bandwidths, frame structure, and so on).

This function creates and manipulates DCI messages for the formats defined in TS 36.212 [2], Section 5.3.3. Later releases of the LTE standard may add UE-specific bit fields to a format. By default, any UE-specific bit fields added after a format is first released, appear in the output but are inactive. Uses for `lteDCI` include creation of a default DCI message, blind decoding of DCI format types, and determining the sizes of the bit fields.

For information on link bandwidth assignment, see “Specifying Number of Resource Blocks” on page 1-128.

`[dciout,bitsout] = lteDCI(enb,dciin)` also returns a vector, `bitsout`, representing the set of message fields mapped to the information bit payload (including any zero padding).

`[ ___ ] = lteDCI(enb,dciin,opts)` formats the returned `dciout` using options defined in the cell array, `opts`.

This syntax supports output options from prior syntaxes.

`[ ___ ] = lteDCI(enb,chs,dciin,opts)` permits formats to be extended with additional bit fields on a per-UE basis using the UE-specific channel configuration structure, `chs`.

`[ ___ ] = lteDCI(enb,bitsin,opts)` uses `bitsin` to initialize all the message fields. `bitsin` is treated as the DCI information bit payload and directly maps to `bitsout`, (`bitsout` == `bitsin`). By default the format is deduced directly from the length of `bitsin`. Therefore, the length of `bitsin` must be one of the valid format sizes for the given cell-wide parameters, `enb`. For more information, see `lteDCIInfo`.

When multiple formats have the same payload size, the first matching format is selected. The function checks formats 0 and 1A first, favoring the more likely common search space. If no match is found, the remaining formats are searched in alphanumerical order. To override the blind format matching in this syntax, add an explicit `enb.DCIFormat` field.

`[ ___ ] = lteDCI(enb,chs,bitsin,opts)` permits formats to be extended with additional bit fields on a per-UE basis using the UE-specific channel configuration structure, `chs`. The DCI payload sizes for the combination of cell-wide and UE-specific parameters define the set of valid `bitsin` lengths. For more information, see `lteDCIInfo`.

As with the previous syntax, the format type is deduced from the length of `bitsin`. To override the blind format matching in this syntax, add an explicit `chs.DCIFormat` field.

`[ ___ ] = lteDCI(istr,opts)` accepts an input structure, `istr`. The fields described in the structures `enb` and `dciin` must be present as part of `istr`. In this syntax, `dciout`, also carries forward the `NDLRB` and `DCIFormat` fields supplied in `istr`.

This syntax is not recommended and will be removed in a future release. Instead, use one of the previous syntaxes that separates the parameters into different input structures.

Examples

Create DCI

Create a format 1A DCI message structure with the distributed VRB allocation type. The allocation message fields are contained in the `dci1A.Allocation` substructure. When

the format 1A `AllocationType` field is properly initialized at the input to the function, the appropriate set of fields is output. For format 1A, setting `AllocationType` to 1 gives a distributed allocation and 0 gives a localized allocation.

```
enb = struct('NDLRB',50,'CellRefP',1,'DuplexMode','FDD');
dciin = struct('DCIFormat','Format1A','AllocationType',1);
dci1A = lteDCI(enb,dciin)

allocfields = dci1A.Allocation
```

```
dci1A =

  struct with fields:

           DCIFormat: 'Format1A'
                 CIF: 0
      AllocationType: 1
          Allocation: [1×1 struct]
           ModCoding: 0
              HARQNo: 0
             NewData: 0
                  RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
          SRSRequest: 0
    HARQACKResOffset: 0


allocfields =

  struct with fields:

    RIV: 0
    Gap: 0
```

The field values of this structure can be set and passed back through the function. Output the information bits with the new values.

```
dci1A.RV = 1;
dci1A.Allocation.RIV = 6;
dci1Aupdated = lteDCI(enb,dci1A)

allocfields = dci1Aupdated.Allocation
```

```
dci1Aupdated =

  struct with fields:

           DCIFormat: 'Format1A'
                 CIF: 0
      AllocationType: 1
          Allocation: [1×1 struct]
           ModCoding: 0
              HARQNo: 0
             NewData: 0
                  RV: 1
            TPCPUCCH: 0
            TDDIndex: 0
          SRSRequest: 0
    HARQACKResOffset: 0


allocfields =

  struct with fields:

    RIV: 6
    Gap: 0
```

Create Format 1 TDD DCI Message

Create a format 1 DCI message structure with the resource allocation type 1 and TDD modulation scheme. Set `AllocationType` to 1, and output the set of allocation fields. `AllocationType` is the resource allocation header bit for format 1. Also initialize the `ModCoding` field at the input. All noninitialized fields default to 0.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.DuplexMode = 'TDD';

dciin.DCIFormat = 'Format1';
dciin.AllocationType = 1;
dciin.ModCoding = 7;

dci1 = lteDCI(enb,dciin)
allocfields = dci1.Allocation
```

```
dci1 =

  struct with fields:

          DCIFormat: 'Format1'
                CIF: 0
     AllocationType: 1
         Allocation: [1×1 struct]
          ModCoding: 7
             HARQNo: 0
            NewData: 0
                 RV: 0
           TPCPUCCH: 0
           TDDIndex: 0
    HARQACKResOffset: 0


allocfields =

  struct with fields:

      Bitmap: '00000000000000'
    RBSubset: 0
       Shift: 0
```

For the specified configuration, the `Allocation` substructure includes the character vector bit field, `Bitmap`, plus `RBSubset` and `Shift` fields.

Create DCI Bit Message

Create a format 1A DCI message structure and output the `bitsout` message. Modify the DCI message and observe the change.

Create cell-wide settings and DCI message settings structures. For the DCI message, assign format 1A and allocation type 0. Generate the DCI message. View the DCI message structure and bits output.

```
enb = struct('NDLRB',25,'CellRefP',1,'DuplexMode','FDD');
dciin = struct('DCIFormat','Format1A','AllocationType',0);

[dciout,bitsout] = lteDCI(enb,dciin);

dciout
```

```
bitsout'

dciout =

  struct with fields:

          DCIFormat: 'Format1A'
                CIF: 0
     AllocationType: 0
         Allocation: [1×1 struct]
          ModCoding: 0
             HARQNo: 0
            NewData: 0
                 RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
         SRSRequest: 0
    HARQACKResOffset: 0


ans =

  1×25 int8 row vector

  Columns 1 through 19

   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

  Columns 20 through 25

   0   0   0   0   0   0
```

The first bit in `bitsout` is a 1 for DCI message format 1A. The second bit is 0 for `AllocationType` = 0.

Modify the allocation type to 1. Regenerate the DCI message. View the DCI message structure and bits output.

```
dciin = struct('DCIFormat','Format1A','AllocationType',1);

[dciout,bitsout] = lteDCI(enb,dciin);

dciout
```

```
bitsout'

dciout =

  struct with fields:

           DCIFormat: 'Format1A'
                 CIF: 0
      AllocationType: 1
          Allocation: [1×1 struct]
           ModCoding: 0
              HARQNo: 0
             NewData: 0
                  RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
          SRSRequest: 0
    HARQACKResOffset: 0


ans =

  1×25 int8 row vector

  Columns 1 through 19

   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

  Columns 20 through 25

   0   0   0   0   0   0
```

Note the `AllocationType` and the second bit of `bitsout` both changed from 0 to 1.

Modify the DCI message format to 0. Regenerate the DCI message. View the DCI message structure and bits output.

```
dciin = struct('DCIFormat','Format0','AllocationType',1);

[dciout,bitsout] = lteDCI(enb,dciin);

dciout
bitsout'
```

```
dciout =

  struct with fields:

         DCIFormat: 'Format0'
               CIF: 0
        Allocation: [1×1 struct]
         ModCoding: 0
           NewData: 0
               TPC: 0
        CShiftDMRS: 0
          TDDIndex: 0
        CSIRequest: 0
        SRSRequest: 0
    AllocationType: 1


ans =

  1×25 int8 row vector

  Columns 1 through 19

   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

  Columns 20 through 25

   0   0   0   0   1   0
```

The first bit in `bitsout` change from 1 to 0. Because the message formats 0 and 1A have the same length, the first bit in `bitsout` is used to distinguish these formats. For all other formats, the message length is used to distinguish the format types. For format 0, the setting for `AllocationType` is specified by bit number 24.

Optional DCI Message Views

Create a format 1 DCI message structure and supply the optional `'fieldsizes'` and `'excludeunusedfields'` inputs. By default, the output structure contains all possible fields for the input format. Not all fields are active for the given input parameters. Specifically, some might not be present in the payload bits. To see the number of bits associated with each field, use the optional `'fieldsizes'` input. The `'fieldsizes'`

option also adds the `'Padding'` field to the output indicating the number of padding bits.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.DuplexMode = 'TDD';

dciin.DCIFormat = 'Format1';
dciin.AllocationType = 1;
dciin.ModCoding = 7;

opts = {'fieldsizes'}

dci1 = lteDCI(enb,dciin,opts)
allocfields = dci1.Allocation


opts =

  cell

    'fieldsizes'


dci1 =

  struct with fields:

          DCIFormat: 'Format1'
                CIF: 0
     AllocationType: 1
         Allocation: [1×1 struct]
          ModCoding: 5
             HARQNo: 4
            NewData: 1
                 RV: 2
           TPCPUCCH: 2
           TDDIndex: 2
   HARQACKResOffset: 0
            Padding: 0


allocfields =

  struct with fields:
```

```
      Bitmap: 14
    RBSubset: 2
       Shift: 1
```

View the output to see the sizes for all DCI message fields.

Remove unused (0 bit) fields from the output structure by using the `'excludeunusedfields'` option.

```
opts = {'fieldsizes','excludeunusedfields'}

dci1 = lteDCI(enb,dciin,opts)
allocfields = dci1.Allocation
```

```
opts =

  1×2 cell array

    'fieldsizes'    'excludeunusedfields'


dci1 =

  struct with fields:

         DCIFormat: 'Format1'
    AllocationType: 1
        Allocation: [1×1 struct]
         ModCoding: 5
            HARQNo: 4
           NewData: 1
                RV: 2
          TPCPUCCH: 2
          TDDIndex: 2


allocfields =

  struct with fields:

      Bitmap: 14
    RBSubset: 2
```

```
       Shift: 1
```

The output fields with bit length equal to zero bits no longer appear in the output.

Blindly Recover Modified Format 1A DCI Message

Create a format 1A DCI message structure with the distributed VRB allocation type. The allocation message fields are contained in the `Allocation` substructure. Setting the format 1A `AllocationType` field to 1 specifies a distributed allocation. Setting |AllocationType| to 0 specifies a localized allocation.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.DuplexMode = 'FDD';

dciin.DCIFormat = 'Format1A';
dciin.AllocationType = 1;

[dci1A,bits] = lteDCI(enb,dciin);
dci1A
allocfields = dci1A.Allocation
```

```
dci1A =

  struct with fields:

          DCIFormat: 'Format1A'
                CIF: 0
     AllocationType: 1
         Allocation: [1×1 struct]
          ModCoding: 0
             HARQNo: 0
            NewData: 0
                 RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
         SRSRequest: 0
   HARQACKResOffset: 0


allocfields =
```

```
  struct with fields:

    RIV: 0
    Gap: 0
```

Adjust the `RV` and `RIV` field values of `dci1A`. Pass `dci1A` through `lteDCI` again to update the information bits with the new values. View the updated message fields by blindly recovering them directly from the output DCI message bits.

```
dci1A.RV = 1;
dci1A.Allocation.RIV = 6;
[~,bits] = lteDCI(enb,dci1A);
dci1Arec = lteDCI(enb,bits)

allocfieldsrec = dci1Arec.Allocation
```

```
dci1Arec =

  struct with fields:

           DCIFormat: 'Format1A'
                 CIF: 0
      AllocationType: 1
          Allocation: [1×1 struct]
           ModCoding: 0
              HARQNo: 0
             NewData: 0
                  RV: 1
            TPCPUCCH: 0
            TDDIndex: 0
          SRSRequest: 0
    HARQACKResOffset: 0


allocfieldsrec =

  struct with fields:

    RIV: 6
    Gap: 0
```

Create DCI Message Using UE-Specific Control

Use an additional UE-specific input parameter structure to control UE-specific DCI fields. Create a message to be sent on the EPDCCH that is intended for a UE configured with the carrier indicator field, `CIF`.

Initialize cell-wide structure `enb`, DCI format structure `dciin`, UE-specific structure `chs`, and ouput options structure `opts`.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.DuplexMode = 'TDD';

dciin.DCIFormat = 'Format1';
dciin.AllocationType = 1;
dciin.ModCoding = 7;

chs.ControlChannelType = 'EPDCCH';
chs.EnableCarrierIndication = 'On';
chs.EnableSRSRequest = 'Off';
chs.EnableMultipleCSIRequest = 'Off';

opts = {'fieldsizes','excludeunusedfields'}
```

```
opts =

  1×2 cell array

    'fieldsizes'    'excludeunusedfields'
```

Create and view the DCI message.

```
dci1 = lteDCI(enb,chs,dciin,opts)
allocfields = dci1.Allocation
```

```
dci1 =

  struct with fields:

           DCIFormat: 'Format1'
```

```
                CIF: 3
     AllocationType: 1
         Allocation: [1×1 struct]
          ModCoding: 5
             HARQNo: 4
            NewData: 1
                 RV: 2
           TPCPUCCH: 2
           TDDIndex: 2
   HARQACKResOffset: 2


allocfields =

  struct with fields:

      Bitmap: 14
    RBSubset: 2
       Shift: 1
```

Based on the UE-specific settings in `chs`, the output includes the three bit `CIF` field and the two bit `HARQACKResOffset` field. If these fields were present in `dciin`, their values would be mapped into the appropriate positions in the information bits at the output.

Create DCI Message Using UE-Specific Control And Bit Stream

Use an additional UE-specific input parameter structure to control UE-specific DCI fields. Create a message to be sent on the EPDCCH that is intended for a UE configured with the carrier indicator field, `CIF`.

Initialize cell-wide structure `enb`, UE-specific structure `chs`, and output options structure `opts`.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.DuplexMode = 'TDD';

chs.DCIFormat = 'Format1B';
chs.ControlChannelType = 'EPDCCH';
chs.EnableCarrierIndication = 'On';
chs.EnableSRSRequest = 'Off';
chs.EnableMultipleCSIRequest = 'Off';
chs.NTxAnts = 1;
```

```
opts = {'fieldsizes','excludeunusedfields'};
```

Based on the UE-specific settings in `chs`, the DCI message length is extended to include fields `CIF` (3 bits) and `HARQACKResOffset` (2 bits). Using `lteDCIInfo` and `chs` to determine the correct input bitstream length, create `bitsin`.

```
info = lteDCIInfo(enb,chs);

bitsin = zeros(getfield(info,chs.DCIFormat),1);
```

Create a new DCI message using cell-wide settings, UE-specific Control and `bitsin`.

```
[dciout,bitsout] = lteDCI(enb,chs,bitsin,opts);
dciout
```

```
dciout =

  struct with fields:

          DCIFormat: 'Format1B'
                CIF: 3
     AllocationType: 1
         Allocation: [1×1 struct]
          ModCoding: 5
             HARQNo: 4
            NewData: 1
                 RV: 2
            TPCPUCCH: 2
            TDDIndex: 2
                TPMI: 2
                 PMI: 1
   HARQACKResOffset: 2
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
DCIFormat	Required (see syntax descriptions for applicability)	`'Format0'`, `'Format1'`, `'Format1A'`, `'Format1B'`, `'Format1C'`, `'Format1D'`, `'Format2'`, `'Format2A'`, `'Format2B'`, `'Format2C'`, `'Format2D'`, `'Format3'`, `'Format3A'`, `'Format4'`, `'Format5'`	Downlink control information (DCI) format
CellRefP	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

`dciin` — DCI settings

structure

DCI settings, specified as a structure that can contain these fields.

Parameter Field	Required or Optional	Values	Description
DCIFormat	Required, except when `bitsin` is input	`'Format0'`, `'Format1'`, `'Format1A'`, `'Format1B'`, `'Format1C'`, `'Format1D'`, `'Format2'`, `'Format2A'`, `'Format2B'`, `'Format2C'`,	Downlink control information (DCI) format

Parameter Field	Required or Optional	Values	Description
		`'Format2D'`, `'Format3'`, `'Format3A'`, `'Format4'`, `'Format5'`	

Any format-specific fields can be initialized by adding them to `dciin`. See `dciout` for specific fields output for each `DCIFormat`.

`opts` — Output format options for output DCI structure

`{'fieldvalues', 'includeallfields'}` (default) | optional | character vector | cell array of character vectors

Output format options for output DCI structure, specified as a character vector or a cell array of character vectors. You can specify a format for the *Field content* and *Fields to include*.

Category	Options	Description
Field content	`'fieldvalues' (default)`	Set the fields to zero or to their input values.
	`'fieldsizes'`	Sets the field values to their bit sizes and adds the `Padding` field to `dciout`. `Padding` indicates the number of padding bits appended.
Fields to include	`'includeallfields' (default`	`dciout` includes all possible fields for the requested DCI format.
	`'excludeunusedfields'`	`dciout` excludes fields that have zero length for the given parameter set.

Example: `{'fieldsizes','excludeunusedfields'}` returns field sizes in `dciout` and exclude fields that have zero length for the given parameter set.

`chs` — User-equipment-related channel configuration

structure

User-equipment-related (UE-related) channel configuration, specified as a structure containing these UE-specific fields.

Note: All fields in `chs` are optional. The presence of these optional fields depends on:

- Whether the transmission of DCI message is in a PDCCH using common search space mapping or in an EPDCCH.

- The release-specific features configured at the destination UE.

These additional UE-specific bit fields are off by default.

`DCIFormat` — DCI format name

`'Format0'` | `'Format1'` | `'Format1A'` | `'Format1B'` | `'Format1C'` | `'Format1D'` | `'Format2'` | `'Format2A'` | `'Format2B'` | `'Format2C'` | `'Format2D'` | `'Format3'` | `'Format3A'` | `'Format4'` | `'Format5'`

DCI format name, specified as a character vector. See syntax descriptions for applicability.

Data Types: `char`

`ChannelControlType` — Physical control channel type

`'PDCCH'` (default) | `'EPDCCH'` | optional

Physical control channel type used to carry DCI formats, specified as `'PDCCH'` or `'EPDCCH'`. The setting for `ChannelControlType` affects the presence of the HARQ-ACK resource offset field and message padding.

Data Types: `char`

`SearchSpace` — Search space mapping

`'UESpecific'` (default) | `'Common'` | optional

Search space mapping for DCI formats 0/1A/1C, specified as `'UESpecific'` or `'Common'`. This field is only applicable for PDCCH. None of the additional fields can be present when formats 0 or 1A are mapped into the PDCCH common search space.

Data Types: `char`

`EnableCarrierIndication` — Option to enable carrier indication

`'Off'` (default) | `'On'` | optional

Option to enable carrier indication field (CIF) in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableCarrierIndication` is disabled. When

`EnableCarrierIndication` is enabled (`'On'`), the CIF is present in the UE-specific configuration.

Data Types: `char`

`EnableSRSRequest` — Option to enable SRS request

`'Off'` (default) | `'On'` | optional

Option to enable SRS request in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableSRSRequest` is disabled. When `EnableSRSRequest` is enabled (`'On'`), the SRS request field is present in UE-specific formats 0/1A for FDD or TDD and formats 2B/2C/2D for TDD.

Data Types: `char`

`EnableMultipleCSIRequest` — Option to enable multiple CSI requests

`'Off'` (default) | `'On'` | optional

Option to enable multiple CSI requests in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableMultipleCSIRequest` is disabled. When `EnableMultipleCSIRequest` is enabled (`'On'`), the UE is configured to process multiple channel state information (CSI) requests from cells. Enabling multiple CSI requests affects the length of the CSI request field in UE-specific formats 0 and 4.

Data Types: `char`

`NTxAnts` — Number of UE transmission antennas

1 (default) | 2 | 4 | optional

Number of UE transmission antennas, specified as 1, 2, or 4. The number of UE transmission antennas affects the length of the precoding information field in DCI format 4.

Data Types: `double`

Data Types: `struct`

`bitsin` — Input bits

vector

Input bits, specified as a column vector. `bitsin` is treated as the DCI information bit payload, that is, `bitsout` == `bitsin`. The length of `bitsin` must be one of the valid sizes for the format type and number of resource blocks. For information on link bandwidth assignment, see “Specifying Number of Resource Blocks” on page 1-128. For information on valid sizes, see `lteDCIInfo`.

When `bitsin` is specified, the structure `dciin` does not require the `DCIFormat` field. If the `DCIFormat` field is not present, `lteDCI` attempts to decode the format from the length of the payload vector `bitsin`.

Data Types: `double`

`istr` — Input structure

structure

Input structure, specified as a structure that includes all the fields described in the structures `enb` and `dciin`.

Use of the `istr` input syntax is not recommended and will be removed in a future release. Instead, use one of the previous syntaxes that separates the parameters into different input structures.

Output Arguments

`dciout` — DCI message structure

structure

DCI message structure, returned as a structure whose fields match the associated DCI format contents.

The field names associated with `dciout` depend on the DCI format field in `dciin`. By default, all values are set to zero. However, if any of the DCI fields are already present in the input `dciin`, their values are carried forward into `dciout`. The input field values appear in the associated bit positions in `bitsout`. Carrying the values forward allows for easy initialization of DCI field values, particularly the resource allocation type, which affects the fields used by the format. `dciout` also carries forward the `NDLRB` and `DCIFormat` fields supplied in `dciin`.

This table presents the fields associated with each DCI format as defined in TS 36.212 [2], Section 5.3.3.

DCI Formats	dciout Fields	Size	Description
`'Format0'`	`DCIFormat`	-	`'Format0'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`FreqHopping`	1 bit	PUSCH frequency hopping flag

DCI Formats	dciout Fields	Size	Description
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation, coding scheme, and redundancy version
	`NewData`	1 bit	New data indicator
	`TPC`	2 bits	PUSCH TPC command
	`CShiftDMRS`	3 bits	Cyclic shift for DM RS
	`TDDIndex`	2 bits	For TDD config 0, this field is the Uplink Index. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`CSIRequest`	1, 2, or 3 bits	CSI request
	`SRSRequest`	0 or 1 bit	SRS request. This field can only be present in DCI formats scheduling PUSCH which are mapped onto the UE specific search space given by the C-RNTI
	`AllocationType`	1 bit	Resource allocation type, only present if $N_{\mathrm{RB}}^{\mathrm{UL}} \leq N_{\mathrm{RB}}^{\mathrm{DL}}$.
`'Format1'`	`DCIFormat`	-	`'Format1'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme

DCI Formats	dciout Fields	Size	Description
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format1A'`	`DCIFormat`	-	`'Format1A'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version
	`TPCPUCCH`	2 bits	PUCCH TPC command

DCI Formats	dciout Fields	Size	Description
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`SRSRequest`	0 or 1 bit	SRS request. This field can only be present in DCI formats scheduling PUSCH which are mapped onto the UE specific search space given by the C-RNTI
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format1B'`	`DCIFormat`	-	`'Format1B'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version
	`TPCPUCCH`	2 bits	PUCCH TPC command

DCI Formats	dciout Fields	Size	Description
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`TPMI`	2 bits for two antennas 4 bits for four antennas	PMI information
	`PMI`	1 bit	PMI confirmation
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format1C'`	`DCIFormat`	-	`'Format1C'`
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
`'Format1D'`	`DCIFormat`	-	`'Format1D'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version

DCI Formats	dciout Fields	Size	Description
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`TPMI`	2 bits for two antennas 4 bits for four antennas	Precoding TPMI information
	`DlPowerOffset`	1 bit	Downlink power offset
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2'`	`DCIFormat`	-	`'Format2'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.

DCI Formats	dciout Fields	Size	Description
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`SwapFlag`	1 bit	Transport block to codeword swap flag
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`PrecodingInfo`	3 bits for two antennas 6 bits for four antennas	Precoding information
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2A'`	`DCIFormat`	-	`'Format2A'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.

DCI Formats	dciout Fields	Size	Description
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`SwapFlag`	1 bit	Transport block to codeword swap flag
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`PrecodingInfo`	0 bits for two antennas 2 bits for four antennas	Precoding information

DCI Formats	dciout Fields	Size	Description
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2B'`	`DCIFormat`	-	`'Format2B'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`ScramblingId`	1 bit	Scrambling identity
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2

DCI Formats	dciout Fields	Size	Description
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2C'`	`DCIFormat`	-	`'Format2C'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`TxIndication`	3 bits	Antenna ports, scrambling identity, and number of layers indicator
	`SRSRequest`	Varies	SRS request. Only present for TDD.
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1

DCI Formats	dciout Fields	Size	Description
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2D'`	`DCIFormat`	-	`'Format2D'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number

DCI Formats	dciout Fields	Size	Description
	`TxIndication`	3 bits	Antenna ports, scrambling identity, and number of layers indicator
	`SRSRequest`	Varies	SRS request. Only present for TDD.
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`REMappingAndQCL`	2 bits	PDSCH RE Mapping and Quasi-Co-Location Indicator
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format3'`	`DCIFormat`	-	`'Format3'`
	`TPCCommands`	Varies	TPC commands for PUCCH and PUSCH
`'Format3A'`	`DCIFormat`	-	`'Format3A'`
	`TPCCommands`	Varies	TPC commands for PUCCH and PUSCH
`'Format4'`	`DCIFormat`	-	`'Format4'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPC`	2 bits	PUSCH TPC command

DCI Formats	dciout Fields	Size	Description
	`CShiftDMRS`	3 bits	Cyclic shift for DM-RS
	`TDDIndex`	2 bits	For TDD config 0, this field is Uplink Index. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`CSIReq`	Varies	CSI request
	`SRSRequest`	2 bits	SRS request
	`AllocationType`	1 bit	Resource allocation header type 0 or type 1.
	`ModCoding`	5 bits	Modulation, coding scheme, and redundancy version
	`NewData`	1 bit	New data indicator
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`PrecodingInfo`	3 bits for two antennas 6 bits for four antennas	Precoding information
`'Format5'`	`DCIFormat`	-	`'Format5'`
	`PSCCHResource`	6 bits	Resource for PSCCH
	`TPC`	1 bit	TPC command for PSCCH and PSSCH
	`FreqHopping`	1 bit	Frequency hopping flag

DCI Formats	dciout Fields	Size	Description
	`Allocation`	Varies	Resource block assignment and hopping resource allocation
	`TimeResourcePatte`	7 bits	Time resource pattern

The `DCIFormat` field indicates the DCI format. All other fields are represented by an integer which is converted to a set of binary message bits for each individual field.

The `ModCoding` fields in the table correspond to the variable I_{MCS} defined in TS 36.213 [3], Section 7.1.7, Table 7.1.7.1-1. This field expects to be assigned a decimal number. The call to `lteDCI` serializes `ModCoding` into a 5-bit field value. For example, the `ModCoding` field for 64QAM modulation (Q_m) and transport block index (I_{TBS}) 15 is assigned 17 (a decimal number).

The fields included in the `Allocation` structure vary based on the format type as outlined in these tables. All fields take a character vector of zeros and ones with the appropriate bit length.

Resource allocation type 0			
DCI Formats	**`Allocation` Fields**	**Size (bits)**	**Description**

`'Format1'`
`'Format2'`
`'Format2A'`
`'Format2B'`
	`Bitmap`	Varies	Bitmap value in terms of RBG, specified as a character vector

Resource allocation type 1			
DCI Formats	**`Allocation` Fields**	**Size (bits)**	**Description**

`'Format1'`
`'Format2'`
`'Format2A'`
`'Format2B'`
	`Bitmap`	Varies	Bitmap value in terms of RBG, specified as a character vector

	`RBSubset`	2 bits	Selected resource blocks subset indicator
	`Shift`	1 bit	Shift of the resource allocation span indicator

Resource allocation type 2 (localized)			
DCI Formats	**`Allocation` Fields**	**Size (bits)**	**Description**

`'Format1A'`
`'Format1B'`
`'Format1C'`
`'Format1D'`
	`RIV`	Varies	Resource indication value

Resource allocation type 2 (distributed)			
DCI Formats	**`Allocation` Fields**	**Size (bits)**	**Description**

`'Format1A'`
`'Format1B'`
`'Format1C'`
`'Format1D'`
	`RIV`	Varies	Resource indication value

	`Gap`	1 bit	Gap value: 0 (gap1), 1 (gap2)

Uplink Nonhopping allocation			
DCI Formats	**`Allocation` Fields**	**Size (bits)**	**Description**
`'Format0'` `'Format5'`	`RIV`	Varies	Resource indication value

Uplink Hopping allocation			
DCI Formats	**`Allocation` Fields**	**Size (bits)**	**Description**
`'Format0'` `'Format5'`	`RIV`	Varies	Resource indication value
	`HoppingBits`	Varies	When the number of hopping bits is 1, `HoppingBits` value can be 0 or 1. When the number of hopping bits is 2, `HoppingBits` value can be 00, 01, 10, or 11. See TS 36.213 [3], Table 8.4-2.

`bitsout` — DCI message in bit payload form
bit vector

DCI message in bit payload form, returned as a column vector. `bitsout` represents the set of message fields mapped to the information bit payload (including any zero-padding).

Definitions

Specifying Number of Resource Blocks

The number of resource blocks specifies the uplink and downlink bandwidth. The LTE System Toolbox™ implementation assumes symmetric link bandwidth unless you specifically assign different values to `NULRB` and `NDLRB`. If the number of resource blocks is initialized in only one link direction, then the initialized number of resource blocks (`NULRB` or `NDLRB`) is used for both uplink and downlink. When this mapping is used, no warning is displayed. An error occurs if `NULRB` and `NDLRB` are both undefined.

Algorithms

Resource allocation type 0

In type 0 resource allocation, a bitmap represents a resource block group (RBG) allocated to a UE. `P` gives the RBG size, which can be deduced from TS 36.213 [3], Table 7.1.6.1-1 for a given system bandwidth. The number of bits in the `Bitmap` field is equal to $\lceil NDLRB / P \rceil$. Each bit in the `Bitmap` selects a small contiguous group whose size depends on the bandwidth (RBG: 1,...,4). The maximum resource block (RB) coverage of any type 0 allocation is the entire bandwidth, that is, a type 0 allocation with all the bits in bitmap set to `'1'` is equivalent to the entire bandwidth.

Example 50 RB bandwidth

The number of bits in `Bitmap` are 17. Each bit in the 17-bit bitmap selects a group of three RB (apart from the last group, which only contains two RB for this bandwidth). Each bit is associated with a group of RBs with the same color.

Resource allocation type 1

In type 1 resource allocation, a bitmap indicates physical resource blocks inside a selected resource block group subset p, where $0 \le p < P$. The maximum resource block (RB) coverage of any type 1 allocation is a subset of entire bandwidth. A type 1 allocation, even with all the bits in the `Bitmap` set to `'1'`, does not span the entire bandwidth. Each bit in the bitmap selects a single RB from "islands" of small contiguous groups whose size (RBG) and separation depend on the total bandwidth. This grouping provides the provision of selecting a single RB without turning on any other RB.

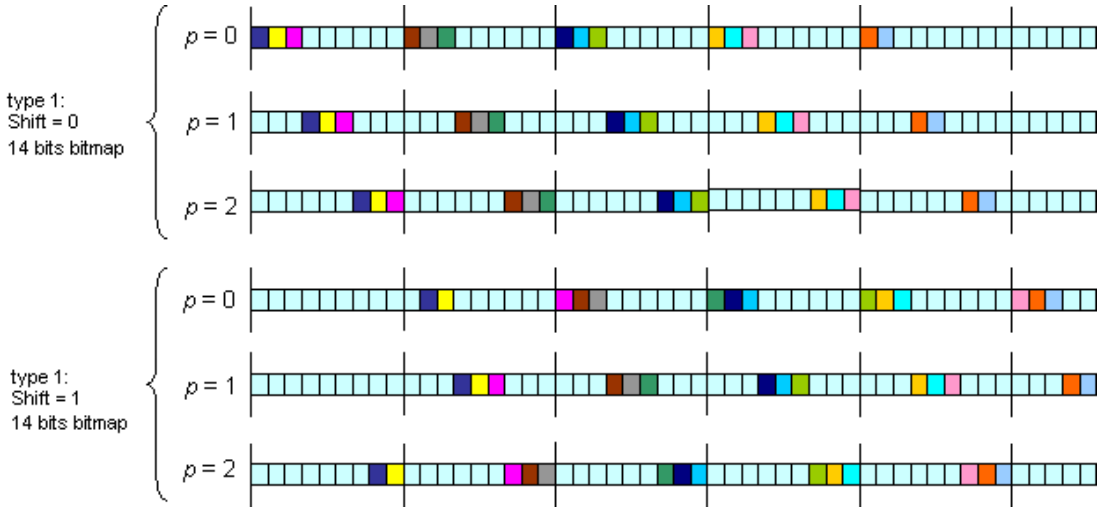
In type 1, the resource block assignment signaling is split into three field parts:

1. `RBSubset` — Represents the selected resource block group subset
2. `Shift` — Indicates whether to apply an offset when interpreting the bitmap
3. `Bitmap` — Contains the bitmap that indicates to the UE the specific physical resource block within the resource block group subset.

In comparison to type 0, the bitmap size for type 1 is always short by $\lceil \log_2(P) \rceil + 1$ bits, where P is defined as in resource allocation type 0.

Example 50 RB bandwidth

The number of bits in `Bitmap` are 14 (3 bits short as compared to type 0, due to `RBSubset` and `Shift` parameters). Each bit in the 14-bit bitmap selects an individual RB inside a selected subset. The figure shows all the bits in `Bitmap` set to `'1'` for different subsets and offset values.



Resource allocation type 2

In type 2 resource allocation, physical resource blocks are not directly allocated. Instead, virtual resource blocks are allocated, which are then mapped onto physical resource blocks. Type 2 allocation supports both localized and distributed virtual resource block allocation, differentiated by one-bit flag. The starting point of the virtual resource block and the length in terms of the contiguously allocated virtual resource blocks can be derived from Resource Indication Value (RIV) signaled within the DCI.

Example 50 RB bandwidth

A UE is allocated a bandwidth of 25 resource blocks (L_{CRBs}=25), starting from resource block 10 (RB_{start}=10) in the frequency domain. To calculate the RIV value, refer to the formula given in TS 36.213 [3], Section 7.1.6.3, which yields RIV = 1210. Using this RIV, which is signaled in the DCI, the UE can unambiguously derive the starting resource block and the number of allocated resource blocks from RIV again.

Uplink Nonhopping Resource Allocation

For uplink nonhopping resource allocation, the rules for type 2 localized resource allocation apply for deriving the resource allocation from the RIV value.

Uplink Hopping Resource Allocation

When `FreqHopping` is set to 1, uplink hopping resource allocation is available. For uplink hopping resource allocation, two types of hopping are used: Type 1 PUSCH Hopping and Type 2 PUSCH Hopping. Do not confuse these types with downlink resource allocation types 1 and 2 described earlier. Type 1 PUSCH Hopping is calculated using the RIV value and parameters signaled by higher layers. Type 2 PUSCH Hopping is calculated using a predefined pattern, which is a function of the subframe and frame number, as defined in TS 36.211 [1], Section 5.3.4. The fundamental set of resource blocks used as part of the hopping is calculated via the rules for type 2 localized resource allocation from the RIV value, except either 1 or 2 (depending on system bandwidth) hopping bits have been deducted from the resource allocation bitmap. These hopping bits specify whether Type 1 or Type 2 PUSCH Hopping is used, and for the case of 2 bits, variations of the position of the Type 1 hopping in the frequency domain. The definition of the hopping bits can be found in TS 36.213 [3], Table 8.4-2. Bandwidth dependency for the number of hopping bits allocated follows the following rule:

- If the system BW is `NULRB<=49`, the number of hopping bits is 1, and `HoppingBits` can be 0 or 1.
- If the system BW is `NULRB>49`, the number of hopping bits is 2, and `HoppingBits` can be 00, 01, 10, or 11.

References

[1] 3GPP TS 36.211. "Physical channels and modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCIDecode` | `lteDCIEncode` | `lteDCIInfo` | `lteDCIResourceAllocation` | `lteSCI`

Introduced in R2014a

lteDCIDecode

Downlink control information decoding

Syntax

```
[dcibits,crc_rnti] = lteDCIDecode(dcilen,softbits)
[dcibits,crc_rnti] = lteDCIDecode(enb,softbits)
[dcibits,crc_rnti] = lteDCIDecode(enb,chs,softbits)
```

Description

`[dcibits,crc_rnti] = lteDCIDecode(dcilen,softbits)` recovers a downlink control information (DCI) message, given the DCI vector length, `dcilen`, and a `softbits` input vector. For more information, see “DCI Message Decoding” on page 1-141.

`[dcibits,crc_rnti] = lteDCIDecode(enb,softbits)` uses the cell-wide configuration structure, `enb`. With this syntax, the DCI message length is deduced from `enb.DCIFormat` and cell-wide settings in `enb`.

`[dcibits,crc_rnti] = lteDCIDecode(enb,chs,softbits)` uses the UE-specific channel configuration structure, `chs`. With this syntax, the DCI message length is deduced from `chs.DCIFormat`, the cell-wide configuration in `enb`, and the UE-specific channel configuration in `chs`.

Examples

DCI Decoding

Perform DCI decoding of a sample codeword and return the decoded vector, `decodedDCIbits`, of the length defined for the DCI Format 1 message.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.DuplexMode = 'FDD';
```

```
dciInfo = lteDCIInfo(enb);
dcilen = dciInfo.Format1

ue.PDCCHFormat = 1;
ue.RNTI = 10;
ue.NDLRB = 50;

dciBits = zeros(dcilen,1);
cw = lteDCIEncode(ue,dciBits);

[decodedDCIbits,crcRNTI] = lteDCIDecode(dcilen,cw);

decodedDCIbitslen = size(decodedDCIbits)
crcRNTI


dcilen =

  uint64

   31


decodedDCIbitslen =

    31     1


crcRNTI =

  uint32

   10
```

The `decodedDCIbits` length matches the value of `dcilen`. The `crcRNTI` output has a value of 10, corresponding to the RNTI values used in CRC masking.

DCI Decoding with ENB Structure

Perform DCI decoding of a sample codeword and return the decoded vector, `decodedDCIbits`, of the length defined for the DCI Format 1 message. The `lteDCIDecode` function uses fields in `enb` to determine DCI length.

```
enb.NDLRB = 25;
enb.CellRefP = 1;
enb.DuplexMode = 'FDD';

dciInfo = lteDCIInfo(enb);
dcilen = dciInfo.Format1

ue.PDCCHFormat = 1;
ue.RNTI = 7;
ue.NDLRB = 25;

dciBits = zeros(dcilen,1);
cw = lteDCIEncode(ue,dciBits);
```

```
dcilen =

  uint64

   27
```

Define the `enb` configuration structure for recovery of the DCI message and RNTI. Perform DCI decoding using `enb`.

```
enb.DCIFormat = 'Format1';

[decodedDCIbits,crcRNTI] = lteDCIDecode(enb,cw);

decodedDCIbitslen = size(decodedDCIbits)
crcRNTI
```

```
decodedDCIbitslen =

    27     1


crcRNTI =

  uint32

   7
```

The `decodedDCIbits` length matches the value of `dcilen`. The `crcRNTI` value recovered corresponds to and matches `ue.RNTI`, which is the RNTI value used in the CRC masking.

DCI Decoding Using Channel Structure

Perform DCI decoding of a sample codeword and return the decoded vector, `decodedDCIbits`, of the length defined for the DCI Format 2A message.

```
enb.NDLRB = 25;
enb.CellRefP = 1;
enb.DuplexMode = 'FDD';

dciInfo = lteDCIInfo(enb);
dcilen = dciInfo.Format2A

ue.PDCCHFormat = 2;
ue.RNTI = 5;
ue.NDLRB = 25;

dciBits = zeros(dcilen,1);
cw = lteDCIEncode(ue,dciBits);
```

```
dcilen =

  uint64

   36
```

Define the ue-specific configuration structure, `chs`, for recovery of the DCI message and RNTI. Perform DCI decoding using `enb` and `chs`.

```
chs.DCIFormat = 'Format2A';
chs.ControlChannelType  = 'PDCCH';
chs.EnableCarrierIndication  = 'Off';

[decodedDCIbits,crcRNTI] = lteDCIDecode(enb,chs,cw);

decodedDCIbitslen = size(decodedDCIbits)
crcRNTI
```

```
decodedDCIbitslen =
```

```
    36     1

crcRNTI =

  uint32

   5
```

The `decodedDCIbits` length matches the value of `dcilen`. The `crcRNTI` value recovered corresponds to and matches `ue.RNTI`, which is the RNTI value used in the CRC masking.

Input Arguments

`dcilen` — Length of recovered DCI message vector

integer

Length of recovered DCI message vector, specified as a positive integer.

Data Types: `double`

`softbits` — Floating-point soft bits

vector

Floating-point soft bits, specified as a column vector.

Data Types: `double | int8`

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`DCIFormat`	Required (see syntax descriptions for applicability)	`'Format0'`, `'Format1'`, `'Format1A'`, `'Format1B'`, `'Format1C'`, `'Format1D'`, `'Format2'`, `'Format2A'`, `'Format2B'`, `'Format2C'`, `'Format2D'`, `'Format3'`, `'Format3A'`, `'Format4'`, `'Format5'`	Downlink control information (DCI) format
`CellRefP`	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

`chs` — User-equipment-related channel configuration

structure

User-equipment-related (UE-related) channel configuration, specified as a structure containing these UE-specific fields.

Note: All fields in `chs` are optional. The presence of these optional fields depends on:

- Whether the transmission of DCI message is in a PDCCH using common search space mapping or in an EPDCCH.

- The release-specific features configured at the destination UE.

These additional UE-specific bit fields are off by default.

`DCIFormat` — DCI format name

`'Format0'` | `'Format1'` | `'Format1A'` | `'Format1B'` | `'Format1C'` | `'Format1D'` | `'Format2'` | `'Format2A'` | `'Format2B'` | `'Format2C'` | `'Format2D'` | `'Format3'` | `'Format3A'` | `'Format4'` | `'Format5'`

DCI format name, specified as a character vector. See syntax descriptions for applicability.

Data Types: `char`

`ChannelControlType` — Physical control channel type

`'PDCCH'` (default) | `'EPDCCH'` | optional

Physical control channel type used to carry DCI formats, specified as `'PDCCH'` or `'EPDCCH'`. The setting for `ChannelControlType` affects the presence of the HARQ-ACK resource offset field and message padding.

Data Types: `char`

`SearchSpace` — Search space mapping

`'UESpecific'` (default) | `'Common'` | optional

Search space mapping for DCI formats 0/1A/1C, specified as `'UESpecific'` or `'Common'`. This field is only applicable for PDCCH. None of the additional fields can be present when formats 0 or 1A are mapped into the PDCCH common search space.

Data Types: `char`

`EnableCarrierIndication` — Option to enable carrier indication

`'Off'` (default) | `'On'` | optional

Option to enable carrier indication field (CIF) in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableCarrierIndication` is disabled. When `EnableCarrierIndication` is enabled (`'On'`), the CIF is present in the UE-specific configuration.

Data Types: `char`

`EnableSRSRequest` — Option to enable SRS request

`'Off'` (default) | `'On'` | optional

Option to enable SRS request in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableSRSRequest` is disabled. When `EnableSRSRequest` is enabled (`'On'`),

the SRS request field is present in UE-specific formats 0/1A for FDD or TDD and formats 2B/2C/2D for TDD.

Data Types: `char`

`EnableMultipleCSIRequest` — Option to enable multiple CSI requests

`'Off'` (default) | `'On'` | optional

Option to enable multiple CSI requests in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableMultipleCSIRequest` is disabled. When `EnableMultipleCSIRequest` is enabled (`'On'`), the UE is configured to process multiple channel state information (CSI) requests from cells. Enabling multiple CSI requests affects the length of the CSI request field in UE-specific formats 0 and 4.

Data Types: `char`

`NTxAnts` — Number of UE transmission antennas

1 (default) | 2 | 4 | optional

Number of UE transmission antennas, specified as 1, 2, or 4. The number of UE transmission antennas affects the length of the precoding information field in DCI format 4.

Data Types: `double`

Data Types: `struct`

Output Arguments

`dcibits` — Recovered DCI message bit vector

vector

Recovered DCI message bit vector, returned as a column vector. The length of `dcibits` is defined though structure `enb` in terms of the DCI message format and the bandwidth.

Data Types: `int8`

`crc_rnti` — 16-bit integer result of the CRC decoder

vector

16-bit integer result of the CRC decoder, returned as a column vector. `crc_rnti` is equivalent to the RNTI value that would need to mask (XOR) the CRC for no CRC error.

Data Types: `uint32`

Definitions

DCI Message Decoding

Downlink control information (DCI) message decoding performs the inverse DCI processing operation as specified in TS 36.212 [1], Section 5.3.3. Specifically, `lteDCIDecode` performs rate recovery, and Viterbi and CRC decoding to recover the DCI message bit vector (`dcibits`) from an input vector of received soft bits previously coded by the DCI processing. `lteDCIDecode` also returns the 16-bit integer result of the CRC decoder, `crc_rnti`, which is equivalent to the RNTI value that would need to mask (XOR) the CRC for no CRC error. Using the RNTI, recovered with no CRC errors, enables the system to match the recovered DCI message with a specific `ue`.

The length of the DCI information payload to be recovered can be specified

- Directly by `dcilen`
- Determined using the fields in `enb` that specify the DCI message format (`DCIFormat`) and bandwidth (either `NDLRB` or `NULRB`).

For information on link bandwidth assignment, see “Specifying Number of Resource Blocks” on page 1-141.

Specifying Number of Resource Blocks

The number of resource blocks specifies the uplink and downlink bandwidth. The LTE System Toolbox implementation assumes symmetric link bandwidth unless you specifically assign different values to `NULRB` and `NDLRB`. If the number of resource blocks is initialized in only one link direction, then the initialized number of resource blocks (`NULRB` or `NDLRB`) is used for both uplink and downlink. When this mapping is used, no warning is displayed. An error occurs if `NULRB` and `NDLRB` are both undefined.

References

[1] 3GPP TS 36.212. “Multiplexing and channel coding.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCI` | `lteDCIEncode` | `lteDCIInfo` | `lteDCIResourceAllocation` | `ltePDCCHDecode`

Introduced in R2014a

lteDCIInfo

Downlink control information message information

Syntax

```
info = lteDCIInfo(enb)
info = lteDCIInfo(enb,chs)
```

Description

`info = lteDCIInfo(enb)` returns a structure indicating the minimum possible payload sizes, including zero-padding bits when necessary, for all downlink control information (DCI) message formats, given the cell-wide configuration in `enb`. This syntax uses default values for the UE-specific channel configuration.

To access the individual bit field sizes for each separate format, use the related function `lteDCI`.

TS 36.212 [1], Section 5.3.3.1, along with the referenced procedures of TS 36.213 [2], specify the rules defining the relationship between the bit field sizes and message padding per format, and the cell-wide and UE-specific parameters.

For information on link bandwidth assignment, see “Specifying Number of Resource Blocks” on page 1-151.

`info = lteDCIInfo(enb,chs)` permits formats to be extended with additional bit fields on a per-UE basis, using the UE-specific channel configuration, `chs`.

Examples

Get DCI Message Information

Find the minimum payload sizes of all DCI message formats for NDLRB = 50 (10 MHz symmetric link bandwidth), FDD duplexing, and PDCCH transmission.

```
enb = struct('NDLRB',50,'DuplexMode','FDD','CellRefP',1);
lteDCIInfo(enb)
```

```
ans =

  struct with fields:

     Format0: 27
     Format1: 31
    Format1A: 27
    Format1B: 28
    Format1C: 13
    Format1D: 28
     Format2: 43
    Format2A: 41
    Format2B: 41
    Format2C: 42
    Format2D: 45
     Format3: 27
    Format3A: 27
     Format4: 36
     Format5: 27
```

Get DCI Message Using UE-Specific Configuration

Using the UE-specific channel structure, `chs`, extend the DCI formats to include optional fields dependent on the target UE protocol configuration.

Show the minimum DCI message size per format for `NDLRB` = 50 (10 MHz symmetric link bandwidth), FDD duplexing, and PDCCH transmission.

```
enb = struct('NDLRB',50,'DuplexMode','FDD','CellRefP',1);
dciout = lteDCIInfo(enb)
```

```
dciout =

  struct with fields:

     Format0: 27
     Format1: 31
    Format1A: 27
    Format1B: 28
    Format1C: 13
    Format1D: 28
     Format2: 43
```

```
    Format2A: 41
    Format2B: 41
    Format2C: 42
    Format2D: 45
     Format3: 27
    Format3A: 27
     Format4: 36
     Format5: 27
```

Default settings for the UE-specific channel structure, `chs`, are:

```
chs.ControlChannelType = 'PDCCH';
chs.SearchSpace = 'UESpecific';
chs.EnableCarrierIndication = 'Off';
chs.EnableMultipleCSIRequest = 'Off';
chs.EnableSRSRequest = 'Off';
chs.NTxAnts = 1;
```

Enable carrier indication, and show the sizes per format when the DCI message is configured to include the UE-specific 3 bit carrier indicator field (CIF).

```
chs.EnableCarrierIndication = 'On';

dciout = lteDCIInfo(enb,chs)
```

```
dciout =

  struct with fields:

     Format0: 29
     Format1: 34
    Format1A: 29
    Format1B: 31
    Format1C: 13
    Format1D: 31
     Format2: 46
    Format2A: 43
    Format2B: 43
    Format2C: 45
    Format2D: 47
     Format3: 27
    Format3A: 27
     Format4: 39
```

```
    Format5: 29
```

The sizes have not changed for formats 1C/3/3A, because the CIF does not apply to them. Also, because of the padding rules, the original lengths for some of the formats increased by less than 3 bits. These lengths are for formats mapped into the UE-specific search space, not formats 3/3A.

Change the UE-specific parameter to map the CIF into the PDCCH common search space.

```
chs.SearchSpace = 'Common';
dciout = lteDCIInfo(enb,chs)
```

```
dciout =

  struct with fields:

     Format0: 27
     Format1: 34
    Format1A: 27
    Format1B: 31
    Format1C: 13
    Format1D: 31
     Format2: 46
    Format2A: 43
    Format2B: 43
    Format2C: 45
    Format2D: 47
     Format3: 27
    Format3A: 27
     Format4: 39
     Format5: 27
```

When the DCI message is configured for PDCCH-common search space, the format 0/1A length returns to its original size.

As specified in TS 36.212, with regard to search space, these points apply:

- Only formats 0/1A/1C can be mapped into either the PDCCH common or UE-specific search spaces.
- Formats 3/3A can be mapped into the common search space only.

- All other formats are mapped into UE-specific spaces only.
- There is no common search space for the EPDCCH.

Input Arguments

enb — DCI message format and bandwidth

structure

DCI message format and bandwidth, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL}) For information on link bandwidth assignment, see "Specifying Number of Resource Blocks" on page 1-151.
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL}) For information on link bandwidth assignment, see "Specifying Number of Resource Blocks" on page 1-151.
CellRefP	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or

Parameter Field	Required or Optional	Values	Description
			• `'TDD'` for Time Division Duplex

`chs` — User Equipment (UE) related channel configuration

structure

User-equipment-related (UE-related) channel configuration, specified as a structure containing these UE-specific fields.

Note: All fields in `chs` are optional. The presence of these optional fields depends on:

- Whether the transmission of DCI message is in a PDCCH using common search space mapping or in an EDPCCH.

- The release-specific features configured at the destination UE.

These additional UE-specific bit fields are off by default.

`EnableCarrierIndication` — Option to enable carrier indication

`'Off'` (default) | `'On'` | optional

Option to enable carrier indication field (CIF) in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableCarrierIndication` is disabled. When `EnableCarrierIndication` is enabled (`'On'`), the CIF is present in the UE-specific configuration.

Data Types: `char`

`ChannelControlType` — Physical control channel type

`'PDCCH'` (default) | `'EPDCCH'` | optional

Physical control channel type used to carry DCI formats, specified as `'PDCCH'` or `'EPDCCH'`. The setting for `ChannelControlType` affects the presence of the HARQ-ACK resource offset field and message padding.

Data Types: `char`

`SearchSpace` — Search space mapping

`'UESpecific'` (default) | `'Common'` | optional

Search space mapping for DCI formats 0/1A/1C, specified as `'UESpecific'` or `'Common'`. This field is only applicable for PDCCH. None of the additional fields can be present when formats 0 or 1A are mapped into the PDCCH common search space.

Data Types: `char`

`EnableSRSRequest` — Option to enable SRS request

`'Off'` (default) | `'On'` | optional

Option to enable SRS request in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableSRSRequest` is disabled. When `EnableSRSRequest` is enabled (`'On'`), the SRS request field is present in UE-specific formats 0/1A for FDD or TDD and formats 2B/2C/2D for TDD.

Data Types: `char`

`EnableMultipleCSIRequest` — Option to enable multiple CSI requests

`'Off'` (default) | `'On'` | optional

Option to enable multiple CSI requests in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableMultipleCSIRequest` is disabled. When `EnableMultipleCSIRequest` is enabled (`'On'`), the UE is configured to process multiple channel state information (CSI) requests from cells. Enabling multiple CSI requests affects the length of the CSI request field in UE-specific formats 0 and 4.

Data Types: `char`

`NTxAnts` — Number of UE transmission antennas

1 (default) | 2 | 4 | optional

Number of UE transmission antennas, specified as 1, 2, or 4. The number of UE transmission antennas affects the length of the precoding information field in DCI format 4.

Data Types: `double`

Data Types: `struct`

Output Arguments

`info` — Payload sizes for all DCI message formats

structure

Payload sizes for all DCI message formats, returned as a structure with the following parameter fields.

Parameter Field	Description	Values	Data Type
`Format0`	`Format0` payload size. `Format0` is the DCI format used for the scheduling of PUSCH.	Integer	`uint64`
`Format1`	`Format1` payload size. `Format1` is the DCI format used for the scheduling of one PDSCH codeword.	Integer	`uint64`
`Format1A`	`Format1A` payload size. `Format1A` is the DCI format used for the compact scheduling of one PDSCH codeword and random access procedure.	Integer	`uint64`
`Format1B`	`Format1B` payload size. `Format1B` is the DCI format used for the compact scheduling of one PDSCH codeword with precoding information.	Integer	`uint64`
`Format1C`	`Format1C` payload size. `Format1C` is the DCI format used for very compact scheduling of one PDSCH codeword.	Integer	`uint64`
`Format1D`	`Format1D` payload size. `Format1D` is the DCI format used for the compact scheduling of one PDSCH codeword with precoding and power offset information.	Integer	`uint64`
`Format2`	`Format2` payload size. `Format2` is the DCI format used for the scheduling of two PDSCH codewords with precoding information for closed-loop spatial multiplexing.	Integer	`uint64`
`Format2A`	`Format2A` payload size. `Format2A` is the DCI format used for the scheduling of two PDSCH codewords with precoding information for open-loop spatial multiplexing.	Integer	`uint64`
`Format2B`	`Format2B` payload size. `Format2B` is the DCI format used for the scheduling of dual-layer transmission, for antenna ports 7 and 8.	Integer	`uint64`
`Format2C`	`Format2C` payload size. `Format2C` is the DCI format used for the scheduling of up to eight-layer transmission, for antenna ports 7–14, using TM9.	Integer	`uint64`

Parameter Field	Description	Values	Data Type
`Format2D`	`Format2D` payload size. `Format2D` is the DCI format used for the scheduling of up to eight-layer transmission, for antenna ports 7–14, using TM10.	Integer	`uint64`
`Format3`	`Format3` payload size. `Format3` is the DCI format used for the transmission of transmit power control (TPC) commands for PUCCH and PUSCH with **2-bit** power adjustments.	Integer	`uint64`
`Format3A`	`Format3A` payload size. `Format3A` is the DCI format used for the transmission of transmit power control (TPC) commands for PUCCH and PUSCH with **1-bit** power adjustments.	Integer	`uint64`
`Format4`	`Format4` payload size. `Format4` is the DCI format used for the scheduling of PUSCH with multi-antenna port transmission mode.	Integer	`uint64`
`Format5`	`Format5` payload size. `Format5` is the DCI format used for the scheduling of PSCCH, and also contains several SCI format 0 fields used for the scheduling of PSSCH.	Integer	`uint64`

According to the rules defined in TS 36.212 [1], Section 5.3.3, the payload size of DCI `Format0` and `Format1A` should always be the same and either format will be appended with padding bits, if necessary, to fulfill this condition.

None of the DCI format payload sizes should equal the ambiguous sizes defined in TS 36.212 [1], Table 5.3.3.1.2-1. If necessary, padding bits are added to the DCI format payload. When transmitting DCI messages using PDCCH, the ambiguous format payload sizes are 12, 14, 16, 20, 24, 26, 32, 40, 44, and 56.

Definitions

Specifying Number of Resource Blocks

The number of resource blocks specifies the uplink and downlink bandwidth. The LTE System Toolbox implementation assumes symmetric link bandwidth unless you specifically assign different values to `NULRB` and `NDLRB`. If the number of resource blocks

is initialized in only one link direction, then the initialized number of resource blocks (`NULRB` or `NDLRB`) is used for both uplink and downlink. When this mapping is used, no warning is displayed. An error occurs if `NULRB` and `NDLRB` are both undefined.

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCI` | `lteDCIDecode` | `lteDCIEncode` | `lteDCIResourceAllocation` | `lteSCIInfo`

Introduced in R2014a

lteDCIEncode

Downlink control information encoding

Syntax

```
cw = lteDCIEncode(ue,dcibits)
cw = lteDCIEncode(ue,dcibits,outlen)
```

Description

`cw = lteDCIEncode(ue,dcibits)` returns the vector resulting from downlink control information (DCI) processing of the input bit vector, `dcibits`, given the field settings in the structure, `ue`.

As described in TS 36.212 [1], Section 5.3.3, DCI processing involves CRC attachment with `ue.RNTI` masking of the CRC, convolutional coding, and rate matching to the capacity of the PDCCH format.

`cw = lteDCIEncode(ue,dcibits,outlen)` rate matches the output to `outlen`. For this syntax, `ue.PDCCHFormat` is ignored if present. The ability to request arbitrary output length makes this syntax useful for golden reference comparisons. Use this syntax for DCI encoding of PDCCH or EPDCCH transmissions.

Examples

Encode DCI with Zero RNTI

Perform DCI processing on an all-zero input. This processing results in an all-zero output when you set `RNTI` to 0.

Generate a `dcibits` input vector with zeros for a DCI format 1 message. `enb` is defined with 50 downlink RBs, 1 cell-specific reference signal antenna port, and FDD duplex mode.

```
enb = struct('NDLRB',50,'CellRefP',1,'DuplexMode','FDD');
dciInfo = lteDCIInfo(enb);
```

```
dcibits = zeros(dciInfo.Format1,1);
```

Define a `ue` parameter structure with PDCCH format 1 and RNTI set to 0.

```
ue = struct('PDCCHFormat',1,'RNTI',0);
```

Encode the DCI bits.

```
cw = lteDCIEncode(ue,dcibits);
cw(1:5)
```

```
ans =

  5×1 int8 column vector

   0
   0
   0
   0
   0
```

For PDCCH format 1, the output vector length is 144. For this example, the output is an all-zero vector becasue the DCI bits were 0 and `RNTI` was set to 0.

Encode DCI with Unity RNTI

Perform DCI processing on an all-zero input with `RNTI` set to 1. This processing results in a nonzero output when you set `RNTI` to 1.

Generate a `dcibits` input vector with zeros for a DCI format 1 message. `enb` is defined with 50 downlink RBs, 1 cell-specific reference signal antenna port, and FDD duplex mode.

```
enb = struct('NDLRB',50,'CellRefP',1,'DuplexMode','FDD');
dciInfo = lteDCIInfo(enb);
dcibits = zeros(dciInfo.Format1,1);
```

Define a `ue` parameter structure with PDCCH format 1 and RNTI set to 1.

```
ue = struct('PDCCHFormat',1,'RNTI',1);
```

Encode the DCI bits.

```
cw = lteDCIEncode(ue,dcibits);
```

```
cw(1:10)

ans =

  10×1 int8 column vector

   0
   0
   0
   0
   0
   0
   0
   1
   0
   0
```

For PDCCH format 1, the output vector length is 144. For this example, with `RNTI` set to 1, the output vector is not all-zeros.

Encode DCI Rate Matching Output Length

Perform DCI processing on an all-zero input. Set the output length to 100 bits.

Define `enb` with 50 downlink RBs, 1 cell-specific reference signal antenna port, and FDD duplex mode. Use `lteDCIInfo` to determine DCI message lengths for the defined configuration. Generate a `dcibits` input vector with zeros for a format 1 DCI message.

```
enb = struct('NDLRB',50,'CellRefP',1,'DuplexMode','FDD');
dciInfo = lteDCIInfo(enb);
dcibits = zeros(dciInfo.Format1,1);
```

Define a `ue` parameter structure with PDCCH format 1 and RNTI set to 0.

```
ue = struct('PDCCHFormat',1,'RNTI',0);
```

Encode the DCI bits.

```
cw1 = lteDCIEncode(ue,dcibits);
size(cw1)

ans =
```

```
   144     1
```

Encode the DCI bits again, setting the output length to 100 bits.

```
cw2 = lteDCIEncode(ue,dcibits,100);
size(cw2)
```

```
ans =

   100     1
```

The output vector length for `cw2` is 100, rather than the encoded PDCCH format 1 length of 144 bits in `cw1`, as expected for the configuration.

Encode DCI Message on EPDCCH

Use the DCI encoding function, `lteDCIEncode`, to code a DCI for transmission on EPDCCH. The required size is output by the `lteEPDCCHIndices` function and defined by `info.EPDCCHG`.

Specify the cell-wide settings in parameter structure `enb`.

```
enb.NDLRB = 6;
enb.NSubframe = 0;
enb.NCellID = 0;
enb.CellRefP = 1;
enb.CyclicPrefix = 'Normal';
enb.DuplexMode = 'FDD';
enb.NFrame = 0;
enb.CSIRSPeriod = 'Off';
enb.ZeroPowerCSIRSPeriod = 'Off';
```

Specify the channel transmission configuration in parameter structure `chs`.

```
chs.ControlChannelType = 'EPDCCH';
chs.SearchSpace = 'UESpecific';
chs.EnableCarrierIndication = 'Off';
chs.EnableMultipleCSIRequest = 'Off';
chs.EnableSRSRequest = 'Off';
chs.NTxAnts = 1;
chs.EPDCCHECCE = [2 3];
```

```
chs.EPDCCHType = 'Localized';
chs.EPDCCHPRBSet = 4:5;
chs.EPDCCHStart = 2;
chs.EPDCCHNID = 0;
chs.PDCCHFormat = 1;
chs.RNTI = 1;
dciInfo = lteDCIInfo(enb,chs);
dciin = zeros(dciInfo.Format1A,1);
```

Determine the EPDCCH data bit capacity, output by `lteEPDCCHIndices` in `info.EPDCCHG`.

```
[ind,info] = lteEPDCCHIndices(enb,chs);
info
```

```
info =

  struct with fields:

         EPDCCHG: 114
        EPDCCHGd: 57
         nEPDCCH: 114
           NECCE: 8
     NECCEPerPRB: 4
    NEREGPerECCE: 4
     EPDCCHPorts: 4
```

Encode the DCI bits.

```
cw1 = lteDCIEncode(chs,dciin);
size(cw1)
```

```
ans =

   144     1
```

Encode the DCI bits again, setting the output length to `info.EPDCCHG` bits.

```
cw2 = lteDCIEncode(chs,dciin,info.EPDCCHG);
size(cw2)
```

```
ans =

   114     1
```

The output vector length for `cw2` is 114, rather than the encoded format 1A length of 144 bits in `cw1`, as expected for the configuration.

Input Arguments

`ue` — Parameter structure for DCI processing

structure

Parameter structure for DCI processing, specified as a structure that must have these fields.

Parameter Field	Required or Optional	Values	Description
`PDCCHFormat`	Required	0, 1, 2, 3	PDCCH format
`RNTI`	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

`dcibits` — DCI message bit vector

vector

DCI message bit vector, specified as a column vector. `dcibits` are the DCI processing input bits to be transmitted on a single PDCCH.

Data Types: `double | int8`

`outlen` — Output vector length

optional | nonnegative scalar integer

Output vector length, specified as a nonnegative scalar integer.

Output Arguments

`cw` — Output vector

vector

Output vector resulting from DCI processing, returned as a column vector. `cw` is the result of DCI processing the input vector, `dcibits`. Depending on the function syntax used, the length of `cw` is either:

- $72*2^{\texttt{ue.PDCCUFormat}}$ elements, where $2^{\texttt{ue.PDCCUFormat}}$ represents the number of control channel elements (CCE) and one CCE is 72 bits.
- Rate matched to `outlen`.

Data Types: `int8`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCI` | `lteDCIDecode` | `lteDCIInfo` | `lteDCIResourceAllocation` | `lteEPDCCH` | `ltePDCCH`

Introduced in R2013b

lteDCIResourceAllocation

DCI message physical resource blocks allocation

Syntax

```
[prbset, nrbg, rbgsize] = lteDCIResourceAllocation(enbue,dcistr)
[prbset, nrbg, rbgsize] = lteDCIResourceAllocation(dcistr)
```

Description

`[prbset, nrbg, rbgsize] = lteDCIResourceAllocation(enbue,dcistr)` returns a matrix containing the zero-based physical resource block (PRB) indices `prbset`, the number of resource block groups `nrbg`, and the resource block group size `rbgsize`, for the specified DCI message settings structure `enbue` and DCI message structure `dcistr`.

TS 36.213 [1] specifies resource allocation types used for downlink, uplink and sidelink. For more information, see “Resource Allocation Types” on page 1-180.

If you specify DCI Format 0, Format 4, or Format 5 in `dcistr.DCIFormat`, the function sets the system bandwidth based on the number of uplink resource blocks, `enbue.NULRB`. If you do not specify `enbue.NULRB`, the function sets the system bandwidth based on the number of downlink resource blocks, `enbue.NDLRB`. For all other formats, the function first checks `enbue.NDLRB` for the number of resource blocks. For more information, see “Specifying Number of Resource Blocks” on page 1-182.

`[prbset, nrbg, rbgsize] = lteDCIResourceAllocation(dcistr)` returns outputs `prbset`, `nrbg`, and `rbgsize` as above, except the fields described in structure `enbue` must be present as part of `dcistr`.

Calling `lteDCIResourceAllocation` specifying the `dcistr` structure as the only input argument is not recommended because this signature will be removed in a future release.

Examples

Get Allocated PRB Indices for DCI Message

Allocate DCI resource and shows the allocation of the DCI resources.

Create a DCI message structure with a system bandwidth of 50 resourse blocks and DCI Format 1A.

```
enb = struct('NDLRB',50);
dciStr = lteDCI(enb,struct('DCIFormat','Format1A','AllocationType',1));
```

Return allocated physical resource block indices, the number of resource block groups, and the resource block group size.

```
[prbSet, nrBg, rbgSize] = lteDCIResourceAllocation(enb,dciStr)
```

```
prbSet =

  1×2 uint64 row vector

    0   27


nrBg =

  int32

   17


rbgSize =

  int32

   3
```

Display Uplink PRB Allocation Type 1

Display the PRB allocations associated with the sequence of subframes in a frame for DCI Format 0 and uplink resource allocation type 1.

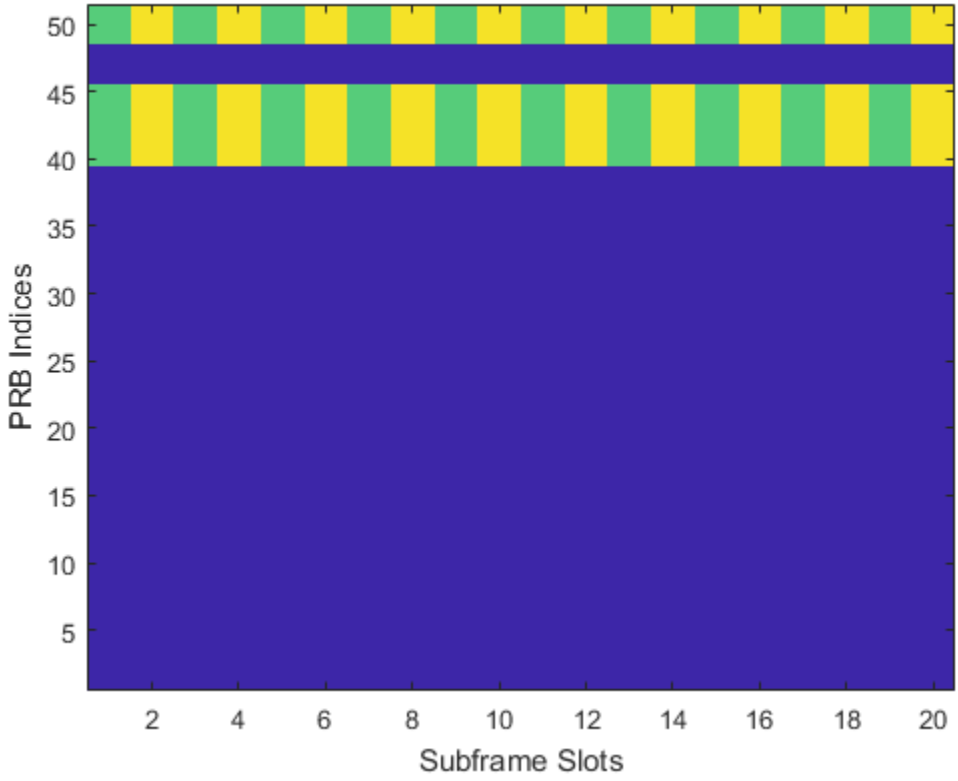
Configure a type 1 uplink resource allocation (multi-cluster). TS 36.213, Section 8.1.2 describes the resourse indication value (RIV) determination.

```
enb = struct('NDLRB',50);
dci = lteDCI(enb,struct('DCIFormat','Format0','AllocationType',1));
dci.Allocation.RIV = 1;
```

Display an image of the PRBs used in each slot of each subframe in a frame.

- Create a `subframeslots` matrix full of zeros. There are 20 slots per frame, specifically two slots per subframe and ten subframes per frame.
- Loop through assigning a PRB set of indices for each subframe. Also assign a value in `subframeslots` for each occupied PRB index.

```
subframeslots = zeros(enb.NDLRB,20);
for i = 0:9
    enb.NSubframe = i;
    prbSet = lteDCIResourceAllocation(enb,dci);
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots);
axis xy;
xlabel('Subframe Slots');
ylabel('PRB Indices');
```



Observe from the image that the same set of PRB indices is used in each slot.

Display Uplink Hopping PRB Allocation

Display the PRB allocations associated with the sequence of subframes in a frame for an uplink resource allocation with hopping.

Configure a type 1 uplink resource allocation that has type 0 hopping and slot and subframe hopping.

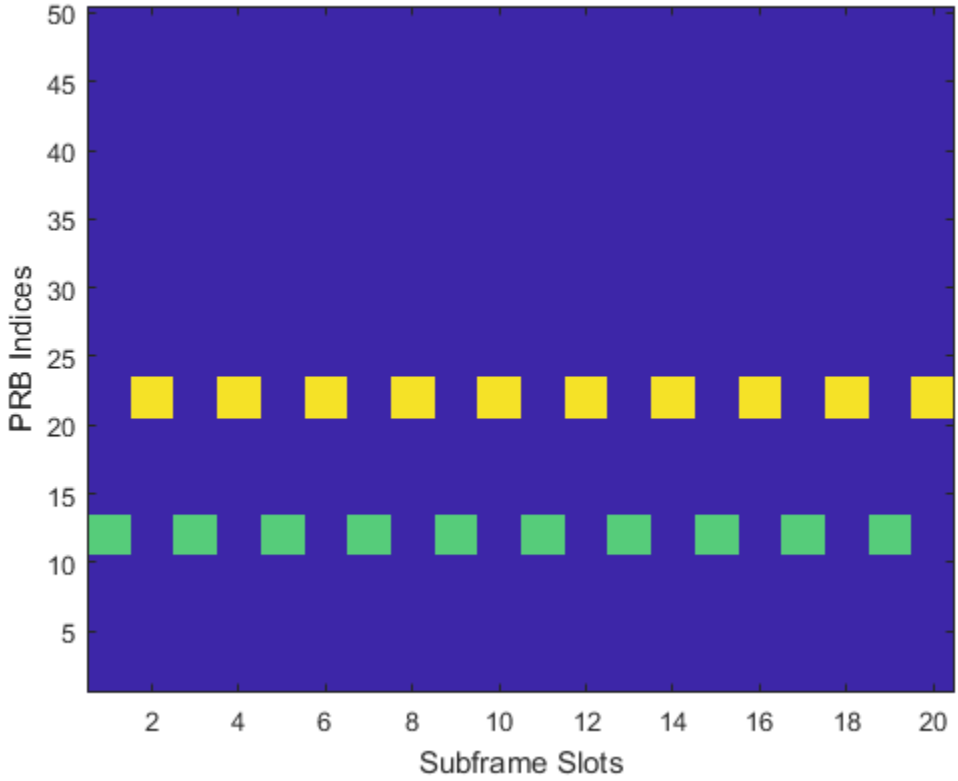
```
enb = struct('NDLRB',50,'NCellID',0);
dci = lteDCI(enb,struct('DCIFormat','Format0','AllocationType',0,...
    'FreqHopping',1));
```

```
dci.Allocation.HoppingBits = 0;
dci.Allocation.RIV = 110;
enb.PUSCHHopping = 'InterAndIntra';
enb.MacTxNumber = 0;
enb.NSubbands = 1;
enb.PUSCHHoppingOffset = 10;
```

Display an image of the PRBs used in each slot of each subframe in a frame.

- Create a `subframeslots` matrix full of zeros. There are 20 slots per frame, specifically two slots per subframe and ten subframes per frame.
- Loop through assigning a PRB set of indices for each subframe. Also assign a value in `subframeslots` for each occupied PRB index.

```
subframeslots = zeros(enb.NDLRB,20);
for i = 0:9
    enb.NSubframe = i;
    prbSet = lteDCIResourceAllocation(enb,dci);
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots)
axis xy
xlabel('Subframe Slots')
ylabel('PRB Indices')
```



Observe from the image that the occupied PRB indices hops in odd and even slots.

Input Arguments

enbue — DCI message settings

structure

DCI message settings, specified as a structure. `enbue` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CellRefP	Optional	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following: • `'FDD'` — Frequency division duplex (default) • `'TDD'` — Time division duplex
The following parameters apply when `dcistr.DCIFormat = 'Format0' or 'Format4'`			
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
The following parameters apply when `dcistr.FreqHopping` = 1			
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
NFrame	Required	0 (default), nonnegative scalar integer	Frame number
PUSCHHopping	Optional	`'Inter'` (default), `'InterAndIntra'`	Uplink subframe hopping mode
MacTxNumber	Optional	Scalar integer from 0 (default) to 27	Number of the current MAC (re-)transmission, *CURRENT_TX_NB*
NSubbands	Optional	1 (default), 2, 3, or 4	Number of subbands.
PUSCHHoppingO	Optional	Scalar integer from 0 (default) to 98	PUSCH hopping offset
The following parameters apply for DCI Format 5 (`dcistr = 'Format5'`).			

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
The following parameters apply for DCI Format 5 (`dcistr = 'Format5'`) with frequency hopping (`dcistr.FreqHopping = 1`).			
NSubframePSSC	Required	Integer	Subframe number in PSSCH subframe pool
PSSCHHoppingP	Optional	Integer from 0 (default) to 510. All values ≥ 504 are set to 510.	PSSCH hopping parameter
NSubbands	Optional	1, 2, or 4	Number of subbands
PSSCHHoppingO	Optional	Integer from 0 (default) to 110	PSSCH hopping offset
PRBPool	Optional	Integer vector	PSSCH resource block pool (sidelink transmission mode 2). A vector of zero-based indices giving the PRBs in the pool. If absent or empty then the pool is assumed to be the full transmission bandwidth

Data Types: `struct`

`dcistr` — DCI message structure

structure

DCI message structure, returned as a structure whose fields match those of the associated DCI format.

The field names associated with `dcistr` are dependent on the DCI format. The format is expected to be one of the formats generated by `lteDCI`. The LTE standard defines resource allocations types for downlink, uplink, and sidelink. For more information, see “Resource Allocation Types” on page 1-180

The following table details the DCI formats and accompanying `dcistr` parameter fields.

DCI Formats	dciout Fields	Size	Description
`'Format0'`	`DCIFormat`	-	`'Format0'`

DCI Formats	dciout Fields	Size	Description
	`CIF`	0 or 3 bits	Carrier indicator field
	`FreqHopping`	1 bit	PUSCH frequency hopping flag
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation, coding scheme, and redundancy version
	`NewData`	1 bit	New data indicator
	`TPC`	2 bits	PUSCH TPC command
	`CShiftDMRS`	3 bits	Cyclic shift for DM RS
	`TDDIndex`	2 bits	For TDD config 0, this field is the Uplink Index. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`CSIRequest`	1, 2, or 3 bits	CSI request
	`SRSRequest`	0 or 1 bit	SRS request. This field can only be present in DCI formats scheduling PUSCH which are mapped onto the UE specific search space given by the C-RNTI
	`AllocationType`	1 bit	Resource allocation type, only present if $N_{\mathrm{RB}}^{\mathrm{UL}} \leq N_{\mathrm{RB}}^{\mathrm{DL}}$.
`'Format1'`	`DCIFormat`	-	`'Format1'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.

DCI Formats	dciout Fields	Size	Description
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format1A'`	`DCIFormat`	-	`'Format1A'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version

DCI Formats	dciout Fields	Size	Description
	TPCPUCCH	2 bits	PUCCH TPC command
	TDDIndex	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	SRSRequest	0 or 1 bit	SRS request. This field can only be present in DCI formats scheduling PUSCH which are mapped onto the UE specific search space given by the C-RNTI
	HARQACKResOffset	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
'Format1B'	DCIFormat	-	'Format1B'
	CIF	0 or 3 bits	Carrier indicator field
	AllocationType	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	Allocation	Varies	Resource block assignment/ allocation
	ModCoding	5 bits	Modulation and coding scheme
	HARQNo	3 bits (FDD) 4 bits (TDD)	HARQ process number
	NewData	1 bit	New data indicator
	RV	2 bits	Redundancy version
	TPCPUCCH	2 bits	PUCCH TPC command

DCI Formats	dciout Fields	Size	Description
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`TPMI`	2 bits for two antennas 4 bits for four antennas	PMI information
	`PMI`	1 bit	PMI confirmation
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format1C'`	`DCIFormat`	-	`'Format1C'`
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
`'Format1D'`	`DCIFormat`	-	`'Format1D'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version

DCI Formats	dciout Fields	Size	Description
	TPCPUCCH	2 bits	PUCCH TPC command
	TDDIndex	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	TPMI	2 bits for two antennas 4 bits for four antennas	Precoding TPMI information
	DlPowerOffset	1 bit	Downlink power offset
	HARQACKResOffset	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
'Format2'	DCIFormat	-	'Format2'
	CIF	0 or 3 bits	Carrier indicator field
	AllocationType	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	Allocation	Varies	Resource block assignment/ allocation
	TPCPUCCH	2 bits	PUCCH TPC command
	TDDIndex	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.

DCI Formats	dciout Fields	Size	Description
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`SwapFlag`	1 bit	Transport block to codeword swap flag
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`PrecodingInfo`	3 bits for two antennas 6 bits for four antennas	Precoding information
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2A'`	`DCIFormat`	-	`'Format2A'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.

DCI Formats	dciout Fields	Size	Description
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`SwapFlag`	1 bit	Transport block to codeword swap flag
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`PrecodingInfo`	0 bits for two antennas 2 bits for four antennas	Precoding information

DCI Formats	dciout Fields	Size	Description
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2B'`	`DCIFormat`	-	`'Format2B'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`ScramblingId`	1 bit	Scrambling identity
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2

DCI Formats	dciout Fields	Size	Description
	NewData2	1 bit	New data indicator for transport block 2
	RV2	2 bits	Redundancy version for transport block 2
	HARQACKResOffset	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
'Format2C'	DCIFormat	-	'Format2C'
	CIF	0 or 3 bits	Carrier indicator field
	AllocationType	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	Allocation	Varies	Resource block assignment/ allocation
	TPCPUCCH	2 bits	PUCCH TPC command
	TDDIndex	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	HARQNo	3 bits (FDD) 4 bits (TDD)	HARQ process number
	TxIndication	3 bits	Antenna ports, scrambling identity, and number of layers indicator
	SRSRequest	Varies	SRS request. Only present for TDD.
	ModCoding1	5 bits	Modulation and coding scheme for transport block 1

DCI Formats	dciout Fields	Size	Description
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2D'`	`DCIFormat`	-	`'Format2D'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number

DCI Formats	dciout Fields	Size	Description
	`TxIndication`	3 bits	Antenna ports, scrambling identity, and number of layers indicator
	`SRSRequest`	Varies	SRS request. Only present for TDD.
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`REMappingAndQCL`	2 bits	PDSCH RE Mapping and Quasi-Co-Location Indicator
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format3'`	`DCIFormat`	-	`'Format3'`
	`TPCCommands`	Varies	TPC commands for PUCCH and PUSCH
`'Format3A'`	`DCIFormat`	-	`'Format3A'`
	`TPCCommands`	Varies	TPC commands for PUCCH and PUSCH
`'Format4'`	`DCIFormat`	-	`'Format4'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPC`	2 bits	PUSCH TPC command

DCI Formats	dciout Fields	Size	Description
	`CShiftDMRS`	3 bits	Cyclic shift for DM-RS
	`TDDIndex`	2 bits	For TDD config 0, this field is Uplink Index. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`CSIReq`	Varies	CSI request
	`SRSRequest`	2 bits	SRS request
	`AllocationType`	1 bit	Resource allocation header type 0 or type 1.
	`ModCoding`	5 bits	Modulation, coding scheme, and redundancy version
	`NewData`	1 bit	New data indicator
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`PrecodingInfo`	3 bits for two antennas 6 bits for four antennas	Precoding information
`'Format5'`	`DCIFormat`	-	`'Format5'`
	`PSCCHResource`	6 bits	Resource for PSCCH
	`TPC`	1 bit	TPC command for PSCCH and PSSCH
	`FreqHopping`	1 bit	Frequency hopping flag

DCI Formats	dciout Fields	Size	Description
	`Allocation`	Varies	Resource block assignment and hopping resource allocation
	`TimeResourcePatte`	7 bits	Time resource pattern

Data Types: `struct`

Output Arguments

`prbset` — Physical resource block indices

nonnegative integer column-vector | nonnegative integer column-matrix

Physical resource block indices, returned as a nonnegative integer column-vector or *N*-by-2 matrix of zero-based indices. The returned `prbset` will be a single column vector or a two-column matrix depending on whether the allocation type defines a different set of PRB indices in the first and second slots of the subframe.

Data Types: `uint64`

`nrbg` — Number of resource block groups in the allocation

integer

Number of resource block groups in the allocation, returned as an integer.

Data Types: `int32`

`rbgsize` — Resource block group size

integer

Number of resource blocks in a group, returned as an integer.

Data Types: `int32`

Definitions

Resource Allocation Types

The LTE standard specifies resource allocation types used for downlink, uplink and sidelink. For a detailed description of the resource allocation types, see `lteDCI`.

- For downlink, the LTE standard specifies three resource allocation types: type 0, 1, and 2. In terms of the DCI formats, formats 1, 2, 2A, 2B, 2C , and 2D can use either resource allocation type 0 or type 1, with the choice signalled by `dcistr.AllocationType`=0 and `dcistr.AllocationType`=1 respectively. DCI formats 1A, 1B, 1C, and 1D use resource allocation type 2, which can be configured to be localized or distributed across resource blocks, signalled by `dcistr.AllocationType`=0 and `dcistr.AllocationType`=1 respectively.
- For uplink allocations (signaled in DCI format 0 messages), the allocation type is either hopping or non-hopping, signalled by `dcistr.FreqHopping`=1 and `dcistr.FreqHopping`=0, respectively.
    - For hopping allocations, there are two types of hopping: type 1 PUSCH hopping and type 2 PUSCH hopping (frequency hopping with a predefined pattern). The hopping type is signalled by `dcistr.Allocation.HoppingBits` as described in TS 36.213 [1], Table 8.4-2.
    - For non-hopping uplink allocations, there are two types of resource allocation: type 0 and type 1. These are signalled by `dcistr.AllocationType`=0 and `dcistr.AllocationType`=1 respectively. In case of DCI format 0 and uplink resource allocation type 1, the concatenation of the frequency hopping flag field (`dcistr.FreqHopping`) and the resource block assignment and hopping resource allocation field provides the resource allocation field (`dcistr.Allocation`). Type 0 allocations create a single contiguous set of PRB, whereas type 1 can create two contiguous PRB sets. The DCI format 4 messages can only signal non-hopping resource allocations type 0 and type 1.
- For sidelink PSSCH (signaled by DCI format 5 messages), allocations are the same as uplink PUSCH allocation type 0, both non-hopping and hopping, but with a different set of additional parameters required in the hopping case. Details for sidelink transmission mode 1 and mode 2 are specified in TS 36.213 [1], Sections 14.1.1.2 and 14.1.1.4 respectively.

All allocations define a single set of PRB for both slots in a subframe (`prbset` is a column vector) except for the distributed resource allocation type 2 and uplink hopping allocations, where different PRB sets are used across the slot pair.

The allocation type may also define a minimum unit of resource block allocation, which is defined by the resource block group size, `rbgsize`. This specifies the number of resource blocks in a group. There are `nrbg` resource block groups in the allocation.

Specifying Number of Resource Blocks

The number of resource blocks specifies the uplink and downlink bandwidth. The LTE System Toolbox implementation assumes symmetric link bandwidth unless you specifically assign different values to `NULRB` and `NDLRB`. If the number of resource blocks is initialized in only one link direction, then the initialized number of resource blocks (`NULRB` or `NDLRB`) is used for both uplink and downlink. When this mapping is used, no warning is displayed. An error occurs if `NULRB` and `NDLRB` are both undefined.

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCI` | `lteDLSCH` | `lteEPDCCH` | `ltePDCCH` | `lteSCIResourceAllocation`

Introduced in R2014a

lteDLChannelEstimate

Downlink channel estimation

Syntax

```
[hest,noisest] = lteDLChannelEstimate(enb,rxgrid)
[hest,noisest] = lteDLChannelEstimate(enb,cec,rxgrid)
[hest,noisest] = lteDLChannelEstimate(enb,pdsch,cec,rxgrid)
[hest,noisest] = lteDLChannelEstimate(enb,epdcch,cec,rxgrid)
```

Description

`[hest,noisest] = lteDLChannelEstimate(enb,rxgrid)` returns the estimated channel response between each transmit and receive antenna,`hest`, and an estimate of the noise power spectral density on the reference signal subcarriers, `noisest`, given the cell-wide settings structure, `enb`, and the resource grid, `rxgrid`. For more information, see “Channel Estimation Processing” on page 1-194.

`[hest,noisest] = lteDLChannelEstimate(enb,cec,rxgrid)` specifies channel estimation method and parameters in the channel estimator configuration structure `cec`.

`[hest,noisest] = lteDLChannelEstimate(enb,pdsch,cec,rxgrid)` specifies the Physical Downlink Shared Channel (PDSCH) transmission configuration, `pdsch`.

`[hest,noisest] = lteDLChannelEstimate(enb,epdcch,cec,rxgrid)` specifies the Enhanced Physical Downlink Control Channel (EPDCCH) transmission configuration, `epdcch`.

Examples

Estimate Downlink Channel Characteristics

Perform channel estimation on an RMC R.12 (4-antenna transmit diversity) waveform.

Initialize a cell-wide configuration strurcture for transmission of RMC R.12.

```
rc = 'R.12';
enb = lteRMCDL(rc);
```

Initialize channel estimator configuration (`cec`). The averaging window size is configured in terms of resource elements (REs), time and frequency. Here cubic interpolation will be used with an averaging window of 1-by-1 REs. No noise estimate is required and there is no need for averaging because no noise is added for this example. Therefore, it is acceptable to set the frequency window and time window size to '1'.

```
cec.FreqWindow = 1;
cec.TimeWindow = 1;
cec.InterpType = 'cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 3;
cec.InterpWindow = 'Causal';
```

Use `lteRMCDLTool` and the cell-wide configuration structure to generate a transmit waveform.

```
txWaveform = lteRMCDLTool(enb,[1;0;0;1]);
```

Model the propagation channel by combining all transmit antennas onto one receive antenna.

Perform OFDM demodulation.

With the cell parameters defined, channel estimation configured and a received waveform demodulated the channel characteristics for the received resource grid is estimated. Display the size of the channel estimate. `hest` is an M-by-N-by-NRxAnts-by-CellRefP array.

```
rxWaveform = sum(txWaveform,2);

rxGrid = lteOFDMDemodulate(enb,rxWaveform);

hest = lteDLChannelEstimate(enb,cec,rxGrid);
size(hest)


ans =

    72   140     1     4
```

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are applicable when `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameters are applicable when `cec.Reference` is set to `'CSIRS'`. See footnote 1.			

Parameter Field	Required or Optional	Values	Description
CSIRefP	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
CSIRSConfig	Required	Scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRSPeriod	Optional	`'On'` (default), `'Off'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configuration.
1	CSI-RS-based channel estimation is strictly only valid within the standard for the `'Port7-14'` transmission scheme. For more information, see TS 36.211 [3], Section 6.10.5.3.		

`rxgrid` — Received resource element grid
3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols.

- N_{SC} is the number of subcarriers
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes.

    Note: To adhere to the estimation method defined in TS 36.104 [1] and TS 36.141 [2], `rxgrid` must contain 10 subframes.
  - $N_{SymPerSF}$ is the number of OFDM symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 OFDM symbols.
    - For extended cyclic prefix, each subframe contains 12 OFDM symbols.
- N_R is the number of receive antennas

`cec` — Channel estimator configuration

structure

Channel estimator configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`PilotAverage`	Required	`'UserDefined'` (defau `'TestEVM'` See footnote 1.	Type of pilot averaging
`FreqWindow`	Required	Nonnegative scalar integer	Size of window in resource elements used to average over frequency during channel estimation See `hest` for additional information.
`TimeWindow`	Required	Nonnegative scalar integer	Size of window in resource elements used to average over time during channel estimation See `hest` for additional information.
`InterpType`	Required	`'nearest'`, `'linear'`, `'natural'`, `'cubic'`, `'v4'`, `'none'` See footnote 2.	Type of 2-D interpolation used during interpolation. For details, see `griddata`. Supported choices are shown in the following table.

Value	Description
`'nearest'`	Nearest neighbor interpolation
`'linear'`	Linear interpolation
`'natural'`	Natural neighbor interpolation
`'cubic'`	Cubic interpolation
`'v4'`	MATLAB 4 `griddata` method
`'none'`	Disables interpolation

Parameter Field	Required or Optional	Values	Description
The following parameters are applicable when `InterpType` is not set to `'none'`.			
`InterpWindow`	Required	`'Causal'`, `'Non-causal'`, `'Centred'`, `'Centered'`	Interpolation window type used during channel estimation. Options `'Centred'` and `'Centered'` are equivalent. For more information, see "Noise Reduction and Interpolation" on page 1-195.
`InterpWinSiz`	Required	Positive scalar number. If `InterpWindow` is set to `'Causal'` or `'Non-causal'`, all numbers ≥1. If `InterpWindow` is set to `'Centred'` or `'Centered'`, only odd integers ≥1.	Window size across which to interpolate. The interpolation window size is specified in number of subframes.
The following parameters are applicable when EPDCCH channel estimation is requested or `pdsch.TxScheme` is set to `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`.			
`Reference`	Optional	`'DMRS'` (default), `'CSIRS'`, `'CellRS'`, `'EPDCCHDMRS'`	Specifies point of reference (signals to internally generate) for channel estimation

Parameter Field	Required or Optional	Values	Description
1 The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation upon the pilots. Pilots near the edge of the resource grid are averaged less as they have no neighbors outside of the grid. For `cec.FreqWindow` = 12 × *X* (that is, any multiple of 12) and `cec.TimeWindow` = 1, the estimator enters a special case where an averaging window of (12 × *X*)-in-frequency is used to average the pilot estimates. For this special case, the averaging is always applied across (12 × *X*) subcarriers, even at the upper and lower band edges; therefore the first (6 × *X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. This provides the appropriate despreading operation required for the case multi-antenna transmission where the DRS signals associated with each antenna occupy the same time/frequency locations but use different orthogonal cover codes to allow them to be differentiated at the receiver. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and follows the method described in TS 36.104/141, Annex E/F for the purposes of transmitter EVM testing. **2** For `cec.InterpType` = `'none'`, no interpolation is performed between pilot symbols and no virtual pilots are created. `hest` will contain channel estimates in the locations of transmitted reference symbols for each received antenna and all other elements of `hest` are zero. The averaging of pilot symbols estimates described by `cec.TimeWindow` and `cec.FreqWindow` are still performed.			

`pdsch` — PDSCH-specific channel transmission configuration

structure

PDSCH-specific channel transmission configuration, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`TxScheme`	Required	`'Port0'`, `'TxDiversity'` `'CDD'`, `'Spat` `'Mult` `'Port` `'Port`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>'Port
'Port</td><td>
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table>
</td></tr>
<tr><td>PRBSet</td><td>Required</td><td>Integer column vector or two-column matrix</td><td>Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. PRBSet can be assigned as:
a column vector, the resource allocation is the same in both slots of the subframe,
a two-column matrix, this parameter specifies different PRBs for each slot in a subframe,
a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes).
PRBSet varies per subframe for the RMCs 'R.25'(TDD), 'R.26'(TDD), 'R.27'(TDD), 'R.43'(FDD), 'R.44', 'R.45', 'R.48', 'R.50', and 'R.51'.</td></tr>
<tr><td>RNTI</td><td>Required</td><td>0 (default), scalar integer</td><td>Radio network temporary identifier (RNTI) value (16 bits)</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
The following parameters are applicable when `pdsch.TxScheme` is set to `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`.			
`NLayers`	Required	1,2,3,4	Number of transmission layers

`epdcch` — EPDCCH-specific channel transmission configuration

structure

EPDCCH-specific channel transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`EPDCCHType`	Required	'Localized', 'Distributed'	EPDCCH transmission type.
`EPDCCHPRBSe`	Required	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2. If no transmission is required, leave this parameter empty.	EPDCCH PRB pair indices
`EPDCCHNID`	Required	Nonnegative integer	EPDCCH nID parameter for scrambling sequence initialization

For EPDCCH channel estimation, `cec.Reference` must be set to `'EPDCCHDMRS'`. Channel estimation is only performed in the PRB pairs indicated by `EPDCCHPRBSet`, but is performed for all EPDCCH candidate locations within those PRB pairs. In other PRBs the channel estimate is interpolated according to `cec.InterpType`. As indicated in TS 36.211 [3], Table 6.8A.5-1:

- For `EPDCCHType` = `'Localized'`, channel estimation is performed in the set of antenna ports p=107...110, p=107,109 or p=107,108 depending on the cell configuration.
- For `EPDCCHType` = `'Distributed'`, channel estimation is performed in the pair of EPDCCH antenna ports used for EPDCCH transmission (p=107,109 for normal cyclic prefix and p=107,108 for extended cyclic prefix).
- In other EPDCCH antenna ports, the channel estimate is zero.

For 'UserDefined' pilot averaging, if `cec.TimeWindow`=2 and `cec.FreqWindow`=1, the "despreading" pilot averaging behaviour described for the PDSCH is used because the EPDCCH DMRS and PDSCH DMRS resource element arrangement and use of cover codes is the same.

Output Arguments

`hest` — Estimated channel between transmit and receive antennas

4-D numeric array of complex values

Estimated channel between transmit and receive antennas, returned as a 4-D numeric array. The reference signals used for channel estimation depends on the settings for `pdsch.TxScheme` and `cec.Reference`. Options include cell-specific reference signals (default), PDSCH DM-RS, CSI-RS, or EPDCCH DM-RS.

The fourth dimension of the output channel estimate array varies based on the reference signal option chosen.

Reference signal used for channel estimation	Output array dimensions (See footnote 1)	RS-specific dimension	Transmission scheme
Cell-specific reference signal	N_{SC}-by-N_{Sym}-by-N_R-by-`CellRefP`	`CellRefP` is the number of cell-	`'SpatialMux'`, `'Port0'`,

Reference signal used for channel estimation	Output array dimensions (See footnote 1)	RS-specific dimension	Transmission scheme
		specific reference signal antenna ports.	`'TxDiversity'`, `'CDD'`, `'MultiUser'`, `'Port5'`, `'Port7-8'`, `'Port8'`, `'Port7-14'`
PDSCH DM-RS	N_{SC}-by-N_{Sym}-by-N_R-by-`NLayers`	`NLayers` is the number of transmission layers.	`'Port5'`, `'Port7-8'`, `'Port8'`, and `'Port7-14'`
CSI-RS	N_{SC}-by-N_{Sym}-by-N_R-by-`CSIRefP`	`CSIRefP` is the number of CSI-RS antenna ports.	`'Port5'`, `'Port7-8'`, `'Port8'`, and `'Port7-14'`
EPDCCH DM-RS	N_{SC}-by-N_{Sym}-by-N_R-by-`4`	Estimate across all four possible EPDCCH ports (p=107...110), which ensures consistency with the indexing used by `lteEPDCCHDMRSIndi` and `lteEPDCCHIndices`	—

1 Output array dimensions

- N_{SC} is the number of subcarriers.
- N_{Sym} is the number of OFDM symbols.
- N_R is the number of receive antennas, `NRxAnts`.

When `TxScheme` is set to `'Port7-8'` or `'Port7-14'` and `cec.PilotAverage` is set to `'UserDefined'`, if `cec.TimeWindow` is 2 or 4 and `cec.FreqWindow` is 1, the

estimator enters a special case where an averaging window of two or four pilots in time is used to average the pilot estimates. For this configuration, averaging is always applied across two or four pilots, regardless of their separation in OFDM symbols. Applying the averaging across two or four pilots provides the appropriate "despreading" operation required for the case of UE-RS ports or CSI-RS ports which occupy the same time/frequency locations but use different orthogonal covers to allow them to be differentiated at the receiver.

- For the CSI-RS with any number of configured `enb.CSIRefP` ports, the pilot REs occur in one pair per subframe. The CSI-RS pilot RE pairs require averaging with `cec.TimeWindow` = 2, and result in a single estimate per subframe.
- For the UE-RS with `pdsch.NLayers` from 1 through 4 layers, the pilot REs occur in pairs, repeated in each slot. The UE-RS pilot RE pairs require averaging with `cec.TimeWindow` = 2, and result in two estimates per subframe, one for each slot.
- When configured to use from 5 through 8 layers, the pairs are distinct between the slots of the subframe and the required averaging is `cec.TimeWindow` = 4, resulting in one estimate per subframe. In these cases, `rxgrid` must contain only one subframe because only a single subframe can be estimated.

`noisest` — Power spectral density estimate on reference signal subcarriers
numeric scalar

Power spectral density estimate on reference signal subcarriers, returned as a real-valued numeric scalar. An estimate of the power spectral density of the noise present on the estimated channel response coefficients is computed using the reference signals.

Algorithms

Channel Estimation Processing

Steps associated with the channel estimation processing include:

1. Extract the reference signals, or pilot symbols, for a transmit-receive antenna pair from the received grid. Use the reference signals to calculate the least-squares estimates of the channel response at the pilot symbol positions within a received grid.

    - The least-squares estimates of the reference signals are obtained by dividing the received pilot symbols by their expected value. Any system noise affects the

least-squares estimates. Remove or reduce the noise to achieve a reasonable estimation of the channel at pilot symbol locations. For more information, see "Noise Reduction and Interpolation" on page 1-195.

2. Average the least-squares estimates to reduce any unwanted noise from the pilot symbols.
3. Using the cleaned pilot symbol estimates, interpolate to obtain an estimate of the channel for the entire number of subframes passed into the function.

Noise Reduction and Interpolation

To minimize the effects of noise on the pilot symbol estimates, the least-squares estimates are averaged using an averaging window. This simple method produces a substantial reduction in the level of noise found on the pilot symbols. The two pilot symbol averaging methods, which also define the interpolation method performed to obtain the channel estimate, are `'TestEVM'` and `'UserDefined'`.

- `'TestEVM'` — follows the method described in TS 36.141 [2], Annex F.3.4. Time averaging is performed across each pilot symbol carrying subcarrier, resulting in a column vector containing the time averaged estimates of the channel. Frequency averaging is then performed using a moving window, maximum size 19. Linear interpolation is used to estimate the values between the pilot symbols. The estimated vector is then replicated and used as the entire channel estimate.

  Note: For `'TestEVM'`, there are no user-defined parameters. Estimation behaves as described in TS 36.141 [2].

  The algorithm differs from the implementation described in TS 36.141 [2] due to the number of subframes across which time-averaging is performed. In TS 36.141 [2], the method requires 10 subframes to be used. The function `lteDLChannelEstimate` performs time averaging across the total number of subframes contained in `rxgrid`.

- `'UserDefined'` — uses an averaging window defined by you. The averaging window size is in resource elements. Any pilot symbols located within the window are used to average the value of the pilot symbol found at the center of the window. The averaged pilot symbol estimates are then used to perform a 2-D interpolation across a window of subframes. The location of pilot symbols within the subframe is not ideally suited to interpolation. To account for this, virtual pilots are created and placed outside the area of the current subframe. This approach allows complete and accurate

interpolation to be performed. The `InterpWindow` field defines the causal nature of the available data. Valid settings for `InterpWindow` are `'Causal'`, `'Non-causal'`, or `'Centered'`.

Use the `InterpWindow` setting:

- `'Causal'` when using past data.
- `'Non-causal'` when using future data. It is the opposite of `'Causal'`. Relying only on future data is commonly referred to as an anti-causal method of interpolation.
- `'Centered'` or `'Centred'` when using a combination of past, present, and future data.

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.141. "Base Station (BS) conformance testing." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`griddata` | `lteDLPerfectChannelEstimate` | `lteEqualizeMIMO` | `lteEqualizeMMSE` | `lteEqualizeZF` | `lteOFDMDemodulate`

Topics

"Channel Estimation"

Introduced in R2013b

lteDLConformanceTestTool

Opens the LTE Throughput Analyzer app for performing downlink PDSCH demodulation conformance tests

Syntax

```
lteDLConformanceTestTool
```

Description

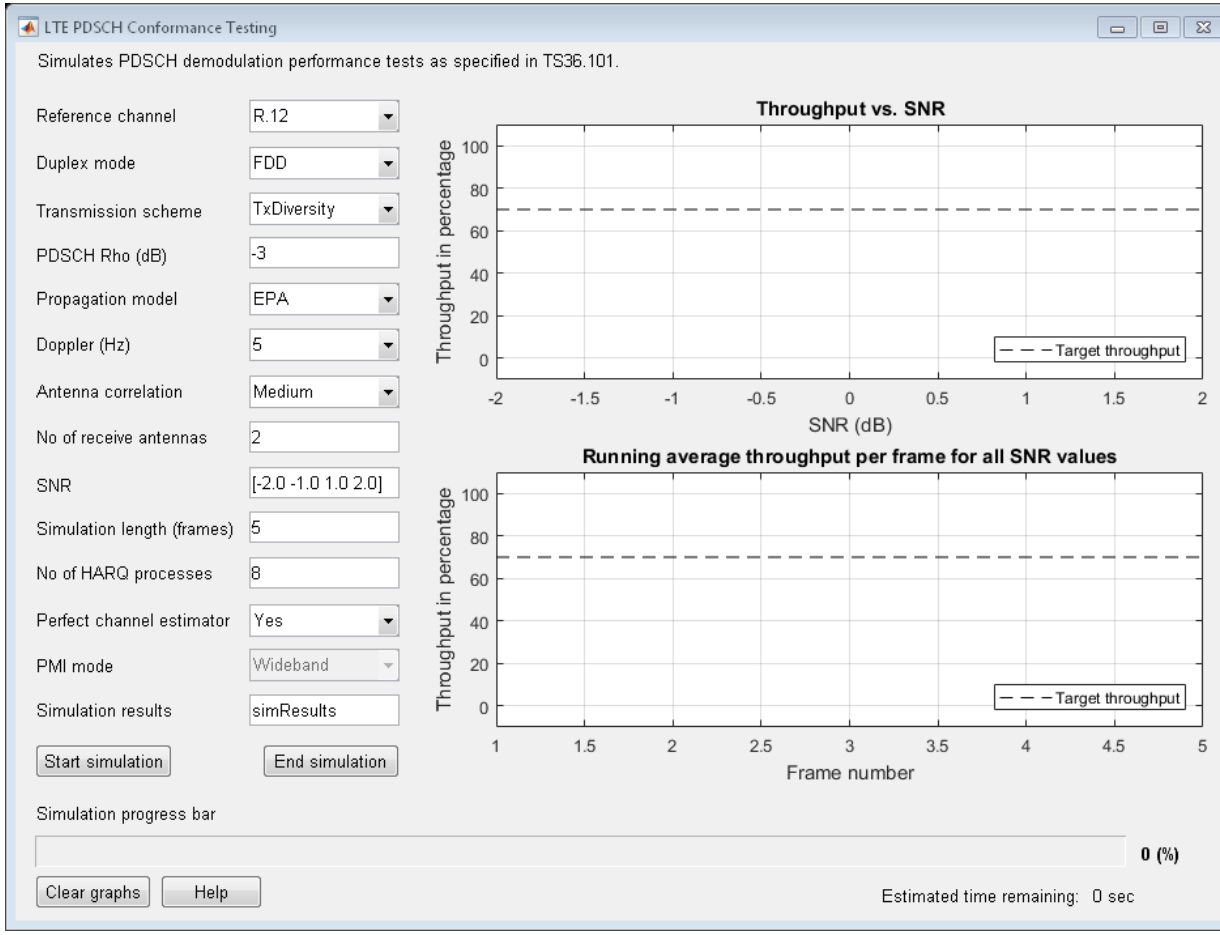
`lteDLConformanceTestTool` opens the LTE Throughput Analyzer app for performing downlink PDSCH demodulation conformance tests as defined in TS 36.101 [1].

The throughput performance graphs update dynamically during the simulation run and provides an early understanding system behavior for a given setup. For more information, see LTE Throughput Analyzer.

Examples

Open Throughput Analyzer App

```
lteDLConformanceTestTool
```



The LTE PDSCH Conformance Testing user interface opens.

- "Analyze Throughput for PDSCH Demodulation Performance Test"

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

Apps
LTE Throughput Analyzer

Functions
`lteRMCDLTool` | `lteRMCULTool` | `lteTestModel`

Topics
“Analyze Throughput for PDSCH Demodulation Performance Test”

Introduced in R2014a

lteDLDeprecode

Downlink deprecoding onto transmission layers

Syntax

```
out = lteDLDeprecode(in,nu,txscheme,codebook)
out = lteDLDeprecode(enb,chs,in)
```

Description

`out = lteDLDeprecode(in,nu,txscheme,codebook)` returns a symbol matrix by performing deprecoding using matrix pseudo-inversion to undo processing described in TS 36.211 [1], Section 6.3.4. The overall operation of the deprecoder is to transpose what is defined in the specification.

`out = lteDLDeprecode(enb,chs,in)` performs deprecoding of the precoded symbol matrix, `in`, according to cell-wide settings `enb` and `chs` (channel transmission configurations).

Examples

Perform Deprecoding on Identity Matrix

Deprecode a precoded identity matrix having codebook index 1 for three layers and four antennas.

```
in  = lteDLPrecode(eye(3),4,'SpatialMux',1);
out = lteDLDeprecode(in,3,'SpatialMux',1)
```

```
out =

   1.0000 + 0.0000i   0.0000 - 0.0000i  -0.0000 + 0.0000i
   0.0000 - 0.0000i   1.0000 + 0.0000i   0.0000 + 0.0000i
  -0.0000 + 0.0000i   0.0000 - 0.0000i   1.0000 + 0.0000i
```

Input Arguments

`in` — Precoded input symbols

numeric matrix

Precoded input symbols, specified as numeric matrix. The size of the matrix is *N*-by-*P*, where *P* is the number of transmission antennas and *N* is the number of symbols per antenna. Generate the matrix by extracting a PDSCH using `ltePDSCHIndices` function on a received resource array. You can perform a similar extraction using the index generator for any other downlink channel that utilizes precoding.

`nu` — Number of layers

integer from 1 to 8

Number of layers, specified as an integer from 1 to 8. The maximum number of layers depends on the transmission scheme, `txscheme`.

Data Types: `double`

`txscheme` — Transmission scheme

`'Port0' | 'TxDiversity' | 'CDD' | 'SpatialMux' | 'MultiUser' | 'Port5' | 'Port7-8' | 'Port8' | 'Port7-14'`

PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.

Transmission scheme	Description
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

Data Types: `char`

`codebook` — Codebook index

integer from 0 to 15

Codebook index to select the precoding matrix, specified as an integer from 0 to 15. This input is ignored for the `'Port0'`, `'TxDiversity'`, and `'CDD'` transmission schemes. Find the precoding matrix corresponding to a particular codebook index in TS 36.211 [1], Section 6.3.4.

Data Types: `double`

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure containing these parameter fields:

Parameter Field	Required or Optional	Values	Description
When `chs.TxScheme` is set to `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, or `'MultiUser'`, these parameters are applicable:			
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
When `chs.TxScheme` is set to `'SpatialMux'`, or `'MultiUser'` and `chs.PMISet` is present, these parameters are applicable:.			
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})

Parameter Field	Required or Optional	Values	Description
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
When `DuplexMode` is set to `'TDD'`, these parameters are applicable:			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

Data Types: `struct`

chs — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields:

Parameter Field	Required or Optional	Values	Description
TxScheme	Required	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, `'MultiUser'`, `'Port5'`,	PDSCH transmission scheme, specified as one of the following options.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>'Port7-8', 'Po
'Port7-14'.</td><td><table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td><td></td></tr>
<tr><td>NLayers</td><td>Required</td><td>Integer from 1 to 8</td><td>Number of transmission layers.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
The following parameters are applicable when `TxScheme` is set to `'SpatialMux'` or `'MultiUser'`. Include either `CodebookIdx` field or both `PMISet` and `PRBSet` fields. For more information, see Algorithms.			
`CodebookIdx`	Required	Integer from 0 to 15	Codebook index used during precoding
`PMISet`	Required	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.

Parameter Field	Required or Optional	Values	Description
The fields `PMISet` and `PRBSet` are used to determine the frequency-domain position occupied by each precoded symbol in `out`. This step is performed to apply the correct subband precoder when multiple PMI mode is used. Alternatively, you can provide the `CodebookIdx` parameter field. `CodebookIdx` is a scalar specifying the codebook index to use across the entire bandwidth. Therefore, the `CodebookIdx` field does not support subband precoding. The relationship between PMI values and codebook index is given in TS 36.213 [2], Section 7.2.4.			

Data Types: `struct`

Output Arguments

`out` — Deprecoded downlink output

matrix

Deprecoded downlink output, returned as N_{SYM}-by-v matrix, containing v layers, with $N_{SYM}N_{SYM}$ symbols in each layer. The symbols for layers and antennas lie in columns rather than in rows.

Data Types: `double`
Complex Number Support: Yes

Algorithms

For transmission schemes `'CDD'`, `'SpatialMux'`, and `'MultiUser'`, and degenerately `'Port0'`,

- Precoding involves multiplying a P-by-v precoding matrix, F, by a v-by-N_{SYM} matrix, representing N_{SYM} symbols on each of v transmission layers. This multiplication yields a P-by-N_{SYM} matrix, representing N_{SYM} precoded symbols on each of P antenna ports. Depending on the transmission scheme, the precoding matrix can be composed of multiple matrices multiplied together. But the size of the product, F, is always P-by-v.

For the `'TxDiversity'` transmission scheme,

- A P^2-by-$2v$ precoding matrix, F, is multiplied by a $2v$-by-N_{SYM} matrix, formed by splitting the real and imaginary components of a v-by-N_{SYM} matrix of symbols on

layers. This multiplication yields a P^2-by-N_{SYM} matrix of precoded symbols, which is then reshaped into a P-by-PN_{SYM} matrix for transmission. Since v is P for the `'TxDiversity'` transmission scheme, F is of size P^2-by-$2P$, rather than P^2-by-$2v$.

When v is P in `'CDD'`, `'SpatialMux'`, and `'MultiUser'` transmission schemes, and when P and v are 2 in the `'TxDiversity'` transmission scheme,

- The precoding matrix, F, is square. Its size is $2P$-by-$2P$ for the transmit diversity scheme and P-by-P otherwise. In this case, the deprecoder takes the matrix inversion of the precoding matrix to yield the deprecoding matrix F^{-1}. The matrix inversion is computed using LU decomposition with partial pivoting (row exchange):

  1. Perform LU decomposition $P_xF = LU$.
  2. Solve $LY = I$ using forward substitution.
  3. Solve $UX = Y$ using back substitution.
  4. $F^{-1} = XP_x$.

The degenerate case of the `'Port0'` transmission scheme falls into this category, with $P = v = 1$.

For the `'CDD'`, `'SpatialMux'`, and `'MultiUser'` transmission schemes,

- The deprecoding is then performed by multiplying F^{-1} by the transpose of the input `symbols` (`symbols` is size N_{SYM}-by-P, so the transpose is a P-by-N_{SYM} matrix). This multiplication recovers the v-by-N_{SYM} (equals P-by-N_{SYM}) matrix of transmission layers.

For the `'TxDiversity'` transmission scheme,

- The deprecoding is performed, multiplying F^{-1} by the transpose of the input `symbols` (`symbols` is size PN_{SYM}-by-P, so the transpose is a P-by-PN_{SYM} matrix), having first been reshaped into a $2P$-by-N_{SYM} matrix. This multiplication yields a $2v$-by-N_{SYM}, matrix which is then split into two v-by-N_{SYM} matrices. To recover the v-by-N_{SYM} matrix of transmission layers multiply the second matrix by j and add the two matrices together (thus recombining real and imaginary parts).

For the other cases, specifically `'CDD'`, `'SpatialMux'`, and `'MultiUser'` transmission schemes with $v \neq P$ and the `'TxDiversity'` transmission scheme with $P = 4$,

- The precoding matrix F is not square. Instead, the matrix is rectangular with size P-by-v, except in the case of `'TxDiversity'` transmission scheme with $P = 4$, where it is of size P^2-by-$(2P = 16)$-by-8. The number of rows is always greater than the number of columns in the matrix F is size m-by-n with $m > n$.
- In this case, the deprecoder takes the matrix pseudo-inversion of the precoding matrix to yield the deprecoding matrix F^+. The matrix pseudo-inversion is computed as follows.

  1. Perform LU decomposition $P_x F = LU$.
  2. Remove the last $m - n$ rows of U to give $\bar{U}$.
  3. Remove the last $m - n$ columns of L to give $\bar{L}$.
  4. $X = \bar{U}^H \left(\bar{U}\bar{U}^H\right)^{-1} \left(\bar{L}^H \bar{L}\right)^{-1} \bar{L}^H$ (the matrix inversions are carried out as in the previous steps).
  5. $F^+ = XP_x$

The application of the deprecoding matrix F^+ is the same process as described for deprecoding the square matrix case with F^+ in place of F^{-1}.

This method of pseudo-inversion is based on*Linear Algebra and Its Application* [3], Chapter 3.4, Equation (56).

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] Strang, Gilbert. *Linear Algebra and Its Application*. Academic Press, 1980. 2nd Edition.

See Also

See Also

`lteDLPrecode` | `lteLayerDemap`

Introduced in R2014a

lteDLFrameOffset

Downlink frame timing estimate

Syntax

```
offset=lteDLFrameOffset(enb,waveform)
[offset,corr]=lteDLFrameOffset(enb,waveform)
[offset,corr]=lteDLFrameOffset(enb,waveform,corrcfg)
[offset,corr]=lteDLFrameOffset(enb,waveform,'TestEVM')
```

Description

`offset=lteDLFrameOffset(enb,waveform)` returns the timing offset, in symbols, between the start of the input `waveform` and the start of the first frame. `offset` is measured using the reference signals defined in the LTE standard.

`lteDLFrameOffset` performs synchronization using the PSS and SSS for the time-domain waveform, given cell-wide settings structure, `enb`. It does not perform PSS/SSS cell identity search. Use `lteCellSearch` to perform cell identity search and provide it to `lteDLFrameOffset` as an input parameter in the cell-wide settings, `enb`.

`[offset,corr]=lteDLFrameOffset(enb,waveform)` also returns a complex matrix, `corr`, of the same dimensions as the input `waveform`.

`[offset,corr]=lteDLFrameOffset(enb,waveform,corrcfg)` provides control over which reference signals are used for timing estimation, as specified in the input structure, `corrcfg`.

`[offset,corr]=lteDLFrameOffset(enb,waveform,'TestEVM')`, provides the input `'TestEVM'` to stipulate alignment of the correlation configuration with TS 36.104, Annex E [1].

Examples

Synchronize and Demodulate Test Model Output

Synchronization and demodulation of Test Model output which has been delayed by five samples.

Initialize cell-wide parameters structure. Generate waveform for test model 1.1 with 5MHz bandwidth. A five sample delay is acheived by inserting five zeros at beginning of waveform. Compute and display the offset. Perform demodulation of the waveform accounting for the offset delay by adjusting waveform start index.

```
enb = lteTestModel('1.1','5MHz');
tx = [0; 0; 0; 0; 0; lteTestModelTool(enb);];

offset = lteDLFrameOffset(enb,tx)
rxGrid = lteOFDMDemodulate(enb,tx(1+offset:end));
```

```
offset =

     5
```

Input Arguments

enb — Cell-wide settings

scalar structure

Cell-wide settings, specified as a structure. `enb` can contain these fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are only required for `CellRS = 'On'` or `'OmitEdgeRBs'`. See `corrcfg`.			
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
The following parameters are only required when `DuplexMode = 'TDD'` and `CellRS = 'On'` or `'OmitEdgeRBs'`. See `corrcfg`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

Data Types: `struct`

`waveform` — Time-domain waveform

numeric matrix

Time-domain waveform, specified as a T-by-P numeric matrix, where T is the number of time-domain samples and P is the number of receive antennas. Use `lteOFDMModulate` or one of the channel model functions (`lteFadingChannel`, `lteHSTChannel`, or `lteMovingChannel`) to generate this matrix.

Data Types: `double | single`

`corrcfg` — Control reference signals used for timing estimation

scalar structure

Control reference signals used for timing estimation, specified as a structure containing any or all of these fields.

Parameter Field	Required or Optional	Values	Description
PSS	Optional	'On' (default), 'Off'	Primary synchronization signal (PSS) correlation mode
SSS	Optional	'On' (default), 'Off'	Secondary synchronization signal (SSS) correlation mode
CellRS	Optional	'Off' (default), 'OmitEdgeRBs', 'On'	Cell-specific reference signal (CRS) correlation mode

For the corrcfg fields, lteDLFrameOffset uses the reference signals, (PSS, SSS, or CellRS) as configured by initializing particular reference signal correlation mode(s) to 'On'. For CellRS, using the mode setting, 'OmitEdgeRBs', instead of 'On', removes the uppermost and lowermost resource block of reference signals from the correlation. The 'OmitEdgeRBs' method is specified for EVM testing in TS 36.104, Annex E [1]. Omitting band edge RBs removes potential transmit filtering nonlinear phase response and the resulting influence on group delay response for the overall band.

Data Types: struct

'TestEVM' — Test EVM setting

'TestEVM'

Test EVM setting, specified as 'TestEVM'. Asdefined in TS 36.104 [1], Annex E, sets correlation with:

- PSS to 'On',
- SSS to 'Off', and
- CellRS to 'OmitEdgeRBs'.

Data Types: char

Output Arguments

offset — Timing offset from the start of the input waveform to the start of the first frame

numeric scalar

Timing offset from the start of the input waveform to the start of the first frame, returned as a numeric scalar. It indicates the number of samples from the start of `waveform`, to the position in `waveform` where the first frame begins. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and the internally generated time-domain reference waveforms containing PSS and SSS signals. The correlation is performed separately for each antenna. `lteDLFrameOffset` uses the antenna with the earliest correlation peak and a correlation peak magnitude at least 50% of the maximum across the antennas to compute `offset`.

Data Types: `double`

`corr` — Signal used to extract timing offset

complex numeric matrix

Signal used to extract the timing offset, returned as a complex numeric matrix of the same size as `waveform`. Each column of `corr` is the correlation for each column (antenna) of `waveform`.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCellSearch` | `lteFadingChannel` | `lteFrequencyCorrect` | `lteFrequencyOffset` | `lteHSTChannel` | `lteMovingChannel` | `lteOFDMDemodulate`

Introduced in R2014a

lteDLPerfectChannelEstimate

Downlink perfect channel estimation

Syntax

```
hest = lteDLPerfectChannelEstimate(enb,propchan)
hest = lteDLPerfectChannelEstimate(enb,propchan,timefreqoffset)
hest = lteDLPerfectChannelEstimate(enb,propchan,timefreqoffset,
ntxants)
```

Description

`hest = lteDLPerfectChannelEstimate(enb,propchan)` performs perfect channel estimation for a system configuration given structures containing the cell-wide settings, and the propagation channel configuration. The perfect channel estimates are only produced for channel models created using `lteFadingChannel` or `lteHSTChannel`.

This function provides a perfect MIMO channel estimate after OFDM modulation. Perfect channel estimation is achieved by setting the channel with the desired configuration and sending a set of known symbols through it for each transmit antenna in turn.

`hest = lteDLPerfectChannelEstimate(enb,propchan,timefreqoffset)` adds the parameter `timefreqoffset`, which specifies the timing and frequency offsets. This parameter allows `hest` to be the precise channel that results when the receiver is precisely synchronized.

`hest = lteDLPerfectChannelEstimate(enb,propchan,timefreqoffset, ntxants)` adds the parameter `ntxants`, which specifies the number of transmit antenna planes.

Note: This syntax is provided to allow modeling of greater than four transmit antenna planes. For this syntax, the `enb.CellRefP` field, is not required and, if included, is not used to define the number of antenna planes.

Examples

Perform Perfect DL Channel Estimation

Perform perfect channel estimation for a given propagation channel configuration in the downlink.

Initialize eNodeB and propagation channel configuration structures.

```
enb.NDLRB = 6;
enb.CyclicPrefix = 'Normal';
enb.CellRefP = 4;
enb.TotSubframes = 1;

chs.Seed = 1;
chs.DelayProfile = 'EPA';
chs.NRxAnts = 2;
chs.DopplerFreq = 5.0;
chs.MIMOCorrelation = 'Low';
chs.InitPhase = 'Random';
chs.InitTime = 0.0;
chs.ModelType = 'GMEDS';
chs.NTerms = 16;
chs.NormalizeTxAnts = 'On';
chs.NormalizePathGains = 'On';
```

Compute the downlink channel estimate and display the dimension of the output channel estimate.

```
H = lteDLPerfectChannelEstimate(enb,chs);
sizeH = size(H)
```

```
sizeH =

    72    14     2     4
```

Perfect DL Channel Estimation on a Time Offset Waveform

Perform perfect channel estimation on a time offset waveform that has passed through a fading channel.

Configuration initialization

- Initialize cell-wide configuration to R.12 (TxDiversity, 6 RB, CellRefP=4, normal cyclic prefix).
- Initialize propagation channel configuration.

```
enb = lteRMCDL('R.1','FDD',1);
enb.TotSubframes = 1;

chan.Seed = 1;
chan.DelayProfile = 'EPA';
chan.NRxAnts = 1;
chan.DopplerFreq = 5.0;
chan.MIMOCorrelation = 'Low';
chan.InitPhase = 'Random';
chan.InitTime = 0.0;
chan.ModelType = 'GMEDS';
chan.NTerms = 16;
chan.NormalizeTxAnts = 'On';
chan.NormalizePathGains = 'On';
```

Waveform processing

- Create waveform and add samples for channel delay.
- Pass through a fading channel, generating time-domain receiver samples.

```
[txwave,txgrid,rmcCfg] = lteRMCDLTool(enb,[1;0;0;1]);
txwave = [txwave; zeros(25,enb.CellRefP)];
chan.SamplingRate = rmcCfg.SamplingRate;
rxwave = lteFadingChannel(chan,txwave);
```

Determine timing offset

- Use lteDLFrameOffset to estimate time offset.
- Account for the timing offset in the received waveform.

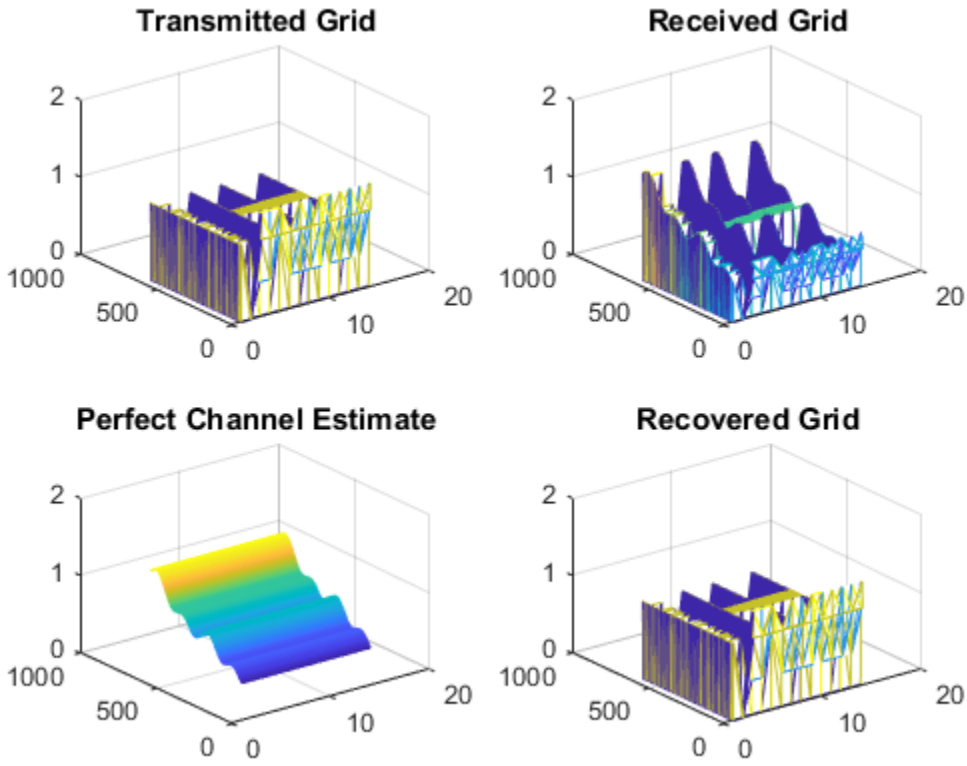
```
toffset = lteDLFrameOffset(enb,rxwave)
rxwave = rxwave(1+toffset:end,:);
```

```
toffset =

     7
```

Demodulation and perfect channel estimation

- Demodulate `rxwave` to generate frequency-domain receiver data in `rxgrid`.
- Equalize with perfect channel estimate using time offset.
- Plot resource element grids to show impact of fading channel on the transmitted signal and recovery of the signal using the perfect channel estimate.

```
rxgrid = lteOFDMDemodulate(enb,rxwave);
hest = lteDLPerfectChannelEstimate(enb,chan,[toffset,0]);
sizeH = size(hest);
recoveredgrid = rxgrid./hest;

subplot(2,2,1)
mesh(abs(txgrid(:,:,1,1)))
title('Transmitted Grid');
subplot(2,2,2)
mesh(abs(rxgrid(:,:,1,1)))
title('Received Grid');
subplot(2,2,3)
mesh(abs(hest(:,:,1,1)))
title('Perfect Channel Estimate');
subplot(2,2,4)
mesh(abs(recoveredgrid(:,:,1,1)))
title('Recovered Grid');
```



Comparing the transmitted grid to the recovered grid shows equalization of the received grid with the perfect channel estimate recovers the transmission.

Perform HST Model Perfect DL Channel Estimation

Perform perfect channel estimation for a high speed train (HST) propagation channel configuration in the downlink. Include time and frequency offsets in the channel estimation computation.

Configuration initialization

Initialize configuration structures for eNodeB and HST propagation channel.

```
enb.NDLRB = 6;
```

```
enb.NCellID = 1;
enb.CyclicPrefix = 'Normal';
enb.CellRefP = 1;
enb.TotSubframes = 1;

hst.NRxAnts = 2;
hst.Ds = 100;
hst.Dmin = 500;
hst.Velocity = 200;
hst.DopplerFreq = 5.0;
hst.InitTime = 0.0;
hst.ModelType = 'GMEDS';
hst.NormalizeTxAnts = 'On';
```

Waveform processing

- Create waveform and add samples for channel delay.
- Pass through an HST channel, generating time-domain receiver samples.

```
[txwave,txgrid,rmcCfg] = lteRMCDLTool(enb,[1;0;0;1]);
txwave = [txwave; zeros(25,enb.CellRefP)];
hst.SamplingRate = rmcCfg.SamplingRate;
rxwave = lteHSTChannel(hst,txwave);
```

Determine timing and frequency offsets

- Use lteDLFrameOffset to estimate time offset.
- Account for the timing offset in the received waveform.
- Use lteFrequencyOffset to estimate frequency offset.

```
toffset = lteDLFrameOffset(enb,rxwave)
rxwave = rxwave(1+toffset:end,:);
foffset = lteFrequencyOffset(enb,rxwave)
```

```
toffset =

     7


foffset =

  -62.2418
```

Demodulation and perfect channel estimation

- Demodulate `rxwave` to generate frequency-domain receiver data in `rxgrid`.
- Equalize with perfect channel estimate using time and frequency offsets.

```
rxgrid = lteOFDMDemodulate(enb,rxwave);
hest = lteDLPerfectChannelEstimate(enb,hst,[toffset,foffset]);
sizeH = size(hest)
recoveredgrid = rxgrid./hest;
```

```
sizeH =

    72    14     2
```

Perform Perfect DL Channel Estimation for Eight Antenna Planes

Perform perfect channel estimation for eight transmit antenna planes for a given propagation channel configuration in the downlink.

Initialize eNodeB and propagation channel configuration structures. Define a local variable for the number of transmit antenna planes.

```
enb.NDLRB = 6;
enb.CyclicPrefix = 'Normal';
enb.TotSubframes = 1;

chs.Seed = 1;
chs.DelayProfile = 'EPA';
chs.NRxAnts = 2;
chs.DopplerFreq = 5.0;
chs.MIMOCorrelation = 'Low';
chs.InitPhase = 'Random';
chs.InitTime = 0.0;
chs.ModelType = 'GMEDS';
chs.NTerms = 16;
chs.NormalizeTxAnts = 'On';
chs.NormalizePathGains = 'On';

txAntPlanes = 8;
```

Compute the downlink channel estimate and display the dimension of the output channel estimate.

```
chest = lteDLPerfectChannelEstimate(enb,chs,[0 0],txAntPlanes);
sizeH = size(chest)
```

```
sizeH =

    72    14     2     8
```

The dimensionality of `chest` indicates two receive and eight transmit antenna planes are included in the channel estimate.

Input Arguments

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPre`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`TotSubfra`	Optional	Nonnegative scalar integer (default 1)	Total number of subframes to generate

Data Types: `struct`

`propchan` — Propagation channel configuration

structure

Propagation channel configuration, specified as a structure that can contain these parameter fields. `propchan` must contain the fields required to parameterize the channel model for a fading channel (`lteFadingChannel`) or a high-speed train channel (`lteHSTChannel`).

Note: Before execution of the channel itself, `lteDLPerfectChannelEstimate` sets `SamplingRate` internally to the sampling rate of the time domain waveform passed to `lteFadingChannel` or `lteHSTChannel` for channel filtering. Therefore, the `propchan` structure does not require the `SamplingRate` field. If one is included, it is not used.

`propchan` structure fields to be included for fading channel model case:

Parameter Field	Required or Optional	Values	Description
`NRxAnts`	Required	Positive scalar integer	Number of receive antennas
`MIMOCorre`	Required	`'Low'`, `'Medium'`, `'UplinkMedium'`, `'High'`, `'Custom'`	Correlation between UE and eNodeB antennas • `'Low'` correlation is equivalent to no correlation between antennas. • `'Medium'` correlation level is applicable to tests defined in TS 36.101 [1]. • `'UplinkMedium'` correlation level is applicable to tests defined in TS 36.104 [2].
`Normalize`	Optional	`'On'` (default), `'Off'`	Transmit antenna number normalization. • `'On'`, this function normalizes the model output by `1/sqrt(`N_{TX}`)`, where N_{TX} is the number of transmit antennas. Normalization by the number of transmit antennas ensures that

Parameter Field	Required or Optional	Values	Description
			the output power per receive antenna is unaffected by the number of transmit antennas. • `'Off'`, normalization is not performed.
`DelayProf`	Required	`'EPA'`, `'EVA'`, `'ETU'`, `'Custom'`, `'Off'`	Delay profile model. For more information, see "Propagation Channel Models". Setting `DelayProfile` to `'Off'` switches off fading completely and implements a static MIMO channel model. In this case, the antenna geometry corresponds to `propchan.MIMOCorrelation`, `propchan.NRxAnts`, and the number of transmit antennas. The temporal part of the model for each link between transmit and receive antennas consists of a single path with zero delay and constant unit gain.
The following fields are applicable when `DelayProfile` is set to a value other than `'Off'`.			
`Doppl`	Required	Scalar	Maximum *Doppler* frequency, in Hz.
`InitT`	Required	Scalar	Fading process time offset, in seconds.
`NTerm`	Optional	16 (default) scalar power of 2	Number of oscillators used in fading path modeling.

Parameter Field	Required or Optional	Values	Description
`ModelT`	Optional	`'GMEDS'` (default), `'Dent'`	Rayleigh fading model type. • `'GMEDS'`, the Rayleigh fading is modeled using the Generalized Method of Exact Doppler Spread (GMEDS), as described in [4]. • `'Dent'`, the Rayleigh fading is modeled using the modified Jakes fading model described in [3]. **Note:** `ModelType` = `'Dent'` is not recommended. Use `ModelType` = `'GMEDS'` instead.
`Norma`	Optional	`'On'` (default), `'Off'`	Model output normalization. • `'On'`, the model output is normalized such that the average power is unity. • `'Off'`, the average output power is the sum of the powers of the taps of the delay profile.

Parameter Field	Required or Optional	Values	Description
InitP	Optional	`'Random'` (default), scalar (in Radians), or N-by-L-by-N_{TX}-by-N_{RX} array	Phase initialization for the sinusoidal components of the model. • `'Random'`, sets the phases randomly initialized according to `Seed`. • A scalar, assumed to be in radians, is used to initialize the phases of all components. • An N-by-L-by-N_{TX}-by-N_{RX} array is used to explicitly initialize the phase in radians of each component. In this case, N is the number of phase initialization values per path, L is the number of paths, N_{TX} is the number of transmit antennas, and N_{RX} is the number of receive antennas. (`NRxAnts`) **Note:** • When `ModelType` is set to `'GMEDS'`, $N = 2 \times$ `NTerms`. • When `ModelType` is set to `'Dent'`, $N =$ `NTerms`.
The following field is applicable when `DelayProfile` is set to a value other than `'Off'` and `InitPhase` is set to `'Random'`.			

Parameter Field	Required or Optional	Values	Description
`Seed`	Required	Scalar	Random number generator seed. To use a random seed, set `Seed` to zero. **Note:** MathWorks® recommends using `Seed` values from 0 to $2^{31} - 1 - (K(K-1)/2)$, where $K = N_{TX} \times N_{RX}$, the product of the number of transmit and receive antennas. `Seed` values outside of this range are not guaranteed to give distinct results.
The following fields are applicable when `DelayProfile` is set to `'Custom'`.			
`Avera`	Required	Vector	Average gains of the discrete paths, expressed in dB.
`PathD`	Required	Vector	Delays of the discrete paths, expressed in seconds. This vector must have the same size as `AveragePathGaindB`.
The following fields are applicable when `MIMOCorrelation` is set to `'Custom'`.			
`TxCor`	Required	Matrix	Correlation between each of the transmit antennas, specified as a N_{TX}-by-N_{TX} complex matrix.
`RxCor`	Required	Matrix	Correlation between each of the receive antennas, specified as a complex matrix of size N_{RX}-by-N_{RX}.

`propchan` structure fields to be included for the high-speed train channel model case:

Parameter Field	Required or Optional	Values	Description
`NRxAnts`	Required	Positive scalar integer	Number of receive antennas

Parameter Field	Required or Optional	Values	Description
`Ds`	Required	Scalar	Train-to-eNodeB double initial distance, in meters. `Ds`/2 is initial distance between train and eNodeB, in meters
`Dmin`	Required	Scalar	eNodeB to railway track distance, in meters
`Velocity`	Required	Scalar	Train velocity, in kilometers per hour
`DopplerFr`	Required	Scalar	Maximum *Doppler* frequency, in Hz.
`InitTime`	Required	Scalar	*Doppler* shift timing offset, in seconds
`Normalize`	Optional	`'On'` (default), `'Off'`	Transmit antenna number normalization. • `'On'`, `lteHSTChannel` normalizes the model output by `1/sqrt(`N_{TX}`)`, where N_{TX} is the number of transmit antennas. Normalization by the number of transmit antennas ensures that the output power per receive antenna is unaffected by the number of transmit antennas. • `'Off'`, normalization is not performed.

Data Types: `struct`

`timefreqoffset` — Timing and frequency offset

[0, 0] (default) | two element row vector, [`toffset`, `foffset`] | nonnegative scalar, `toffset` | optional

Timing and frequency offset, specified as a nonnegative scalar providing `toffset` or two element row vector providing [`toffset`, `foffset`].

`toffset` — Timing offset

0 (default) | nonnegative scalar | optional

Timing offset in samples from the start of the output of the channel to the OFDM demodulation starting point, specified as a nonnegative scalar. The timing offset accounts for delay introduced during propagation, which is useful to obtain the perfect estimate of the channel seen by a synchronized receiver. Use `lteDLFrameOffset` to derive `toffset`.

`foffset` — Frequency offset

0 (default) | scalar | optional

Frequency offset in Hertz of the time-domain waveform, specified as a scalar. Use `lteFrequencyOffset` to derive `foffset`.

Example: `[3 100]` indicates a time offset of three samples and a frequency offset of 100 Hz.

Data Types: `double`

`ntxants` — Number of transmit antenna planes

1 (default) | nonnegative integer | optional

Number of transmit antenna planes, specified as a nonnegative integer.

Output Arguments

`hest` — Perfect channel estimate

4-D array

Perfect channel estimate, returned as an N_{SC}-by-N_{SYM}-by-N_{RX}-by-N_{TX} array.

- N_{SC} is the number of subcarriers.
- N_{SYM} is the number of OFDM symbols.
- N_{RX} is the number of receive antennas as specified by `propchan.NRxAnts`.
- N_{TX} is the number of transmit antenna planes, specified either by the input `ntxants` or by `enb.CellRefP`. If `ntxants` is provided as an input, the `enb.CellRefP` field is not required and, if included, is not used.

Data Types: `double`

Complex Number Support: Yes

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] Dent, P., G. E. Bottomley, and T. Croft. "Jakes Fading Model Revisited." *Electronics Letters*. Vol. 29, 1993, Number 13, pp. 1162–1163.

[4] Pätzold, Matthias, Cheng-Xiang Wang, and Bjørn Olav Hogstad. "Two New Sum-of-Sinusoids-Based Methods for the Efficient Generation of Multiple Uncorrelated Rayleigh Fading Waveforms." *IEEE Transactions on Wireless Communications*. Vol. 8, 2009, Number 6, pp. 3122–3131.

See Also

See Also

`lteDLChannelEstimate` | `lteEqualizeMMSE` | `lteEqualizeZF` | `lteFadingChannel` | `lteOFDMDemodulate` | `lteULPerfectChannelEstimate`

Introduced in R2013b

lteDLPrecode

Downlink precoding of transmission layers

Syntax

```
out = lteDLPrecode(in,ntxants,txscheme,codebook)
out = lteDLPrecode(enb,chs,in)
```

Description

`out = lteDLPrecode(in,ntxants,txscheme,codebook)` performs precoding according to TS 36.211 [1], Section 6.3.4. The `out` matrix returned is identical to the matrix returned by `ltePDSCH` for the same set of parameters. The overall operation of the precoder is the transpose of the matrix defined in the specification. The symbols for layers and antennas lie in columns rather than rows.

This function performs precoding of the matrix of layers, `in`, onto P antennas, using the transmission scheme specified by `txscheme`. For transmission scheme precoding dependencies, see "Algorithms" on page 1-239.

`out = lteDLPrecode(enb,chs,in)` precodes the matrix of layers, `in`, according to cell-wide settings `enb` and channel transmission configurations `chs`.

Examples

Perform Downlink Precoding on Identity Matrix

Perform downlink precoding using an identity matrix as input.

By precoding an identity matrix, you can gain access to the precoding matrices. Obtain the precoding matrix having codebook index 1 for three layers and four antennas.

```
out = lteDLPrecode(eye(3),4,'SpatialMux',1).'
```

```
out =

   0.2887 + 0.0000i   0.0000 - 0.2887i  -0.2887 + 0.0000i
```

```
  0.0000 + 0.2887i   0.2887 + 0.0000i   0.0000 + 0.2887i
 -0.2887 + 0.0000i   0.0000 - 0.2887i   0.2887 + 0.0000i
  0.0000 - 0.2887i   0.2887 + 0.0000i   0.0000 - 0.2887i
```

Input Arguments

`in` — Input layers

matrix

Input layers, specified as an N_{SYM}-by-v matrix, consisting of the N_{SYM} modulation symbols for transmission on v layers. Generate this matrix using `lteLayerMap`.

Data Types: `double`
Complex Number Support: Yes

`ntxants` — Number of antennas

positive integer

Number of antennas, specified as a positive integer.

Data Types: `double`

`txscheme` — Transmission scheme

`'Port0' | 'TxDiversity' | 'CDD' | 'SpatialMux' | 'MultiUser' | 'Port5' | 'Port7-8' | 'Port8' | 'Port7-14'`

PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.

Transmission scheme	Description
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

Data Types: `char`

`codebook` — Codebook index

integer from 0 to 15

Codebook index to select the precoding matrix, specified as an integer from 0 to 15. This input is ignored for the `'Port0'`, `'TxDiversity'`, and `'CDD'` transmission schemes. Find the precoding matrix corresponding to a particular codebook index in the TS 36.211 [1], Section 6.3.4. Since codebook is a scalar, the syntax that includes this parameter does not support subband precoding or multiple PMI mode.

Data Types: `double`

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure containing these parameter fields:

Parameter Field	Required or Optional	Values	Description
When `chs.TxScheme` is set to `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, or `'MultiUser'`, these parameters are applicable:			
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
When `chs.TxScheme` is set to `'SpatialMux'`, or `'MultiUser'` and `chs.PMISet` is present, these parameters are applicable:.			
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})

Parameter Field	Required or Optional	Values	Description
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
When `DuplexMode` is set to `'TDD'`, these parameters are applicable:			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

Data Types: `struct`

chs — Channel-specific transmission configuration

structure | structure array

Channel specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optiona	Values	Description
TxScheme	Optiona	`'Port0'`, `'TxDiversity'`, `'CDD'`,	PDSCH transmission scheme, specified as one of the following options.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>'SpatialMu
'MultiUser
'Port5',
'Port7-8',
'Port8',
'Port7-14'</td><td>
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table>
</td></tr>
<tr><td colspan="4">When chs.TxScheme is set to 'SpatialMux' or 'MultiUser', these parameters are applicable, include either Codebookidx or both PMISet and PRBSet:</td></tr>
<tr><td>Codebool</td><td>Optiona</td><td>Integer from 0 to 15</td><td>Codebook index used during precoding</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
PMISet	Optional	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.
PRBSet	Optional	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.
The fields `PMISet` and `PRBSet` determine the frequency-domain position that each precoded symbol in `out` occupies to apply the correct subband precoder when multiple PMI mode is being used. Alternatively, you can provide `CodebookIdx` field. `CodebookIdx` is a scalar specifying the codebook index to use across the entire bandwidth. Therefore, the `CodebookIdx` field does not support subband precoding. TS 36.213 [2], Section 7.2.4 specifies the relationship between PMI values and codebook indices.			

Data Types: `struct`

Output Arguments

`out` — Precoded downlink output

matrix

Precoded downlink output, returned as an N_{SYM}-by-P matrix. N_{SYM} is the number of symbols per antenna, and P is the number of transmission antennas. The symbols for layers and antennas lie in columns rather than rows.

Data Types: `double`
Complex Number Support: Yes

Algorithms

For transmission schemes `'CDD'`, `'SpatialMux'`, and `'MultiUser'`, and degenerately `'Port0'`,

- Precoding involves multiplying a P-by-v precoding matrix, denoted as F, by a v-by-N_{SYM} matrix, representing N_{SYM} symbols on each of v transmission layers, to yield a P-by-N_{SYM} matrix, consisting of N_{SYM} precoded symbols on each of P antenna ports. Depending on the transmission scheme, the precoding matrix can be composed of multiple matrices multiplied together, but the size of the product, F, is always P-by-v.

For the `'TxDiversity'` transmission scheme,

- A P^2-by-$2v$ precoding matrix, F, is multiplied by a $2v$-by-N_{SYM} matrix, formed by splitting the real and imaginary components of a v-by-N_{SYM} matrix of symbols on layers, to yield a P^2-by-N_{SYM} matrix of precoded symbols, which is then reshaped into a P-by-PN_{SYM} matrix for transmission. As $v = P$ for the `'TxDiversity'` transmission scheme, we can consider F be of size P^2-by-$2P$ rather than P^2-by-$2v$.

For the other cases, specifically `'CDD'`, `'SpatialMux'`, and `'MultiUser'` transmission schemes with $v \neq P$, and the `'TxDiversity'` transmission scheme with $P = 4$,

- The precoding matrix F is not square; it is rectangular with size P-by-v except for the `'TxDiversity'` transmission scheme with $P = 4$ where it is of size P^2-by-($2P$= 16)-

by-8. The number of rows is always greater than the number of columns that is, the matrix F is size m-by-n with m-by-n.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLDeprecode` | `lteLayerMap`

Introduced in R2014a

lteDLResourceGrid

Downlink subframe resource array

Syntax

```
grid = lteDLResourceGrid(enb)
grid = lteDLResourceGrid(enb,p)
```

Description

`grid = lteDLResourceGrid(enb)` returns an empty resource array generated from the cell-wide-specific settings structure `enb`. For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see “Data Structures”.

`grid = lteDLResourceGrid(enb,p)` accepts an additional input, `p`, which directly specifies the number of antenna planes in the array. In this syntax, `CellRefP` is not required as a structure field of `enb`.

Examples

Create Empty Resource Array

Create an empty resource array representing the resource elements for 10MHz bandwidth, one subframe, and two antennas.

```
rgrid = lteDLResourceGrid(struct('NDLRB',50,'CellRefP',2));
size(rgrid)
```

```
ans =

   600    14     2
```

Create DL Subframe Resource Array Using Optional Antenna Plane Input

Create an empty resource array that represents the downlink resource elements for 5 MHz bandwidth, one subframe, extended cyclic prefix, and four antenna ports.

```
cfg = struct('NDLRB',25,'CyclicPrefix','Extended');
p = 4;
griddl = lteDLResourceGrid(cfg,p);
size(griddl)
```

```
ans =

   300    12     4
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure having the following fields.

`NDLRB` — Number of downlink resource blocks

scalar integer from 6 to 110

Number of downlink resource blocks, specified as a scalar integer from 6 to 110.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`CellRefP` — Number of cell-specific reference signal antenna ports

1 | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

Data Types: `double`

Data Types: `struct`

p — Number of antenna planes

positive scalar integer

Number of antenna planes, specified as a positive scalar integer.

Data Types: `double`

Output Arguments

grid — Empty downlink resource grid

3-D numeric array

Empty downlink resource grid, returned as a 3-D numeric array. This array is used to represent the resource elements for one subframe across all configured antenna ports. It has dimensions of:

- When the function has a single input argument, `enb`, an *N*-by-*M*-by-`CellRefP` array is returned. *N* is the number of subcarriers (12×`NDLRB`). *M* is the number of OFDM symbols in a subframe (14 for normal cyclic prefix and 12 for extended cyclic prefix). `CellRefP` is the number of transmit antenna ports.
- When the function has two input arguments, `enb` and `p`, an *N*-by-*M*-by-`p` array is returned. `p` is the number of antenna planes.

Data Types: `double`

See Also

See Also

`lteDLResourceGridSize` | `lteOFDMModulate` | `lteResourceGrid` | `lteResourceGridSize` | `lteULResourceGrid` | `lteULResourceGridSize`

Introduced in R2014a

lteDLResourceGridSize

Size of downlink subframe resource array

Syntax

```
d = lteDLResourceGridSize(enb)
d = lteDLResourceGridSize(enb,p)
```

Description

`d = lteDLResourceGridSize(enb)` returns a three-element row vector of dimension lengths for the resource array generated from the cell-wide settings structure `enb`. For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see "Data Structures".

`d = lteDLResourceGridSize(enb,p)` returns a three-element row vector, where `p` directly specifies the number of antenna planes in the array. In this syntax, `CellRefP` is not required as a structure field of `enb`.

Examples

Determine Downlink Subframe Resource Array Size

Determine the size of a downlink subframe resource array.

Determine the dimensions of a downlink subframe resource array, using cell-wide settings, `enb`. Then, use the returned vector directly to create a resource grid as a multidimensional array.

```
enb = struct('NDLRB',50,'CellRefP',2,'CyclicPrefix','Normal');
rgrid = zeros(lteDLResourceGridSize(enb));
size(rgrid)
```

```
ans =
```

```
   600    14     2
```

The same result can be obtained by calling the `lteDLResourceGrid` function.

Get Downlink Subframe Resource Array Size Using Optional Antenna Plane Input

Get the downlink subframe resource array size from an downlink configuration structure using the antenna plane input. Then, use the returned vector to directly create a MATLAB™ array.

```
cfgdl = struct('NDLRB',50,'CyclicPrefix','Normal');
p = 2;
griddl = zeros(lteDLResourceGridSize(cfgdl,p));
size(griddl)
```

```
ans =

   600    14     2
```

The output grid, `griddl`, is a resource array. This resource array size could be obtained in a similar manner using the `lteResourceGridSize` function.

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure having the following fields.

`NDLRB` — Number of downlink resource blocks

scalar integer from 6 to 110

Number of downlink resource blocks, specified as a scalar integer from 6 to 110. Standard bandwidth values are 6, 15, 25, 50, 75, and 100.

Data Types: `double | char`

`CellRefP` — Number of cell-specific reference signal antenna ports

1 | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

`p` — Number of antenna planes

positive scalar integer

Number of antenna planes, specified as a positive scalar integer. This argument directly specifies the number of antenna planes in the array.

Data Types: `double`

Output Arguments

`d` — Downlink resource grid dimensions

numeric 1-by-3 row vector

Downlink resource grid dimensions, returned as a numeric 1-by-3 row vector. When the function has a single argument, `d` is `[N M CellRefP]`. `N` is the number of subcarriers (12×`NDLRB`). `M` is the number of OFDM or SC-FDMA symbols in a subframe, 14 for normal cyclic prefix and 12 for extended cyclic prefix. `CellRefP` is the number of transmit antenna ports. When the number of antenna planes, `p`, is specified as the second input argument, then `d` is `[N M p]` and the input field `CellRefP` of `enb` is not required.

Data Types: `double`

See Also

See Also

`lteDLResourceGrid` | `lteResourceGridSize` | `lteULResourceGridSize`

Introduced in R2014a

lteDLSCH

Downlink shared channel

Syntax

```
[cwout,chinfo] = lteDLSCH(enb,chs,outlen,trblkin)
```

Description

`[cwout,chinfo] = lteDLSCH(enb,chs,outlen,trblkin)` applies the complete DL-SCH transport channel coding chain to the input data, `trblkin`, and returns the codewords in `cwout`. The encoding process includes type-24A CRC calculation, code block segmentation and type-24B CRC attachment, if any, turbo encoding, rate matching with RV, and code block concatenation. Additional information about the encoding process is returned in the fields of structure `chinfo`. For the case of spatial multiplexing schemes transmitting two codewords, `lteDLSCH` processes a single transport block or pairs of blocks, contained in a cell array. The data type for `cwout` matches the input, `trblkin`. Thus, if `trblkin` is a cell array containing one or two transport blocks, `cwout` is a cell array of one or two codewords. If `trblkin` is a vector of information bits, `cwout` is a vector also. Define pairs of modulation schemes and RV indicators in the appropriate parameter fields to encode a pair of transport blocks.

Examples

Generate DL-SCH Codewords

Generate the DL-SCH codeword as defined by TS36.101 RMC R.7 for FDD duplexing mode

Initialize the `rmc` structure and generate transport block data. Generate the DL-SCH codewords and view the first ten.

```
rmc = lteRMCDL('R.7');
data = randi([0,1],rmc.PDSCH.TrBlkSizes(1),1);

codeWord = lteDLSCH(rmc,rmc.PDSCH,rmc.PDSCH.CodedTrBlkSizes(1),data);
codeWord(1:10)
```

```
ans =

  10×1 int8 column vector

   1
   0
   0
   1
   1
   1
   0
   0
   0
   0
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
If `chs.NSoftBits` is defined include:			
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
When `DuplexMode` is set to `'TDD'` include:			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
When `chs.TxScheme` is set to `'TxDiversity'` include:			
`CellRefP`	Optional	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports

chs — Channel configuration

structure

Channel configuration, specified as a structure. It defines aspects of the PDSCH onto which the codewords are mapped. It also defines the DL-SCH soft buffer size and redundancy versions of the generated codewords.

`chs` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
`NLayers`	Required	Integer from 1 to 8	Total number of transmission layers associated with the transport block or blocks.
`TxScheme`	Optional	`'Port0'` (default), `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, `'MultiUser'`, `'Port5'`, `'Port7-8'`, `'Port7-14'`.	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

Parameter Field	Required or Optional	Values	Description
RV	Required	Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).	Specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is Read-Only.
NSoftbits	Optional	Nonnegative scalar integer (default 0)	Total number of soft buffer bits. The default setting of 0 signifies that there is no buffer limit.

`outlen` — Codeword length

numeric vector of one or two elements

Codeword length, specified as a numeric vector of one or two elements. This vector defines the codeword lengths to which the input transport blocks should be rate matched. It represents the PDSCH capacity for the associated codeword. Therefore, it also represents the lengths of the vectors in `cwout`.

`trblkin` — Transport block information bits to be encoded

numeric vector | cell array of one or two numeric vectors

Transport block information bits to be encoded, specified as a numeric vector or a cell array of numeric vectors. `trblkin` is an input parameter containing the transport block information bits to be encoded. If it is a cell array, all rate matching calculations assume that the pair is transmitting on a single PDSCH, distributed across the total number of layers defined in `chs`, as per TS 36.211 [2]. The lowest order information bit of `trblkin` maps to the most significant bit of the transport block, as defined in TS 36.321 [3], Section 6.1.1 .

Output Arguments

`cwout` — DL-SCH encoded codewords

numeric column vector | cell array of one or two numeric column vectors

DL-SCH encoded codewords, returned as a numeric column vector or a cell array of one or two numeric column vectors. It reflects the data type and size of the input data, `trblkin`.

Data Types: `int8` | `cell`

`chinfo` — Additional information about encoding process

structure array | optional

Additional information about encoding process, returned as a structure array. It contains parameter fields related to code block segmentation and rate matching. If two transport blocks are encoded, `chinfo` is a structure array of two elements, with one element for each block. The code block segmentation fields in this structure can also be created independently using the `lteDLSCHInfo` function.

`chinfo` contains the following fields.

Parameter Field	Description	Values
`C`	Total number of code blocks	Nonnegative scalar integer
`Km`	Lower code block size ($K-$)	Nonnegative scalar integer
`Cm`	Number of code blocks of size `Km` ($C-$)	Nonnegative scalar integer
`Kp`	Upper code block size ($K+$)	Nonnegative scalar integer
`Cp`	Number of code blocks of size `Kp` ($C+$)	Nonnegative scalar integer
`F`	Number of filler bits in first block	Nonnegative scalar integer
`L`	Number of segment cyclic redundancy check (CRC) bits	Nonnegative scalar integer
`Bout`	Total number of bits in all segments	Nonnegative scalar integer
`NLayers`	Number of transmission layers.	Nonnegative scalar integer
`NL`	Number of layers used in rate matching calculation	Nonnegative scalar integer
`Qm`	Bits per symbol variable used in rate matching calculation	Nonnegative scalar integer
`NIR`	Number of soft bits associated with transport block. Soft buffer size for entire input transport block	Nonnegative scalar integer
`RV`	RV value associated with one codeword Included if RV is present at the input.	Nonnegative scalar integer

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.321. "Medium Access Control (MAC) Protocol Specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCHDecode` | `lteDLSCHInfo` | `ltePDSCH`

Introduced in R2014a

lteDLSCHDecode

Downlink shared channel decoding

Syntax

```
[trblkout,blkcrc,stateout] = lteDLSCHDecode(enb,chs,trblklen,cwin,
statein)
```

Description

`[trblkout,blkcrc,stateout] = lteDLSCHDecode(enb,chs,trblklen,cwin, statein)` returns the information bits, `trblkout`, decoded from the input soft LLR codeword data, `cwin`. The DL-SCH decoder includes rate recovery, turbo decoding, block concatenation, and CRC calculations. The function also returns the type-24A transport block CRC decoding result in `blkcrc` and the HARQ process decoding state in `stateout`. The initial HARQ process state can be provided as the optional `statein` parameter. The function is capable of processing both a single codeword or pairs of codewords, contained in a cell array, for the case of spatial multiplexing schemes transmitting two codewords. The type of the return variable, `trblkout`, is the same as the input, `cwin`. If `cwin` is a cell array containing one or two codewords, `trblkout` is a cell array of one or two transport blocks. If `cwin` is a vector of soft data, `trblkout` is a vector also. If you are decoding a pair of codewords, you must provide pairs of modulation schemes and RV indicators in the appropriate parameter fields.

`enb` is an input parameter structure that may include optional fields defining the duplex mode. Since the duplex mode defaults to `'FDD'`, if the `'DuplexMode'` field is absent, `enb` can be an empty structure.

`chs` is an input parameter structure defining aspects of the PDSCH onto which the codewords are mapped and the DL-SCH soft buffer size and redundancy versions of the received codewords.

`trblklen` is an input vector, one or two elements in length, defining the transport block lengths to which the input code blocks are rate recovered and decoded.

`cwin` is an input parameter containing the floating point soft LLR data of the codewords to be decoded. It is either a single vector or a cell array containing one or two vectors. If

it is a cell array, all rate matching calculations assume that the pair is transmitting on a single PDSCH, distributed across the total number of layers defined in `chs`, as per TS 36.211 [1].

`statein` is an optional input structure array, empty or one or two elements, which can input the current decoder buffer state for each transport block in an active HARQ process. If `statein` is not an empty array and it contains a non-empty field, `CBSBuffers`, this field should contain a cell array of vectors representing the LLR soft buffer states for the set of code blocks at the input to the turbo decoder, after explicit rate recovery. The updated buffer states after decoding are returned in the `CBSBuffers` field in the output parameter, `stateout`. The `statein` array would normally be generated and recycled from the `stateout` of previous calls to `lteDLSCHDecode` as part of a sequence of HARQ transmissions.

`trblkout` is the output parameter containing the decoded information bits. It is either a single vector or a cell array containing one or two vectors, depending on the class and dimensionality of `cwin`.

`blkcrc` is an output array, one or two elements, containing the result of the type-24A transport block CRC decoding for the transport blocks.

`stateout`, the final output parameter, is a one- or two-element structure array containing the internal state of each transport block decoder. The `stateout` array is normally reapplied via the `statein` variable of subsequent `lteDLSCHDecode` function calls as part of a sequence of HARQ retransmissions.

Examples

Generate and Decode DL-SCH Transmissions

This example generates and decodes 2 transmissions, one with RV set to 0 and one with RV set to 1, as part of a single codeword HARQ process for RMC R.7.

Set subframe number. Get the definition of RMC R.7. Generate transport block data. Apply DL-SCH transport channel coding chain to `trBlkData`. Create a codeword with RV = 0. Turn logical bits into 'LLR' data

```
nsf = 1;

rmc = lteRMCDL('R.7');
```

```
trBlkSize = rmc.PDSCH.TrBlkSizes(nsf);
codedTrBlkSize = rmc.PDSCH.CodedTrBlkSizes(nsf);
trBlkData = randi([0,1],trBlkSize,1);

rmc.PDSCH.RV = 0;
cw = lteDLSCH(rmc,rmc.PDSCH,codedTrBlkSize,trBlkData);

cw(cw == 0) = -1;
```

Initialize the decoder states for the first HARQ transmission. The returned `decState` contains the decoder buffer state for each transport block for an active HARQ process with RV = 1

```
decState = [];
[rxTrBlk,~,decState] = lteDLSCHDecode(rmc,rmc.PDSCH,trBlkSize,cw,decState);
```

Create a second retransmitted codeword. Turn logical bits into 'LLR' data. Use the previous transmission decoder buffer state, `decState`, as part of the sequence of active HARQ transmissions

```
rmc.PDSCH.RV = 1;
cw = lteDLSCH(rmc,rmc.PDSCH,codedTrBlkSize,trBlkData);

cw(cw == 0) = -1;
rxTrBlk = lteDLSCHDecode(rmc,rmc.PDSCH,trBlkSize,cw,decState);

size(rxTrBlk)
rxTrBlk(1:10)
```

```
ans =

       28336           1


ans =

  10×1 int8 column vector

   1
   1
   0
   1
```

```
1
0
0
1
1
1
```

Input Arguments

enb — Cell-wide settings

scalar structure

Cell-wide settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
If `chs.NSoftBits` is defined include:			
`Duple`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex Because the duplex mode defaults to `'FDD'`, if this field is absent, `enb` can be an empty structure.
When `DuplexMode` is set to `'TDD'` include:			
`TDDCo`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration Only required for `'TDD'` duplex mode.

Data Types: `struct`

chs — Channel configuration

structure

Channel configuration, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
`Modulatio`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`	Modulation type associated with each transport block, specified as a character vector or, if there are 2 blocks, as a cell array of character vectors.
`NLayers`	Required	1, 2, 3, 4	Total number of transmission layers associated with the transport block or blocks.
`TxScheme`	Optional	`'Port0'` (default), `'TxDiversity'`, `'CDD'`, `'Spatia` `'MultiU` `'Port5'` `'Port7-` `'Port8'` `'Port7-`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.
`'Port8'`	Single-antenna port, port 8

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table><tr><th>Transmission scheme</th><th>Description</th></tr><tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr></table></td></tr>
<tr><td>RV</td><td>Required</td><td>0, 1, 2, 3

2-element numeric vector</td><td>Redundancy version indicator, specified as a numeric vector of 1 or 2 values. Possible values are 0, 1, 2, or 3.</td></tr>
<tr><td>NSoftbits</td><td>Optional</td><td>Nonnegative scalar integer (default 0)</td><td>Total number of soft buffer bits. The default setting of 0 signifies that there is no buffer limit.

If NSoftbits is absent, no limit is placed on the number of soft bits.</td></tr>
<tr><td>NTurboDec</td><td>Optional</td><td>5 (default)

Integer from 1 to 30</td><td>Number of turbo decoder iteration cycles</td></tr>
</table>

Data Types: `struct`

`trblklen` — Transport block lengths

one- or two-element numeric vector

Transport block lengths, specified as a one- or two-element numeric vector. It defines the transport block lengths to which the input code blocks should be rate-recovered and decoded.

Data Types: `double`

`cwin` — Soft LLR codeword data

numeric vector | cell array of one or two numeric vectors

Soft LLR data of the codewords to be decoded, specified as either a numeric vector or a cell array containing one or two vectors.

Data Types: `double`

`statein` — Initial HARQ process state

optional | structure array

Initial HARQ process state, specified as a structure array. Optional. This structure array, which can be empty or contain one or two elements, can input the current decoder buffer state for each transport block in an active HARQ process.

Data Types: `struct`

Output Arguments

`trblkout` — Decoded information bits

numeric vector | cell array of one or two numeric vectors

Decoded information bits, returned as a numeric vector or a cell array of one or two numeric vectors. `trblkout` reflects the data type and size of `cwin`.

Data Types: `int8` | `cell`

`blkcrc` — Type-24A transport block CRC decoding result

logical vector of one or two elements

Type-24A transport block CRC decoding result, returned as a logical vector of one or two elements.

Data Types: `logical`

`stateout` — HARQ process decoding state

structure array of one or two elements

HARQ process decoding state, returned as a structure array of one or two elements. It contains the internal state of each transport block in the following fields.

Parameter Field	Values	Description
`CBSBuffers`	Cell array of vectors	Cell array of vectors representing the LLR soft buffer states for the set of code blocks associated with a single transport block. The buffers are positioned at the input to the turbo decoder, after explicit rate recovery.

Parameter Field	Values	Description
CBSCRC	Logical vector	Array of type-24B code block set CRC decoding results
BLKCRC	Logical scalar	Type-24A transport block CRC decoding error

Data Types: `struct`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCH` | `lteDLSCHInfo` | `ltePDSCHDecode`

Introduced in R2014a

lteDLSCHInfo

DL-SCH segmentation information

Syntax

```
info = lteDLSCHInfo(blklen)
info = lteDLSCHInfo(enb,chs,blklen)
```

Description

`info = lteDLSCHInfo(blklen)` returns a structure containing the Downlink Shared Channel (DL-SCH) code block segmentation information for the given transport block length.

`info = lteDLSCHInfo(enb,chs,blklen)` returns a structure containing the DL-SCH code block segmentation information for the given eNodeB cell-wide settings structure, channel configuration structure, and transport block length.

Examples

Display DL-SCH Segmentation Information

Show the sizing information before turbo coding for an input transport block of length 132. The info structure fields shows that there are 4 filler bits and the total size of the one segment after CRC addition is 160.

```
lteDLSCHInfo(132)
```

```
ans =

  struct with fields:

       C: 1
      Km: 0
```

```
      Cm: 0
      Kp: 160
      Cp: 1
       F: 4
       L: 0
    Bout: 160
```

Display DL-SCH Transport Channel Information for RMC R.11

Show the DL-SCH transport channel sizing information for an R.11 RMC.

```
rmc = lteRMCDL('R.11');
lteDLSCHInfo(rmc,rmc.PDSCH,rmc.PDSCH.TrBlkSizes(1))
```

```
ans =

  struct with fields:

         C: 3
        Km: 4288
        Cm: 0
        Kp: 4352
        Cp: 3
         F: 0
         L: 24
      Bout: 13056
   NLayers: 2
        NL: 2
        Qm: 4
       NIR: 0
        RV: 0
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
DuplexMode	Optional	'FDD' (default), 'TDD'	Duplexing mode, specified as: • 'FDD' for Frequency Division Duplex or • 'TDD' for Time Division Duplex
When DuplexMode is set to 'TDD' include:			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
When chs.TxScheme is set to 'TxDiversity' include:			
CellRefP	Optional	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports

chs — Channel configuration

structure

Channel configuration, specified as a structure. It defines aspects of the PDSCH onto which the codewords are mapped. It also defines the DL-SCH soft buffer size and redundancy versions of the generated codewords.

chs can contain the following fields.

Parameter Field	Required or Optional	Values	Description
Modulation	Required	'QPSK', '16QAM', '64QAM', or '256QAM'	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
NLayers	Required	Integer from 1 to 8	Total number of transmission layers associated with the transport block or blocks.
TxScheme	Required	'Port0', 'TxDiversity', 'CDD', 'SpatialMux', 'MultiUser', 'Port5', 'Port7-8', 'Port7-14'.	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
'Port0'	Single antenna port, port 0
'TxDiversity'	Transmit diversity

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td>
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table>
</td></tr>
<tr><td>RV</td><td>Required</td><td>Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).</td><td>Specifies the redundancy version for one or two codewords used in the initial subframe number, <code>NSubframe</code>. This parameter field is only for informational purposes and is Read-Only.</td></tr>
<tr><td>NSoftbits</td><td>Optional</td><td>Nonnegative scalar integer (default 0)</td><td>Total number of soft buffer bits. The default setting of 0 signifies that there is no buffer limit.</td></tr>
</table>

`blklen` — Transport block length

positive scalar integer | two-element positive integer vector

Transport block length, specified as a positive integer or a two-element positive integer vector. A two-element vector defines the length of transport blocks for two codewords.

Data Types: `double`

Output Arguments

`info` — DL-SCH code block segmentation information

structure array

DL-SCH code block segmentation information, returned as a structure array including the following fields.

Parameter Field	Description	Values
C	Total number of code blocks	Nonnegative scalar integer
Km	Lower code block size (K–)	Nonnegative scalar integer
Cm	Number of code blocks of size `Km` (C–)	Nonnegative scalar integer
Kp	Upper code block size (K+)	Nonnegative scalar integer
Cp	Number of code blocks of size `Kp` (C+)	Nonnegative scalar integer
F	Number of filler bits in first block	Nonnegative scalar integer
L	Number of segment cyclic redundancy check (CRC) bits	Nonnegative scalar integer
Bout	Total number of bits in all segments	Nonnegative scalar integer
When syntax includes `enb` and `chs` inputs, output `info` also includes these fields:		
NLayers	Number of layers associated with one codeword	Nonnegative scalar integer
NL	Number of layers used in rate matching calculation	Nonnegative scalar integer
Qm	Bits per symbol variable used in rate matching calculation	Nonnegative scalar integer
NIR	Number of soft bits associated with transport block. Soft buffer size for entire input transport block	Nonnegative scalar integer
RV	RV value associated with one codeword Included if RV is present at the input.	Nonnegative scalar integer

See Also

See Also

`lteDLSCH` | `lteDLSCHDecode`

Introduced in R2014a

lteDMRS

UE-specific demodulation reference signals

Syntax

```
sym = lteDMRS(enb,chs)
sym = lteDMRS(enb,chs,opts)
```

Description

`sym = lteDMRS(enb,chs)` returns the downlink UE-specific demodulation reference signal (DM-RS) symbols for transmission in a single subframe, given structures containing the cell-wide settings, and the PDSCH configuration settings. For more information, see "DM-RS Associated with PDSCH" on page 1-274.

`sym = lteDMRS(enb,chs,opts)` allows control of the format of the returned symbols with the options cell array, `opts`.

Examples

Map PDSCH DM-RS Symbols to Grid

Map DM-RS symbols for 4 layers onto an 8 antenna grid.

Initialize cell-wide settings for RMC `'R.1'` (10 MHz bandwidth, 1 RB allocation) and change to Release 10 transmission (`'Port7-14'`). Use `enb.PDSCH` for the channel configuration structure input. Generate and map DM-RS without clearing the REs that should not be mapped because of the DM-RS on other ports.

```
enb = lteRMCDL('R.1');
enb.PDSCH.TxScheme = 'Port7-14';
enb.PDSCH.NLayers = 4;
ntxants = 8;
enb.PDSCH.W = lteCSICodebook(enb.PDSCH.NLayers,ntxants,[0 0]).';

subframe = ones(lteResourceGridSize(enb,ntxants));
enb.PDSCH.NTxAnts = size(enb.PDSCH.W,2);
dmrsInd = lteDMRSIndices(enb,enb.PDSCH);
```

```
dmrs = lteDMRS(enb,enb.PDSCH);
subframe(dmrsInd) = dmrs;
```

View the size of the output symbols, indices, and the Release 10 transmission `subframe`.

```
size(dmrs)
size(dmrsInd)
size(subframe)
```

```
ans =

   192     1


ans =

   192     1


ans =

   600    14     8
```

Map Non-Precoded DM-RS Symbols to Grid

Map non-precoded DM-RS symbols onto an 4 layer grid, and clear the REs which should not be used because of the DM-RS of other ports.

Initialize cellwide settings for RMC `'R.1'` (10 MHz bandwidth, 1 RB allocation) and change to Release 10 transmission (`'Port7-14'`). Generate and map DM-RS clearing the REs that should not be used because of the DM-RS on other ports.

```
enb = lteRMCDL('R.1');
enb.PDSCH.TxScheme = 'Port7-14';
enb.PDSCH.NLayers = 4;

subframe = ones(lteResourceGridSize(enb,enb.PDSCH.NLayers));
dmrsInd = lteDMRSIndices(enb,enb.PDSCH,'rs+unused');
dmrs = lteDMRS(enb,enb.PDSCH,'rs+unused');
subframe(dmrsInd) = dmrs;

size(dmrs)
size(dmrsInd)
```

```
size(subframe)

ans =

    96     1


ans =

    96     1


ans =

   600    14     4
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or

Parameter Field	Required or Optional	Values	Description
			• `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

`chs` — PDSCH-specific channel transmission configuration

structure

PDSCH-specific channel transmission configuration, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD),

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td>'R.26'(TDD), 'R.27'(TDD), 'R.43'(FDD), 'R.44', 'R.45', 'R.48', 'R.50', and 'R.51'.</td></tr>
<tr><td>TxScheme</td><td>Optional</td><td>'Port5' (default), 'Port7-8', 'Port8', 'Port7-14'</td><td>DM-RS-specific transmission scheme, specified as one of the following options.
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port5'</td><td>Rel-8 single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Rel-9 single-antenna port, port 7 if NLayers is 1. Rel-9 dual-layer transmission, ports 7 and 8 if NLayers is 2.</td></tr>
<tr><td>'Port8'</td><td>Rel-9 single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Rel-10 up to 8 layer transmission, ports 7–14 if NLayers a value from 1 to 8.</td></tr>
</table></td></tr>
<tr><td>NLayers</td><td>Optional</td><td>1 (default), 2, 3, 4, 5, 6, 7, 8</td><td>Number of transmission layers.</td></tr>
<tr><td>W</td><td>Optional</td><td>Numeric matrix, [] (default)</td><td>NLayers-by-P precoding matrix for the wideband UE-specific beamforming of the DM-RS. P is the number of transmit antennas. An empty matrix, [], signifies no precoding.</td></tr>
<tr><td colspan="4">The following parameter is applicable when TxScheme is set to 'Port7-8', 'Port8', or 'Port7-14'.</td></tr>
<tr><td>NSCID</td><td>Optional</td><td>0 (default), 1</td><td>Scrambling identity (ID)</td></tr>
<tr><td colspan="4">The following parameter is applicable when TxScheme is set to 'Port5'.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
`RNTI`	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

`opts` — Symbol generation options

`{'ind', 'rsonly'}` (default) | character vector | cell array of character vectors

Symbol generation options, specified as a character vector or a cell array of character vectors containing the following values.

Option	Values	Description

Symbol style	`'ind'` (default), `'mat'`	Style for returning DM-RS symbols, specified as one of the following options.
		• `'ind'` — returns the DM-RS symbols as an N_{RE}-by-1 vector (default)
		• `'mat'` — returns the DM-RS symbols as a matrix. To form a matrix, a column may contain duplicate entries. In this style, each column contains symbols for —
		  • an individual port or layer, if symbols are not precoded,
		  • or the projected layers per transmit antenna if symbols are precoded.
		N_{RE} is the number of resource elements.

Symbol format	`'rsonly'` (default), `'rs+unused'`	Format for returning DM-RS symbols, specified as one of the following options. • `'rsonly'` — returns only active DM-RS symbols (default) • `'rs+unused'` — returns include zeros for the RE locations that should be unused because of DM-RS transmission on another port or layer. This format is equivalent to precoding with `W` set to `eye(NLayers)`.

Example: `{'ind','rs+unused'}`, returns the DM-RS symbols as a column vector that includes zeros for the RE locations that should be unused because of DM-RS transmission on another port or layer.

Data Types: `char` | `cell`

Output Arguments

`sym` — DM-RS symbol sequences

N_{RE}-by-1 numeric column vector (default) | numeric matrix

DM-RS symbol sequences, returned as an N_{RE}-by-1 numeric column vector, or a numeric matrix. N_{RE} is the number of resource elements. The `opts` input offers alternative output styles or formats.

`sym` contains the non-precoded or precoded DM-RS symbol sequences concatenated for all the layers, or the transmit antennas for the transmission scheme. The symbols are always ordered as they should be mapped using `lteDMRSIndices` into an *M*-by-*N*-by-*P* array representing the subframe grid across either the non-precoded PDSCH layers or precoded transmit antennas. *M* is the number of subcarriers, *N* is the number of symbols, and *P* is the number of layers, or antennas.

Since precoding projects the DM-RS in each PDSCH layer onto all `NTxAnts` transmit antennas, the output contains the concatenation of all DM-RS across all layers, which are then duplicated in all `chs.NTxAnts` planes of the 3-D grid.

- The output is returned empty unless `chs.TxScheme` is set to one of the schemes related to DM-RS, specifically `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`.
- If the `chs.TxScheme` is single port, `chs.NLayers` = 1 implicitly.
- The output does not include any elements allocated to PBCH, PSS, and SSS. If the subframe contains no DM-RS, an empty vector is returned.
- If the precoding matrix, field `chs.`*W*, is not present or is empty, the output is returned containing only the concatenated non-precoded DM-RS symbols for the `NLayers` ports.
- Otherwise, the output, `sym`, contains all DM-RS symbol values after they are precoded using the `NLayers`-by-`NTxAnts` beamforming matrix, *W*, onto `NTxAnts` transmit antennas. The symbols are ordered by:
  - The concatenation of DM-RS symbols per layer/port if not precoded
  - The projected layers per transmit antenna if precoded.

For more information, see “DM-RS Associated with PDSCH” on page 1-274.

Data Types: `double`
Complex Number Support: Yes

Definitions

DM-RS Associated with PDSCH

As specified in TS 36.211, Section 6.10.3, UE-specific demodulation reference signal (DM-RS) associated with the physical downlink shared channel (PDSCH):

- are transmitted in a single subframe on antenna ports p=5, p=7, p=8, or p=7, 8,..., (`NLayers`+6).
- are present and are a valid reference for PDSCH demodulation only if the PDSCH transmission is associated with the corresponding antenna port according to TS 36.213, Section 7.1.
- are transmitted only on the physical resource blocks upon which the corresponding PDSCH is mapped.

These DM-RS are for use with Release 8, 9, and 10 non-codebook-based PDSCH transmission schemes.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteEPDCCHDMRS` | `ltePRBS` | `lteCellRS` | `lteCSIRS` | `lteDMRSIndices` | `ltePDSCH` | `ltePRS`

Introduced in R2014a

lteDMRSIndices

UE-specific DM-RS resource element indices

Syntax

```
ind = lteDMRSIndices(enb,chs)
ind = lteDMRSIndices(enb,chs,opts)
```

Description

`ind = lteDMRSIndices(enb,chs)` returns the indices of the downlink UE-specific demodulation reference signal (DM-RS) resource elements (RE) in a subframe, given structures containing the cell-wide settings, and the PDSCH settings. For more information, see "DM-RS Associated with PDSCH" on page 1-282.

`ind = lteDMRSIndices(enb,chs,opts)` formats the returned indices using the options defined in a cell array, `opts`.

Examples

Generate PDSCH DM-RS Indices

Generate DM-RS Resource Element (RE) indices in default format for RMC R.28.

Initialize cell-wide parameters to RMC R.28 using the `lteRMCDL` function. Use `enb.PDSCH` for the channel configuration structure. Generate the RE indices.

```
enb = lteRMCDL('R.28');
ind = lteDMRSIndices(enb,enb.PDSCH);
```

View first four rows of index column vector

```
size(ind)
ind(1:4)
```

```
ans =

    24     1


ans =

  4×1 uint32 column vector

   1801
   1805
   1809
   3603
```

Generate Zero-Based DM-RS Indices

Generate 0-based Resource Element indices in subscript form for RMC R.28. The resultant matrix has three columns, with each row representing [subcarrier, symbol, antenna port].

Initialize cell-wide parameters to RMC R.28 using the `lteRMCDL` function.

```
enb = lteRMCDL('R.28');
```

Generate zero-based RE indices in subscript form.

```
ind = lteDMRSIndices(enb,enb.PDSCH,{'0based','sub'});
```

View first four rows of index matrix.

```
size(ind)
ind(1:4,:)
```

```
ans =

    24     3


ans =

  4×3 uint32 matrix
```

```
0    3    0
4    3    0
8    3    0
2    6    0
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter is only applicable when `TxScheme` is set to `'Port5'`.			

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity

`chs` — PDSCH-specific channel transmission configuration

structure

PDSCH-specific channel transmission configuration, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.
`TxScheme`	Optional	`'Port5'` (default), `'Port7-8'`, `'Port8'`, `'Port7-14'`	DM-RS-specific transmission scheme, specified as one of the following options.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table><tr><th>Transmission scheme</th><th>Description</th></tr><tr><td>'Port5'</td><td>Rel-8 single-antenna port, port 5</td></tr><tr><td>'Port7-8'</td><td>Rel-9 single-antenna port, port 7 if NLayers is 1. Rel-9 dual-layer transmission, ports 7 and 8 if NLayers is 2.</td></tr><tr><td>'Port8'</td><td>Rel-9 single-antenna port, port 8</td></tr><tr><td>'Port7-14'</td><td>Rel-10 up to 8 layer transmission, ports 7–14 if NLayers a value from 1 to 8.</td></tr></table></td></tr>
<tr><td>NLayers</td><td>Optional</td><td>1 (default), 2, 3, 4, 5, 6, 7, 8</td><td>Number of transmission layers.</td></tr>
<tr><td>NTxAnts</td><td>Optional</td><td>0 (default), nonnegative integer</td><td>Number of transmission antenna ports. This argument is only present for UE-specific demodulation reference symbols.</td></tr>
</table>

opts — Index generation options

{'ind', '1based', 'rsonly'} (default) | character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	'ind' (default), 'mat', 'sub'	Style for the returned indices, specified as one of the following options. • 'ind' — returns the indices as an N_{RE}-by-1 vector (default) • 'mat' — returns the indices as a matrix. If not precoded, each column contains indices for an individual layer/port. If precoded,

Option	Values	Description
		each column contains symbols for a transmit antenna. To form a matrix, a column can contain duplicate entries. • `'sub'` — returns the indices as an N_{RE}-by-3 matrix. in `[subcarrier, symbol, antenna]` subscript row style. N_{RE} is the number of resource elements.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing format	`'rsonly'` (default), `'rs+unused'`	Format for the returned indices, specified as one of the following options. • `'rsonly'` — returns only active DM-RS symbols (default) • `'rs+unused'` — also includes zeros for the resource element (RE) locations that should be unused because of DM-RS transmission on another port or layer. This format is equivalent to precoding with `NTxAnts` set to `NLayers`.

Example: `{'ind','1based','rs+unused'}`, returns the DM-RS symbols as a column vector in one-based indexing that includes zeros for the RE locations that should be unused because of DM-RS transmission on another port or layer.

Data Types: `char` | `cell`

Output Arguments

`ind` — DM-RS resource element indices

linear indexing N_{RE}-by-1 column vector (default) | linear indexing matrix | numeric 3-column matrix

DM-RS resource element indices, returned as a linear indexing N_{RE}-by-1 column vector, a linear indexing matrix, or a numeric 3-column matrix. The `opts` input offers alternative output styles or formats.

`ind` can directly index the DM-RS elements in an *M*-by-*N*-by-*P* array representing the subframe grid across either the non-precoded PDSCH layers, or precoded transmit antennas. *M* is the number of subcarriers, *N* is the number of symbols, and *P* is the number of layers, or antennas.

For more information, see “DM-RS Associated with PDSCH” on page 1-282.

Data Types: `uint32`

Definitions

DM-RS Associated with PDSCH

As specified in TS 36.211, Section 6.10.3, UE-specific demodulation reference signal (DM-RS) associated with the physical downlink shared channel (PDSCH):

- are transmitted in a single subframe on antenna ports p=5, p=7, p=8, or p=7, 8,..., (`NLayers`+6).
- are present and are a valid reference for PDSCH demodulation only if the PDSCH transmission is associated with the corresponding antenna port according to TS 36.213, Section 7.1.
- are transmitted only on the physical resource blocks upon which the corresponding PDSCH is mapped.

These DM-RS are for use with Release 8, 9, and 10 non-codebook-based PDSCH transmission schemes.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteCellRSIndices` | `lteCSIRSIndices` | `lteDMRS` | `lteEPDCCHDMRSIndices` | `ltePRSIndices` | `lteSRSIndices`

Introduced in R2014a

lteDuplexingInfo

Duplexing information

Syntax

```
info = lteDuplexingInfo(enb)
```

Description

`info = lteDuplexingInfo(enb)` returns a structure, `info`, providing information on the duplexing arrangement. For more information, see “Duplex Mode Configuration” on page 1-287.

Examples

Get TDD Downlink Frame Duplexing Information

Get the number of downlink OFDM symbols in each subframe for a TDD (configuration 0) frame.

A Configuration 0 TDD frame is organized as follows:

- Only subframes 0, 1, 5, and 6 will contain a non-zero number of DL OFDM symbols.
- Subframe 0 and 5 are designated for DL.
- Subframes 1 and 6 are special subframes.
- Subframes 2, 3, 4, 7, 8, and 9 are designated for UL.

Initialize a cell-wide configuration structure for RMC R.0 and a Configuration 0 TDD frame.

```
enb = lteRMCDL('R.0');
enb.DuplexMode = 'TDD';
enb.SSC = 0;
enb.TDDConfig = 0;
```

Loop through all subframes in a frame.

```
for n = 0:9
    enb.NSubframe = n;
    duplexInfo = lteDuplexingInfo(enb);
    fprintf('DL symbols in subframe %d: %d\n',n,duplexInfo.NSymbolsDL)
end
```

```
DL symbols in subframe 0: 14
DL symbols in subframe 1: 3
DL symbols in subframe 2: 0
DL symbols in subframe 3: 0
DL symbols in subframe 4: 0
DL symbols in subframe 5: 14
DL symbols in subframe 6: 3
DL symbols in subframe 7: 0
DL symbols in subframe 8: 0
DL symbols in subframe 9: 0
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure containing these fields. For more information, see “Duplex Mode Configuration” on page 1-287.

`CyclicPrefix` — Cyclic prefix length in downlink

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length in downlink, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`CyclicPrefixUL` — Cyclic prefix length in uplink

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length in uplink, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`DuplexMode` — Duplexing mode

`'FDD'` (default) | `'TDD'` | optional

Duplexing mode, specified as `'FDD'` or `'TDD'`.

Data Types: `double`

`TDDConfig` — Uplink or downlink configuration
0 (default) | integer from 0 to 6 | optional

Uplink or downlink configuration, specified as an integer from 0 to 6. Required only if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

`SSC` — Special subframe configuration
0 (default) | integer from 0 to 9 | optional

Special subframe configuration, specified as an integer from 0 to 9. Required only if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

`NSubframe` — Subframe number
nonnegative integer

Subframe number, specified as a nonnegative integer. Required only if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

Data Types: `struct`

Output Arguments

`info` — Duplexing information
structure

Duplexing information, returned as a structure containing the following fields.

`NSymbols` — Total number of symbols in subframe
nonnegative integer

Total number of symbols in subframe, returned as a nonnegative integer.

`SubframeType` — Type of subframe
`'Downlink' | 'Uplink' | 'Special'`

Type of subframe, returned as `'Downlink'`, `'Uplink'`, or `'Special'`.

`NSymbolsDL` — Number of symbols used for transmission in downlink
nonnegative integer

Number of symbols used for transmission in downlink, returned as a nonnegative integer.

`NSymbolsGuard` — Number of symbols in the guard period
nonnegative integer

Number of symbols in the guard period, returned as a nonnegative integer.

`NSymbolsUL` — Number of symbols used for transmission in uplink
nonnegative integer

Number of symbols used for transmission in uplink (UL), returned as a nonnegative integer.

Definitions

Duplex Mode Configuration

For FDD duplex mode:

- If `CyclicPrefixUL` is present, the link direction is assumed to be uplink.
- If `CyclicPrefixUL` is not present, the link direction is assumed to be downlink, and cyclic prefix is set according to `CyclicPrefix`.
  - If `CyclicPrefix` is also not present, the default `'Normal'` cyclic prefix is used.

For TDD duplex mode:

- The subframe type can be *uplink*, *downlink*, or *special*. `TDDConfig` and `NSubframe` identify the subframe type as specified in TS 36.211 [1], Table 4.2-2.
  - For uplink or downlink subframes, `CyclicPrefixUL` or `CyclicPrefix`, respectively, indicate the relevant cyclic prefix setting.
  - For special subframes, the `lteDuplexingInfo` function uses `SSC` and `CyclicPrefix` to identify the special subframe configuration, as specified in TS 36.211 [1], Table 4.2-1.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteDLResourceGrid` | `lteResourceGrid` | `lteULResourceGrid`

Introduced in R2014a

lteEPDCCH

Enhanced physical downlink control channel

Syntax

```
sym = lteEPDCCH(enb,chs,cw)
```

Description

`sym = lteEPDCCH(enb,chs,cw)` returns a vector `sym` of complex modulation symbols associated with a single Enhanced Physical Downlink Control Channel (EPDCCH) transmission in a subframe. The channel processing includes the stages of scrambling and QPSK modulation. The function is initialized according to the cell-wide settings, `enb`, and the channel transmission configuration, `chs`. For a given input bit vector, `cw`, the column output, `sym`, contains the QPSK symbols ready to be mapped into the resource elements indicated by `lteEPDCCHIndices`.

This function performs no precoding. If necessary, apply precoding externally.

You can obtain the EPDCCH transmission capacity from the `info` structure produced by `lteEPDCCHIndices`.

Examples

Generate Complex Modulated EPDCCH Symbols

Specify the cell-wide settings and channel transmission configuration in parameter structures `enb` and `chs`.

```
enb.NSubframe = 4;
chs.EPDCCHNID = 7;
```

Generate EPDCCH symbols by encoding the input `cw` into QPSK symbols.

```
cw = randi([0 1],100,1);
sym = lteEPDCCH(enb,chs,cw);
```

Display the size and the first 10 indices of `sym`. Because these are QPSK symbols, `sym` contains half as many symbols as the number of bits that can be transmitted on the EPDCCH.

```
size(sym)
sym(1:10)
```

```
ans =

    50     1


ans =

  -0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 - 0.7071i
  -0.7071 + 0.7071i
   0.7071 - 0.7071i
  -0.7071 - 0.7071i
  -0.7071 - 0.7071i
  -0.7071 - 0.7071i
   0.7071 - 0.7071i
```

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure. This argument must contain the following parameter field.

`NSubframe` — Subframe number

nonnegative scalar integer

Subframe number, specified as a nonnegative scalar integer.

Data Types: `double`

Data Types: `struct`

chs — Channel-specific transmission configuration
structure

Channel-specific transmission configuration, specified as a structure. This argument must contain the following parameter field.

EPDCCHNID — EPDCCH scrambling sequence initialization
nonnegative scalar integer

EPDCCH nID parameter for scrambling sequence initialization, specified as a nonnegative scalar integer.

Data Types: `double`

Data Types: `struct`

cw — Input bit vector
vector

Input bit vector containing the bit values of the EPDCCH codeword for modulation.

Output Arguments

sym — EPDCCH modulation symbols
complex-vector

Given an input bit vector, `cw`, the output, `sym`, is returned as a vector of complex modulation symbols associated with a single EPDCCH transmission in a subframe. `sym` contains the QPSK symbols ready to be mapped into the resource elements indicated by `lteEPDCCHIndices`.

See Also

See Also
`lteDCIEncode` | `lteEPDCCHIndices` | `lteEPDCCHPRBS` | `ltePDCCH`

Introduced in R2014b

lteEPDCCHDMRS

EPDCCH demodulation reference signals

Syntax

```
sym = lteEPDCCHDMRS(enb,chs)
sym = lteEPDCCHDMRS(enb,chs,opts)
```

Description

`sym = lteEPDCCHDMRS(enb,chs)` returns the Enhanced Physical Downlink Control Channel Demodulation Reference Signal (EPDCCH DM-RS) symbols for transmission in a single subframe. By default the symbols are returned as a column vector. The order of the symbols is the same as the order that results when you use `lteEPDCCHDMRSIndices` to map them into an *N*-by-*M*-by-4 array. This array represents the resource element subframe grid across the four possible EPDCCH antenna ports (p = 107...110).

The symbols are parameterized in terms of a configured PRB pair set which defines:

- the overall set of possible EPDCCH candidates and
- the aggregation of one or more consecutive enhanced control channel elements (ECCE). This aggregation identifies the specific EPDCCH instance that the DM-RS is associated with.

The DM-RS symbols are created only for the specific PRB pairs and antenna ports that the corresponding EPDCCH is mapped to.

For a localized EPDCCH transmission, the EPDCCH is associated with a single antenna port from p = 107...110, dependent on the `chs.RNTI` and ECCEs selected. Thus, the DM-RS antenna port symbols are output only for that single port.

For a distributed transmission, the EPDCCH is mapped to two antenna ports in an alternating fashion. Therefore, the DM-RS symbols are generated for the PRBs in both ports: p = 107,109 for normal cyclic prefix and p = 107,108 for extended cyclic prefix. The output is ordered so that the symbols for the lowest antenna ports index come first. This order matches that of the DM-RS RE indices produced by `lteEPDCCHDMRSIndices`.

`sym = lteEPDCCHDMRS(enb,chs,opts)` enables additional control over the contents and format of the symbols with the options cell array, `opts`. You can use this syntax to return the symbols as a numeric matrix, where each column contains symbols for an active antenna port.

This function performs no precoding. If necessary, apply precoding externally.

Examples

Generate EPDCCH DM-RS Symbols

Specify the cell-wide settings and channel transmission configuration in parameter structures `enb` and `chs`.

```
enb.NDLRB = 6;
enb.NSubframe = 0;
chs.EPDCCHECCE = [0 7];
chs.EPDCCHType = 'Localized';
chs.EPDCCHPRBSet = 2:3;
chs.EPDCCHNID = 0;
chs.RNTI = 1;
```

Generate EPDCCH demodulation reference signal symbols.

```
sym = lteEPDCCHDMRS(enb,chs)
```

```
sym =

   0.7071 - 0.7071i
   0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 + 0.7071i
   0.7071 - 0.7071i
   0.7071 - 0.7071i
   0.7071 + 0.7071i
   0.7071 - 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 - 0.7071i
   0.7071 - 0.7071i
```

Note: The warning messages generated simply advise you that default values are available and being used for uninitialized parameters. To suppress warnings for defaulted lte parameter settings, precede code with the following command: `lteWarning('off','DefaultValue')`

Generate DM-RS Symbols for EPDCCH Having a Distributed Transmission

Specify the cell-wide settings and channel transmission configuration in parameter structures `enb` and `chs`.

```
enb.NDLRB = 6;
enb.NSubframe = 0;
chs.EPDCCHECCE = [0,7];
chs.EPDCCHType = 'Distributed';
chs.EPDCCHPRBSet = 2:3;
chs.EPDCCHNID = 0;
chs.RNTI = 1;
```

Generate DM-RS symbols for an EPDCCH having a distributed transmission. Return the symbols as a matrix, where each column contains symbols for an active antenna.

```
sym = lteEPDCCHDMRS(enb,chs,'mat')
```

```
sym =

   0.7071 - 0.7071i   0.7071 - 0.7071i
  -0.7071 - 0.7071i  -0.7071 - 0.7071i
   0.7071 + 0.7071i   0.7071 + 0.7071i
   0.7071 - 0.7071i   0.7071 - 0.7071i
   0.7071 - 0.7071i   0.7071 - 0.7071i
  -0.7071 + 0.7071i  -0.7071 + 0.7071i
  -0.7071 - 0.7071i  -0.7071 - 0.7071i
   0.7071 - 0.7071i   0.7071 - 0.7071i
  -0.7071 - 0.7071i  -0.7071 - 0.7071i
  -0.7071 - 0.7071i  -0.7071 - 0.7071i
  -0.7071 + 0.7071i  -0.7071 + 0.7071i
   0.7071 - 0.7071i   0.7071 - 0.7071i
```

Note: The warning messages generated simply advise you that default values are available and being used for uninitialized parameters. To suppress warnings

for defaulted lte parameter settings, precede code with the following command:
`lteWarning('off','DefaultValue')`

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following: • `'FDD'` — Frequency division duplex (default) • `'TDD'` — Time division duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

`chs` — Channel-specific channel transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
EPDCCHECCE	Required	1-element or 2-element vector specifying the 0-based ECCE index or inclusive [begin, end] ECCE index range according to the aggregation level L (L = end – begin + 1). The number of ECCEs in the candidate must be a power of 2. If no transmission is required, leave this parameter empty.	The set of one or several consecutive ECCEs defining the EPDCCH transmission candidate in the overall EPDCCH set.
EPDCCHType	Required	'Localized', 'Distributed'	EPDCCH transmission type
EPDCCHPRBSet	Required	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2. If no transmission is required, leave this parameter empty.	EPDCCH PRB pair indices
EPDCCHNID	Required	Nonnegative scalar integer	EPDCCH nID parameter for scrambling sequence initialization
The following parameters apply when EPDCCHType is set to 'Localized'.			
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

`opts` — Symbol generation options

`{'ind', 'rsonly'}` (default) | character vector | cell array of character vectors

Symbol generation options, specified as a character vector or a cell array of character vectors containing the following values.

Option	Values	Description
Symbol style	`'ind'` (default), `'mat'`	Style for the returned symbols, specified as one of the following: • `'ind'` — returns the symbols as a column vector (default) • `'mat'` — returns the symbols as a matrix in which each column contains symbols for an active antenna port from the set p = 107...110
Symbol format	`'rsonly'` (default), `'rs+unused'`	Format of the returned symbols. • `'rsonly'` — returns only active DM-RS symbols (default) • `'rs+unused'` — also returns zeros for the RE locations, which should be unused because of EPDCCH DM-RS transmission on other EPDCCH antenna ports p = 107...110 that are not used by this EPDCCH transmission.

Example: `{'ind','rs+unused'}`, returns the DM-RS symbols as a column vector that includes zeros for the RE locations that should be unused because of DM-RS transmission on another port or layer.

Data Types: `char` | `cell`

Output Arguments

`sym` — EPDCCH DM-RS symbols

numeric column vector | numeric matrix

EPDCCH demodulation reference signal symbols, returned as a column vector containing the non-precoded DM-RS symbol sequences concatenated for all active PRB pairs and antenna ports. Optionally, the function returns `sym` as a numeric matrix, where each column contains symbols for an active antenna port.

Data Types: `double`

See Also

See Also

`lteCellRS` | `lteCSIRS` | `lteDMRS` | `lteEPDCCH` | `lteEPDCCHDMRSIndices` | `ltePRBS` | `ltePRS`

Introduced in R2014b

lteEPDCCHDMRSIndices

EPDCCH DM-RS resource element indices

Syntax

```
ind = lteEPDCCHDMRSIndices(enb,chs)
ind = lteEPDCCHDMRSIndices(enb,chs,opts)
```

Description

`ind = lteEPDCCHDMRSIndices(enb,chs)` returns indices of the Enhanced Physical Downlink Control Channel Demodulation Reference Signal (EPDCCH DM-RS) resource elements (RE) associated with an EPDCCH transmission candidate in a subframe. By default, `ind` is a column vector of indices in one-based linear indexing form. Use this form to directly index the EPDCCH DM-RS REs of an *N*-by-*M*-by-4 array that represents the subframe resource grid across the four possible EPDCCH antenna ports (p = 107...110). You can also generate alternative index representations. The order of the indices is the same as required for the complex EPDCCH DM-RS symbols mapping. `lteEPDCCHDMRS` generates these symbols.

The indices are parameterized in terms of a configured PRB pair set which defines:

- the overall set of possible EPDCCH candidates and
- the aggregation of one or more consecutive enhanced control channel elements (ECCE). This aggregation identifies the specific EPDCCH instance that the DM-RS are associated with.

The DM-RS indices are created only for the specific PRB pairs and antenna ports that the corresponding EPDCCH is mapped to. They do not account for any external precoding operations.

For a localized EPDCCH transmission, the EPDCCH is associated with a single antenna port from p = 107...110, dependent on the `RNTI` and ECCEs selected. Thus, the DM-RS antenna port indices (1...4 respectively, if one-based) are output for that single port.

For a distributed transmission, the EPDCCH is mapped to two antenna ports in an alternating fashion. Therefore, the DM-RS indices are generated for the PRBs in both

ports: p = 107,109 for normal cyclic prefix and p = 107,108 for extended cyclic prefix. The output is ordered so that the symbols for the lowest antenna index plane come first. These indices are suitable for indexing an N-by-M-by-4 array representing the subframe resource grid across the four possible EPDCCH antenna ports (p = 107...110).

This syntax returns an NRE length column vector of one-based linear indices for the DM-RS resource elements associated with a particular EPDCCH candidate. The function is initialized according to the cell-wide settings, `enb`, and the EPDCCH transmission configuration, `chs`.

`ind = lteEPDCCHDMRSIndices(enb,chs,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate EPDCCH DM-RS Indices

Specify the cell-wide settings and channel transmission configuration in parameter structures `enb` and `chs`.

```
enb = struct('CyclicPrefix','Normal','DuplexMode','FDD');
enb.NDLRB = 6;
enb.NSubframe = 0;
chs.EPDCCHECCE = [0 7];
chs.EPDCCHType = 'Localized';
chs.EPDCCHPRBSet = 2:3;
chs.RNTI = 1;
```

Create the EPDCCH DM-RS indices for an EPDCCH having eight ECCEs.

```
ind = lteEPDCCHDMRSIndices(enb,chs)
```

```
ind =

  12×1 uint32 column vector

   1898
   1903
   1908
   1910
   1915
```

```
1920
1970
1975
1980
1982
1987
1992
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following: • `'FDD'` — Frequency division duplex (default) • `'TDD'` — Time division duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

chs — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
EPDCCHECCE	Required	1-element or 2-element vector specifying the 0-based ECCE index or inclusive [begin, end] ECCE index range according to the aggregation level L (L = end – begin + 1). The number of ECCEs in the candidate must be a power of 2. If no transmission is required, leave this parameter empty.	The set of one or several consecutive ECCEs defining the EPDCCH transmission candidate in the overall EPDCCH set.
EPDCCHType	Required	'Localized', 'Distributed'	EPDCCH transmission type
EPDCCHPRBSet	Required	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2. If no transmission is required, leave this parameter empty.	EPDCCH PRB pair indices
The following parameters apply when EPDCCHType is set to 'Localized'.			
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

`opts` — Index generation options

character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'mat'`, `'sub'`	Style for the returned indices, specified as one of the following: • `'ind'` — returns the indices in linear index form as a column vector (default) • `'mat'` — returns the indices in linear index form as a matrix, where each column contains indices for an individual port. • `'sub'` — returns the indices in `[subcarrier, symbol, antenna]` subscript row style. The number of rows in the output, `ind`, is the number of resource elements (NRE). Thus, `ind` is an NRE-by-3 matrix.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing format	`'rsonly'` (default), `'rs+unused'`	RE locations mode of the returned indices. • `'rsonly'` — returns only active DM-RS locations (default) • `'rs+unused'` — also includes all RE locations, which should be unused because of DM-RS transmission on other EPDCCH antenna ports p = 107...110 that are not used by this EPDCCH transmission

Data Types: `char` | `cell`

Output Arguments

`ind` — EPDCCH DM-RS RE indices

numeric column vector | numeric matrix

EPDCCH DM-RS resource element indices, returned by default as a numeric vector of length NRE-by-1. Optionally, for subscript-specific indexing style [`subcarrier`,

`symbol`, `antenna`], `ind` is returned as an NRE-by-3 numeric matrix. NRE is the number of subframe resource elements. You can also return the indices in a linear indexing matrix, where each column contains indices for an individual antenna port. By default, the indices are returned in one-based linear indexing form, which you can use to directly index the EPDCCH DM-RS resource elements.

Data Types: `double`

See Also

See Also

`lteDMRSIndices` | `lteEPDCCHDMRS` | `lteEPDCCHIndices`

Introduced in R2014b

lteEPDCCHDecode

Enhanced physical downlink control channel (EPDCCH) decoding

Syntax

```
[bits,symbols] = lteEPDCCHDecode(enb,chs,sym)
[bits,symbols] = lteEPDCCHDecode(enb,chs,rxsym,hest,noiseest)
[bits,symbols] = lteEPDCCHDecode(enb,chs,rxsym,hest,noiseest,alg)

[bits,symbols] = lteEPDCCHDecode(enb,chs,grid)
[bits,symbols] = lteEPDCCHDecode(enb,chs,rxgrid,hestgrid,noiseest,
alg)
```

Description

`[bits,symbols] = lteEPDCCHDecode(enb,chs,sym)` returns softbits and received constellation of complex symbols resulting from performing the inverse of enhanced physical downlink control channel (EPDCCH) processing of a single configured EPDCCH candidate given cell-wide settings structure, EPDCCH transmission configuration structure, and EPDCCH symbols. The input symbols are assumed to contain ideal EPDCCH symbols, so no equalization is performed. The output received EPDCCH symbols are QPSK symbol demodulated and descrambled. For more EPDCCH processing information, see `lteEPDCCH` and TS 36.211[1], Section 6.8A.

When using this syntax, the input structures only require `enb.NSubframe` and `chs.EPDCCHNID`.

For more information, see "Syntax Dependent Processing" on page 1-315.

`[bits,symbols] = lteEPDCCHDecode(enb,chs,rxsym,hest,noiseest)` performs EPDCCH decoding and equalization for a single configured EPDCCH candidate given cell-wide settings structure, EPDCCH transmission configuration structure, received EPDCCH symbols `rxsym`, channel estimate `hest`, and noise estimate `noiseest`. The output received EPDCCH symbols are equalized, and QPSK symbol demodulated and descrambled.

`[bits,symbols] = lteEPDCCHDecode(enb,chs,rxsym,hest,noiseest,alg)` performs EPDCCH decoding and equalization for a single configured EPDCCH candidate

and provides control over weighting the output soft bits with channel state information (CSI) calculated during the equalization stage using algorithmic configuration structure, `alg`.

`[bits,symbols] = lteEPDCCHDecode(enb,chs,grid)` performs EPDCCH decoding for all possible EPDCCH candidate locations given cell-wide settings structure, EPDCCH transmission configuration structure, and the resource element grid across all possible EPDCCH antenna ports. The resource element grid is assumed to contain ideal EPDCCH REs, so no equalization is performed. The decoding consists of extraction of all EPDCCH REs from `grid` followed by QPSK symbol demodulation. Each EPDCCH candidate is descrambled individually during EPDCCH search. For this syntax, `chs.EPDCCHECCE` and `chs.EPDCCHNID` are not required as no candidate-specific resource extraction or descrambling is performed.

`[bits,symbols] = lteEPDCCHDecode(enb,chs,rxgrid,hestgrid,noiseest, alg)` performs EPDCCH decoding and equalization for all possible EPDCCH candidate locations given cell-wide settings structure, EPDCCH transmission configuration structure, received resource element grid, channel estimate grid, noise estimate, and provides control over weighting the output soft bits with channel state information (CSI) calculated during the equalization stage using algorithmic configuration structure, `alg`. EPDCCH RE locations extracted from `rxgrid` and `hestgrid` are equalized, then QPSK symbol demodulated. Each EPDCCH candidate is descrambled individually during EPDCCH search. For this syntax, `chs.EPDCCHECCE` and `chs.EPDCCHNID` are not required as no candidate-specific resource extraction or descrambling is performed.

Examples

Decode EPDCCH codeword

Modulate and then demodulate EPDCCH symbols for a codeword of random bits.

Initialize the cell-wide settings structure and the EPDCCH transmission channel configuration structure.

```
enb.NSubframe = 0;
chs.EPDCCHNID = 1;
```

Create an input codeword for EPDCCH and generate EPDCCH symbols.

```
cw = randi([0 1],108,1);
sym = lteEPDCCH(enb,chs,cw);
```

Decode the symbols and confirm the codeword was successfully recovered.

```
rxcw = lteEPDCCHDecode(enb,chs,sym);
isequal(cw,rxcw>0)
```

```
ans =

  logical

   1
```

Decode EPDCCH DCI Message

Perform DCI coding to the capacity of a particular EPDCCH candidate. EPDCCH modulate the coded message and transmit it. Add EPDCCH demodulation reference signals (DMRS) and perfrom channel estimation. Finally, extract the EPDCCH (and corresponding channel estimate) from the resource grid. Perform EPDCCH demodulation and decode the received DCI message.

Initialize the cell-wide settings structure.

```
enb.NSubframe = 0;
enb.NDLRB = 15;
enb.CyclicPrefix = 'Extended';
enb.CellRefP = 2;
enb.NCellID = 1;
enb.CFI = 1;
```

Initialize the EPDCCH transmission channel configuration structure.

```
chs.EPDCCHNID = 1;
chs.EPDCCHPRBSet = (0:3).';
chs.EPDCCHType = 'Localized';
chs.EPDCCHFormat = 2;
chs.ControlChannelType = 'EPDCCH';
chs.DCIFormat = 'Format2D';
chs.RNTI = 11;
```

Create a set of random bits representing a DCI message and performing DCI coding to the capacity of a particular EPDCCH candidate.

```
dciInfo = lteDCIInfo(enb,chs);
dcibits = randi([0 1],dciInfo.(chs.DCIFormat),1);
```

```
candidates = lteEPDCCHSpace(enb,chs);
chs.EPDCCHECCE = candidates(1,:);
[ind,info] = lteEPDCCHIndices(enb,chs);
cw = lteDCIEncode(chs,dcibits,info.EPDCCHG);
```

Generate EPDCCH symbols and resource element grid. Populate the grid.

```
sym = lteEPDCCH(enb,chs,cw);
grid = lteDLResourceGrid(enb,4);
grid(ind) = sym;
grid(lteEPDCCHDMRSIndices(enb,chs)) = lteEPDCCHDMRS(enb,chs);
```

Generate channel estimate.

```
cec.PilotAverage = 'TestEVM';
cec.Reference = 'EPDCCHDMRS';
[hestgrid,noiseest] = lteDLChannelEstimate(enb,chs,cec,grid);
[rxsym,hest] = lteExtractResources(ind,grid,hestgrid);
```

Decode the symbols and DCI message bits. Confirm the DCI message was successfully recovered.

```
rxcw = lteEPDCCHDecode(enb,chs,rxsym,hest,noiseest);
rxdcibits = lteDCIDecode(dciInfo.(chs.DCIFormat),rxcw);
isequal(dcibits,rxdcibits>0)
```

```
ans =

  logical

   1
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
The following parameter is only read when `chs.EPDCCHStart` is not present.			
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following: • `'FDD'` — Frequency division duplex (default) • `'TDD'` — Time division duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number

Parameter Field	Required or Optional	Values	Description
`CSIRSPeriod`	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following CSI-RS resource parameters apply only when `CSIRSPeriod` sets one or more CSI-RS subframe configurations to any value other than `'Off'`. Each parameter length must be equal to the number of CSI-RS resources required.			
`CSIRSConfig`	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
`CSIRefP`	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
`ZeroPowerCSIRS`	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is only applicable if one or more of the above zero power subframe configurations are set to any value other than `'Off'`.			

Parameter Field	Required or Optional	Values	Description
`ZeroPowerCS`	Required	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

`chs` — EPDCCH-specific channel transmission configuration

structure

EPDCCH-specific channel transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`EPDCCHECCE`	Required	1- or 2- element vector specifying the zero-based ECCE index or inclusive [*begin*, *end*] ECCE index range according to the aggregation level `L`, where $L = end - begin + 1$. The number of ECCEs in the candidate must be a power of 2. If no transmission is required, leave this parameter empty.	The set of one of several consecutive ECCEs defining the EPDCCH transmission candidate in the overall EPDCCH set.

Parameter Field	Required or Optional	Values	Description
EPDCCHType	Required	'Localized', 'Distributed'	EPDCCH transmission type
EPDCCHPRBSet	Required	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2. If no transmission is required, leave this parameter empty.	EPDCCH PRB pair indices
EPDCCHStart	Optional	integer from 0 to 4 If this parameter is not present, then the cell-wide CFI parameter is used for the starting symbol.	EPDCCH starting symbol
EPDCCHNID	Required	nonnegative scalar integer	EPDCCH scrambling sequence initialization
The following parameter applies when EPDCCHType is set to 'Localized'.			
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

sym — EPDCCH modulation symbols

complex-vector

EPDCCH modulation symbols associated with a single EPDCCH transmission in a subframe, specified as a complex vector. This input contains the QPSK symbols.

Data Types: double

rxsym — Received EPDCCH symbols

EPDCCHGd-by-*NRxAnts* matrix

Received EPDCCH symbols, specified as a *EPDCCHGd*-by-*NRxAnts* matrix. *EPDCCHGd* is the EPDCCH symbol capacity, given by the `info.EPDCCHGd` field of `lteEPDCCHIndices`. *NRxAnts* is the number of receive antennas. This matrix contains the elements of the received resource grid in the locations of the EPDCCH REs for the candidate configured via `chs.EPDCCHECCE`.

Data Types: `double`

`hest` — Channel estimate

EPDCCHGd-by-*NRxAnts*-by-4 array

Channel estimate, specified as an *EPDCCHGd*-by-*NRxAnts* array. *EPDCCHGd* is the EPDCCH symbol capacity, given by the `info.EPDCCHGd` field of `lteEPDCCHIndices`. *NRxAnts* is the number of receive antennas. The third dimension represents the 4 possible EPDCCH antenna ports (p=107...110). This array contains the elements of the channel estimate array in the locations of the EPDCCH REs for the candidate configured via `chs.EPDCCHECCE`.

Data Types: `double`

`noiseest` — Noise estimate

numeric scalar

Noise estimate of the noise power spectral density per RE on the received subframe, specified as a numeric scalar. The `lteDLChannelEstimate` function provides this estimate.

Data Types: `double`

`alg` — Algorithmic configuration

structure

Algorithmic configuration, specified as a structure. The structure must have the field:

`CSI`	Optional	`'On'` (default), `'Off'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI)

			calculated during the equalization process

Data Types: `double`

`grid` — Resource grid

K-by-*L*-by-4 array

Resource grid across the four possible EPDCCH ports, specified as a *K*-by-*L*-by-4 array. *K* is the number of subcarriers, *L* is the number of OFDM symbols in one frame, and 4 is all possible EPDCCH antenna ports (p=107...110).

Data Types: `double`

`rxgrid` — Received resource elements grid

K-by-*L*-by-*NRxAnts* array

Received resource elements grid, specified as a *K*-by-*L*-by-*NRxAnts* array. *K* is the number of subcarriers, *L* is the number of OFDM symbols in one frame, and *NRxAnts* is the number of receive antennas.

Data Types: `double`

`hestgrid` — Channel estimate grid

K-by-*L*-by-*NRxAnts*-by-4 array

Channel estimate grid, specified as a *K*-by-*L*-by-*NRxAnts*-by-4 array. *K* is the number of subcarriers, *L* is the number of OFDM symbols in one frame, and *NRxAnts* is the number of receive antennas. The 4th dimension represents the 4 possible `EPDCCH` antenna ports (p=107...110).

Data Types: `double`

Output Arguments

`bits` — Decoded bit estimates

column-vector | M_{Tot}-by-4 matrix

Decoded bit estimates for the candidate configured via `chs.EPDCCHECCE`, returned as one of the following:

- a column-vector of length *EPDCCHG* = *EDPCCHGd* × 2.
- M_{Tot}-by-4 matrix. M_{Tot} is the total number of bits associated with EPDCCHs and 4 is all possible EPDCCH antenna ports (p=107...110). Since the `bits` output is used as input to `lteEPDCCHSearch`, where each ECCE candidate has to be descrambled individually, the `bits` output are not descrambled.

`symbols` — Received QPSK symbols

column-vector | (M_{Tot} / 2)-by-4 matrix

Received QPSK symbols corresponding to bits in `bits`, specified as one of the following:.

- A column-vector of length *EPDCCHGd*, where *EPDCCHGd* is the EPDCCH symbol capacity, given by the `info.EPDCCHGd` field of `lteEPDCCHIndices`.
- (M_{Tot} / 2)-by-4 matrix, for all `EPDCCH ECCEs` and all `4 EPDCCH` reference signal ports (p=107...110).

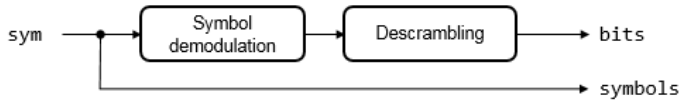
Definitions

Syntax Dependent Processing

The `lteEPDCCHDecode` function works with only one EPDCCH-PRB-Set because `lteDLChannelEstimate` works with only one EPDCCH-PRB-Set. The `lteEPDCCHDecode` function processing performed depends on which input signals are provided to the function. The figures shown here align available syntaxes with processing performed.

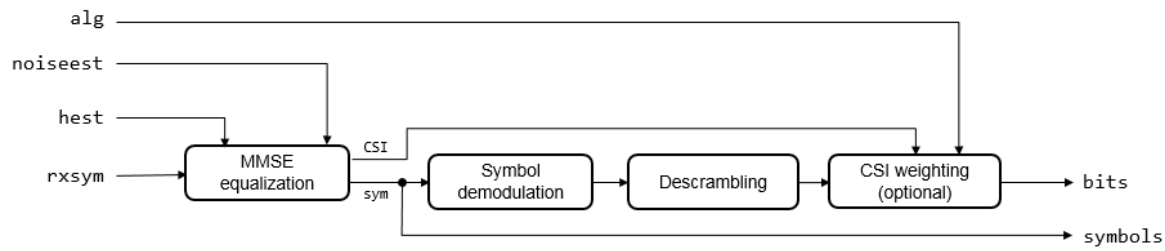
If the symbols for a single configured EPDCCH candidate are input, the function performs symbol demodulation and descrambling. The function assumes the input symbols were already equalized.

```
[bits,symbols] = lteEPDCCHDecode(enb,chs,sym)
```



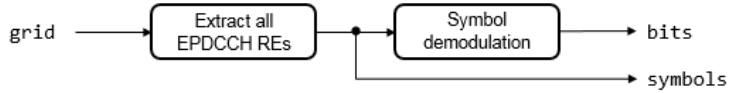
If the symbols for a single configured EPDCCH candidate are input along with channel and noise estimates, the function performs MMSE equalization, then symbol demodulation and descrambling. If the optional `alg` input is provided, CSI weighting is applied to the output bits.

```
[bits,symbols] = lteEPDCCHDecode(enb,chs,rxsym,hest,noiseest,alg)
```

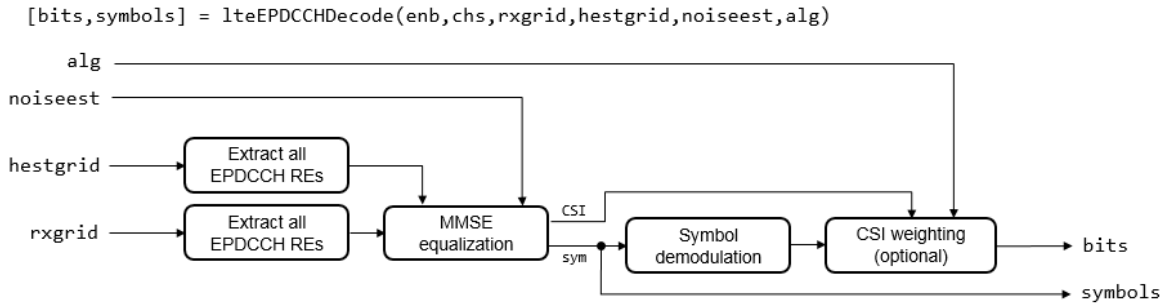


If the resource element grid across all possible EPDCCH antenna ports is input, the function extracts all EPDCCH resource elements and performs EPDCCH decoding for all possible EPDCCH candidate locations. The function assumes the input symbols were already equalized. Each EPDCCH candidate is descrambled individually during EPDCCH search.

```
[bits,symbols] = lteEPDCCHDecode(enb,chs,grid)
```



If the resource element grid is input, along with channel and noise estimates, the function extracts all EPDCCH resource elements and performs MMSE equalization, then symbol demodulation. If the optional `alg` input is provided, CSI weighting is applied to the output bits. Each EPDCCH candidate is descrambled individually during EPDCCH search.



References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteDCIDecode` | `lteEPDCCH` | `lteEPDCCHDMRSIndices` | `lteEPDCCHIndices` | `lteEPDCCHPRBS` | `lteEPDCCHSearch` | `lteEPDCCHSpace`

Introduced in R2016b

lteEPDCCHSearch

Enhanced downlink control information serach

Syntax

```
[dcistr,dcibits] = lteEPDCCHSearch(enb,chs,softbits)
```

Description

`[dcistr,dcibits] = lteEPDCCHSearch(enb,chs,softbits)` recovers DCI message structures, and corresponding vectors of DCI message bits, after blind decoding the multiplexed EPDCCHs. The multiplexed EPDCCHs are within the received EPDCCH payload given by matrix of soft bits. This function carries out search for a single EPDCCH set. For more information, see “EPDCCH Search Processing” on page 1-334.

Examples

Search EPDCCH for DCI Messages

Encode a DCI message and modulate it on the EPDCCH. Perform EPDCCH decoding and then EPDCCH blind-search to recover the DCI message. For `DCI` messages sent on the EPDCCH, set the ControlChannelType to `'EPDCCH'`.

Initialize cell-wide settings structure and EPDCCH transmission channel structure.

```
enb = lteRMCDL('R.43');
chs.RNTI = 42;
chs.ControlChannelType = 'EPDCCH';
chs.EPDCCHType = 'Localized';
chs.EPDCCHPRBSet = [2 3];
chs.EPDCCHNID = 0;
chs.EPDCCHFormat = 1;
chs.DCIFormat = 'Format1A';
```

Create a DCI message. Generate EPDCCH candidates.

```
[dci,dciBits] = lteDCI(enb,chs,struct('DCIFormat',chs.DCIFormat));
```

```
candidates = lteEPDCCHSpace(enb,chs);
chs.EPDCCHECCE = candidates(1,:);
```

Generate RE grid indices and EPDCCH info structure. Encode the DCI message into a codeword for transmission. Generate EPDCCH symbols and populate resource grid.

```
[ind,info] = lteEPDCCHIndices(enb,chs);
cw = lteDCIEncode(chs,dciBits,info.EPDCCHG);

sym = lteEPDCCH(enb,chs,cw);
grid = lteDLResourceGrid(enb,4);
grid(ind) = sym;
```

Decode the EPDCCH trasnmission. Recover and view DCI message.

```
rxsoftbits = lteEPDCCHDecode(enb,chs,grid);

rxdci = lteEPDCCHSearch(enb,chs,rxsoftbits);
rxdci{1}
```

```
ans =

  struct with fields:

          DCIFormat: 'Format1A'
                CIF: 0
     AllocationType: 0
         Allocation: [1×1 struct]
          ModCoding: 0
             HARQNo: 0
            NewData: 0
                 RV: 0
           TPCPUCCH: 0
           TDDIndex: 0
         SRSRequest: 0
   HARQACKResOffset: 0
```

Search for multiple EPDCCH sets. The first EPDCCH set is as configured above and the second is of Distributed type with 8 PRBs.

Transmit the EPDCCH DM-RS for channel estimation.

```
grid(lteEPDCCHDMRSIndices(enb,chs)) = lteEPDCCHDMRS(enb,chs);
```

Configure the channel estimation.

```
cec.PilotAverage = 'TestEVM';
cec.Reference = 'EPDCCHDMRS';
```

Configure two EPDCCH sets.

```
chs.EPDCCHTypeList = {'Localized' 'Distributed'};
chs.EPDCCHPRBSetList = {[2; 3] (8:15).'};
```

Perform the EPDCCH search for each set.

```
for p = 1:numel(chs.EPDCCHTypeList)
    chs.EPDCCHType = chs.EPDCCHTypeList{p};
    chs.EPDCCHPRBSet = chs.EPDCCHPRBSetList{p};
    [hestgrid,noiseest] = lteDLChannelEstimate(enb,chs,cec,grid);
    rxsoftbits = lteEPDCCHDecode(enb,chs,grid,hestgrid,noiseest);
    rxdci = lteEPDCCHSearch(enb,chs,rxsoftbits);
    X = ['EPDCCH set ' num2str(p)];
    disp([X ', DCI messages found: ' num2str(numel(rxdci))])
    if (~isempty(rxdci))
        rxdci{1}
    end
end
```

```
EPDCCH set 1, DCI messages found: 1

ans =

  struct with fields:

           DCIFormat: 'Format1A'
                 CIF: 0
      AllocationType: 0
          Allocation: [1×1 struct]
           ModCoding: 0
              HARQNo: 0
             NewData: 0
                  RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
          SRSRequest: 0
    HARQACKResOffset: 0

EPDCCH set 2, DCI messages found: 0
```

A DCI message is found in EPDCCH set 1 but not in EPDCCH set 2.

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL}) See "Specifying Number of Resource Blocks" on page 1-335.
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
The following parameter is applicable only when `chs.EPDCCHStart` is absent.			
`CFI`	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following:

Parameter Field	Required or Optional	Values	Description
			• 'FDD' — Frequency division duplex (default) • 'TDD' — Time division duplex
The following parameters apply when DuplexMode is set to 'TDD'.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number
CSIRSPeriod	Optional	'Off' (default), 'On', Icsi-rs (0,...,154), [Tcsi-rs Dcsi-rs]. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following CSI-RS resource parameters apply only when CSIRSPeriod sets one or more CSI-RS subframe configurations to any value other than 'Off'. Each parameter length must be equal to the number of CSI-RS resources required.			
CSIRSConfig	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRefP	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports

Parameter Field	Required or Optional	Values	Description
ZeroPowerCSIRS	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is applicable only if one or more of the above zero power subframe configurations are set to any value other than `'Off'`.			
ZeroPowerCS	Required	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

chs — EPDCCH-specific channel transmission configuration

structure

EPDCCH-specific channel transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
EPDCCHType	Required	`'Localized'`, `'Distributed'`	EPDCCH transmission type

Parameter Field	Required or Optional	Values	Description
EPDCCHPRBSet	Required	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2.	EPDCCH PRB pair indices
EPDCCHStart	Optional	integer from 0 to 4 If this parameter is not present, then the cell-wide CFI parameter is used for the starting symbol.	EPDCCH starting symbol
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
EPDCCHNID	Required	nonnegative scalar integer	EPDCCH nID parameter for scrambling sequence initialization.
EPDCCHPRBSetList	Optional	cell array of one or two vectors	PRB pair indices for one or two EPDCCH sets.
EPDCCHPRBTypeList	Optional	cell array of character array	A cell array of character array specifying the EPDCCH transmission types for one or two EPDCCH sets.
EnableCarrierIndica	Optional	`'Off'` (default), `'On'`	UE configured with carrier indication field (affects presence of CIF)

Parameter Field	Required or Optional	Values	Description
`EnableSRSRequest`	Optional	`'Off'` (default), `'On'`	UE configured for SRS request (affects presence of SRS request field in UE-specific formats 0/1A and 2B/2C/2D TDD)
`EnableMultipleCSIRe`	Optional	`'Off'` (default), `'On'`	UE configured for multiple CSI requests (multiple cells/CSI processes) (affects length of CSI request field in UE-specific formats 0/4)
`NTxAnts`	Optional	1 (default), 2, 4	Number of UE transmission antennas (affects length of precoding information field in format 4)

`softbits` — Received `EPDCCH` payload

MTot-by-4 matrix

Received EPDCCH payload containing coded Downlink Control Information (DCI), specified as a *MTot*-by-4 matrix. *MTot* is the total number of bits associated with EPDCCHs, $\frac{nEPDCCH * NECCE}{NECCEPerPRB * 2}$. The matrix contains soft EPDCCH bits estimates for all EPDCCH ECCEs and all EPDCCH reference signal ports.

If `chs.EPDCCHPRBSetList` and `chs.EPDCCHTypeList` are present and each contain two elements, the creation of the EPDCCH candidate locations support two EPDCCH sets. For more information, see TS 36.213 [2], Tables 9.1.4-3a to 9.1.4-5b.

Data Types: `double`

Output Arguments

`dcistr` — DCI message structure
cell array of structures

DCI message structure, returned as a cell array of structures whose fields match of the fields associated DCI format.

The field names associated with `dcistr` depend on the DCI format. The format is expected to be one of the formats generated by `lteDCI`.

The following table details the DCI formats and accompanying `dcistr` parameter fields.

DCI Formats	DCISTRFields	Size	Description
`'Format0'`	`DCIFormat`	—	`'Format0'`
	`FreqHopping`	1-bit	PUSCH frequency hopping flag
	`Allocation`	variable	Resource block assignment/ allocation
	`ModCoding`	5-bits	Modulation, coding scheme, and redundancy version
	`NewData`	1-bit	New data indicator
	`TPC`	2-bits	PUSCH TPC command
	`CShiftDMRS`	3-bits	Cyclic shift for DM RS
	`CQIReq`	1-bit	CQI request
	`TDDIndex`	2-bits	For TDD config 0, this field is the Uplink Index. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format1'`	`DCIFormat`	—	`'Format1'`
	`AllocationType`	1-bit	Resource allocation header: type 0, type 1 (only if downlink bandwidth is >10 PRBs)

DCI Formats	DCISTRFields	Size	Description
	`Allocation`	variable	Resource block assignment/ allocation
	`ModCoding`	5-bits	Modulation and coding scheme
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`NewData`	1-bit	New data indicator
	`RV`	2-bits	Redundancy version
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format1A'`	`DCIFormat`	—	`'Format1A'`
	`AllocationType`	1-bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	variable	Resource block assignment/ allocation
	`ModCoding`	5-bits	Modulation and coding scheme
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`NewData`	1-bit	New data indicator
	`RV`	2-bits	Redundancy version
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format1B'`	`DCIFormat`	—	`'Format1B'`
	`AllocationType`	1-bit	VRB assignment flag: 0 (localized), 1 (distributed)

DCI Formats	DCISTRFields	Size	Description
	`Allocation`	variable	Resource block assignment/ allocation
	`ModCoding`	5-bits	Modulation and coding scheme
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`NewData`	1-bit	New data indicator
	`RV`	2-bits	Redundancy version
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`TPMI`	2-bits (2 antennas), 4-bits (4 antennas)	PMI information
	`PMI`	1-bit	PMI confirmation
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format1C'`	`DCIFormat`	—	`'Format1C'`
	`Allocation`	variable	Resource block assignment/ allocation
	`ModCoding`	5-bits	Modulation and coding scheme
`'Format1D'`	`DCIFormat`	—	`'Format1D'`
	`AllocationType`	1-bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	variable	Resource block assignment/ allocation
	`ModCoding`	5-bits	Modulation and coding scheme
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`NewData`	1-bit	New data indicator
	`RV`	2-bits	Redundancy version

DCI Formats	DCISTRFields	Size	Description
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`TPMI`	2-bits (2 antennas), 4-bits (4 antennas)	Precoding TPMI information
	`DlPowerOffset`	1-bit	Downlink power offset
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format2'`	`DCIFormat`	—	`'Format2'`
	`AllocationType`	1-bit	Resource allocation header: type 0, type 1 (only if downlink bandwidth is >10 PRBs)
	`Allocation`	variable	Resource block assignment/ allocation
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`SwapFlag`	1-bit	Transport block to codeword swap flag
	`ModCoding1`	5-bits	Modulation and coding scheme for transport block 1
	`NewData1`	1-bit	New data indicator for transport block 1
	`RV1`	2-bits	Redundancy version for transport block 1
	`ModCoding2`	5-bits	Modulation and coding scheme for transport block 2
	`NewData2`	1-bit	New data indicator for transport block 2
	`RV2`	2-bits	Redundancy version for transport block 2

DCI Formats	DCISTRFields	Size	Description
	`PrecodingInfo`	3-bits (2-antennas), 6-bits (4-antennas)	Precoding information
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format2A'`	`DCIFormat`	—	`'Format2A'`
	`AllocationType`	1-bit	Resource allocation header: type 0, type 1 (only if downlink bandwidth is >10 PRBs)
	`Allocation`	variable	Resource block assignment/ allocation
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`SwapFlag`	1-bit	Transport block to codeword swap flag
	`ModCoding1`	5-bits	Modulation and coding scheme for transport block 1
	`NewData1`	1-bit	New data indicator for transport block 1
	`RV1`	2-bits	Redundancy version for transport block 1
	`ModCoding2`	5-bits	Modulation and coding scheme for transport block 2
	`NewData2`	1-bit	New data indicator for transport block 2
	`RV2`	2-bits	Redundancy version for transport block 2

DCI Formats	DCISTRFields	Size	Description
	`PrecodingInfo`	0-bits (2 antennas), 2-bits (4 antennas)	Precoding information
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format2B'`	`DCIFormat`	—	`'Format2B'`
	`AllocationType`	1-bit	Resource allocation header: type 0, type 1 (only if downlink bandwidth is >10 PRBs)
	`Allocation`	variable	Resource block assignment/ allocation
	`TPCPUCCH`	2-bits	PUCCH TPC command
	`HARQNo`	3-bits (FDD), 4-bits (TDD)	HARQ process number
	`ScramblingId`	1-bit	Scrambling identity
	`ModCoding1`	5-bits	Modulation and coding scheme for transport block 1
	`NewData1`	1-bit	New data indicator for transport block 1
	`RV1`	2-bits	Redundancy version for transport block 1
	`ModCoding2`	5-bits	Modulation and coding scheme for transport block 2
	`NewData2`	1-bit	New data indicator for transport block 2
	`RV2`	2-bits	Redundancy version for transport block 2

DCI Formats	DCISTRFields	Size	Description
	TDDIndex	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
'Format2C'	DCIFormat	—	'Format2C'
	CIF	variable	Carrier indicator
	AllocationType	1-bit	Resource allocation header: type 0, type 1 (only if downlink bandwidth is >10 PRBs)
	Allocation	variable	Resource block assignment/ allocation
	TPCPUCCH	2-bits	PUCCH TPC command
	HARQNo	3-bits (FDD), 4-bits (TDD)	HARQ process number
	TxIndication	3-bits	Antenna port(s), scrambling identity, and number of layers indicator
	SRSRequest	variable	SRS request. Only present for TDD.
	ModCoding1	5-bits	Modulation and coding scheme for transport block 1
	NewData1	1-bit	New data indicator for transport block 1
	RV1	2-bits	Redundancy version for transport block 1
	ModCoding2	5-bits	Modulation and coding scheme for transport block 2
	NewData2	1-bit	New data indicator for transport block 2
	RV2	2-bits	Redundancy version for transport block 2

DCI Formats	DCISTRFields	Size	Description
	`TDDIndex`	2-bits	For TDD config 0, this field is not used. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
`'Format3'`	`DCIFormat`	—	`'Format3'`
	`TPCCommands`	variable	TPC commands for PUCCH and PUSCH
`'Format3A'`	`DCIFormat`	—	`'Format3A'`
	`TPCCommands`	variable	TPC commands for PUCCH and PUSCH
`'Format4'`	`DCIFormat`	—	`'Format4'`
	`CIF`	variable	Carrier indicator
	`Allocation`	variable	Resource block assignment/ allocation
	`TPC`	2-bits	PUSCH TPC command
	`CShiftDMRS`	3-bits	Cyclic shift for DMRS
	`TDDIndex`	2-bits	For TDD config 0, this field is Uplink Index. For TDD Config 1-6, this field is the Downlink Assignment Index. Not present for FDD.
	`CQIReq`	variable	CQI request
	`SRSRequest`	2-bits	SRS request
	`AllocationType`	1-bit	Resource allocation header: non-hopping PUSCH resource allocation type 0, type 1
	`ModCoding`	5-bits	Modulation, coding scheme and redundancy version
	`NewData`	1-bit	New data indicator

DCI Formats	DCISTRFields	Size	Description
	`ModCoding1`	5-bits	Modulation and coding scheme for transport block 1
	`NewData1`	1-bit	New data indicator for transport block 1
	`ModCoding2`	5-bits	Modulation and coding scheme for transport block 2
	`NewData2`	1-bit	New data indicator for transport block 2
	`PrecodingInfo`	3-bits (2 antennas), 6-bits (4 antennas)	Precoding information

Data Types: `struct`

`dcibits` — Recovered `DCI` message bit vector
cell array of vectors

Recovered DCI message bit vector, returned as a column vector. The length of `dcibits` is defined though structure `enb` in terms of the DCI message format and the bandwidth.

Data Types: `int8`

Definitions

EPDCCH Search Processing

EPDCCH search processing blindly decodes DCI messages based on their lengths. The lengths and order in which the DCI messages are searched for is provided by `lteDCIInfo`. For DCI messages conveyed on the EPDCCH, set `ControlChannelType` to `'EPDCCH'` when calling `lteDCIInfo`.

If one or more messages have the same length, the first message format in the list is used to decode the message. The other potential message formats are ignored. The `lteEPDCCHSearch` function does not consider transmission mode during blind search, and no DCI message format is filtered based on transmission mode. It does not search for format 3 and 3A (power adjustment commands for PUSCH and PUCCH). It also does

not search for format 1C as this format is never used in the UE-specific search space. EPDCCH is never used for common search space messages. For more information on the association between transmission mode, transmission scheme, DCI format, and search space, see TS 36.213 [2], Section 7.1 and Table 7.1-5A.

Specifying Number of Resource Blocks

The number of resource blocks specifies the uplink and downlink bandwidth. The LTE System Toolbox implementation assumes symmetric link bandwidth unless you specifically assign different values to `NULRB` and `NDLRB`. If the number of resource blocks is initialized in only one link direction, then the initialized number of resource blocks (`NULRB` or `NDLRB`) is used for both uplink and downlink. When this mapping is used, no warning is displayed. An error occurs if `NULRB` and `NDLRB` are both undefined.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteEPDCCH` | `lteEPDCCHDecode` | `lteEPDCCHIndices` | `lteEPDCCHPRBS` | `lteEPDCCHSpace`

Introduced in R2016b

lteEPDCCHSpace

EPDCCH search space candidates

Syntax

```
[ind,info] = lteEPDCCHSpace(enb,chs)
```

Description

`[ind,info] = lteEPDCCHSpace(enb,chs)` returns a matrix or cell array of EPDCCH ECCE candidate indices, and related dimensional information for the given cell-wide settings structure and EPDCCH transmission configuration structure. Depending on the configuration, the function returns a matrix of candidates for a single EPDCCH set, or a cell array containing one or two matrices of candidates for one or two EPDCCH sets.

Examples

EPDCCH Search Space

EPDCCH Search Space for DCI Format 2A and 1.

For a particular configuration, establish the sizes of DCI messages for format 2A and format 1. Note that for DCI messages conveyed on the EPDCCH, ControlChannelType should be set to `'EPDCCH'`.

```
enb.NDLRB = 50;
enb.CellRefP = 1;
enb.NCellID = 0;
enb.NSubframe = 0;
enb.CFI = 1;
chs.EPDCCHType = 'Localized';
chs.EPDCCHPRBSet = (0:3).';
chs.EPDCCHFormat = 1;
chs.RNTI = 7;
chs.ControlChannelType = 'EPDCCH';
```

```
dcisizes = lteDCIInfo(enb,chs);
format2Asize = dcisizes.Format2A
format1size = dcisizes.Format1


format2Asize =

  uint64

   42


format1size =

  uint64

   33
```

Create the EPDCCH search space candidates for a localized EPDCCH transmission of a DCI format 2A message.

```
chs.DCIFormat = 'Format2A';
[candidates,info] = lteEPDCCHSpace(enb,chs)


candidates =

     4     7
     8    11
    12    15
     0     3


info =

  struct with fields:

          nEPDCCH: 126
       NECCEPerPRB: 4
      NEREGPerECCE: 4
    NECCEPerEPDCCH: 4
        EPDCCHCase: 1
             NECCE: 16
```

Create the candidates for a DCI format 1 message for the same configuration. The DCI format 1 message is smaller than the format 2A message, resulting in a change of case number (`info.EPDCCHCase`) from 1 to 3. The aggregation level (`info.NECCEPerEPDCCH`) changes from 4 to 2, resulting in a greater number of candidates.

```
chs.DCIFormat = 'Format1';
[candidates,info] = lteEPDCCHSpace(enb,chs)
```

```
candidates =

     2     3
     4     5
     6     7
    10    11
    12    13
    14    15


info =

  struct with fields:

           nEPDCCH: 126
       NECCEPerPRB: 4
      NEREGPerECCE: 4
    NECCEPerEPDCCH: 2
        EPDCCHCase: 3
             NECCE: 16
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
The following parameter applies only when `chs.EPDCCHStart` is absent.			
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number

Parameter Field	Required or Optional	Values	Description
CSIRSPeriod	Optional	'Off' (default), 'On', Icsi-rs (0,...,154), [Tcsi-rs Dcsi-rs]. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following CSI-RS resource parameters apply only when CSIRSPeriod sets one or more CSI-RS subframe configurations to any value other than 'Off'. Each parameter length must be equal to the number of CSI-RS resources required.			
CSIRSConfig	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRefP	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
ZeroPowerCSIRS	Optional	'Off' (default), 'On', Icsi-rs (0,...,154), [Tcsi-rs Dcsi-rs]. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is only applicable if one or more of the above zero power subframe configurations are set to any value other than 'Off'.			

Parameter Field	Required or Optional	Values	Description
ZeroPowerCS	Required	16-bit bitmap character vector (truncated if not 16 bits or '0' MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then '0' MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the '4' CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

chs — EPDCCH-specific channel transmission configuration

structure

EPDCCH-specific channel transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
EPDCCHType	Required if the EPDCCH type list parameter filed is absent	'Localized', 'Distributed'	EPDCCH transmission type
EPDCCHPRBSet	Required if the EPDCCH Type list parameter field is absent	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2.	EPDCCH PRB pair indices
EPDCCHFormat	Required	1, 2, 3, or 4	Number of ECCEs per EPDCCH transmission (equivalently the aggregation level L) as

Parameter Field	Required or Optional	Values	Description
			required by TS 36.211 Table 6.8A 1–2.
`EPDCCHStart`	Optional	0, 1, 2, 3, or 4 If this parameter is not present, then the cell-wide CFI parameter is used for the starting symbol.	EPDCCH starting symbol
`RNTI`	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
`DCIFormat`	Optional	`'Format0'`, `'Format1'`, `'Format1A'`, `'Format1B'`, `'Format1C'`, `'Format1D'`, `'Format2'`, `'Format2A'`, `'Format2B'`, `'Format2C'`, `'Format2D'`, `'Format3'`, `'Format3A'`, `'Format4'`, `'Format5'`	Downlink control information (DCI) format
`EPDCCHPRBSetList`	Optional	cell array of one or two vectors	PRB pair indices for one or two EPDCCH sets
`EPDCCHTypeList`	Optional	cell array of one or two arrays	EPDCCH transmission types for one or two EPDCCH sets

Output Arguments

`ind` — EPDCCH ECCE candidate indices

M-by-2 matrix | cell array

EPDCCH ECCE candidate indices, returned as an *M*-by-2 matrix or a cell array containing 2 *M*-by-2 matrices. *M* is the number of EPDCCH candidates monitored for the configuration provided. This variable is defined in TS 36.213 Tables 9.1.4-1a to 9.1.4-5b. Each two-element row of the matrix `ind` (or the rows of each matrix in cell array `ind`) contains the inclusive indices of a single EPDCCH candidate location.

- If `chs.EPDCCHPRBSetList` and `chs.EPDCCHTypeList` are present and either `chs.EPDCCHPRBSet` or `chs.EPDCCHType` are absent, one or two EPDCCH sets are returned in a cell array containing one or two matrices, one for each set.
- If both `chs.EPDCCHPRBSet` and `chs.EPDCCHType` are present, only the single candidate matrix which matches the `PRB` set size and EPDCCH type given by `chs.EPDCCHPRBSet` and `chs.EPDCCHType` wil be returned. This allows the number of candidates *M* to be correctly calculated for TS 36.213 Tables 9.1.4-3a to 9.1.4-5b (corresponding to two `EPDCCH` sets) while returning a single set of candidates in matrix form. This format is consistent with the parameterization other EPDCCH-related functions that take `CHS.EPDCCHPRBSet` and `CHS.EPDCCHType` as parameters and operate on a single EPDCCH set.
- If `chs.EPDCCHPRBSetList` is absent, then `chs.EPDCCHPRBSet` is required, and if `chs.EPDCCHTypeList` is absent then `chs.EPDCCHType` is required.

`info` — Dimensional information about the `EPDCCH` search space candidates

scalar structure

Dimensional information about the `EPDCCH` search space candidates, returned as a scalar structure containing:

Parameter Field	Description	Values
`nEPDCCH`	Number of REs in a PRB pair configured for possible EPDCCH transmission. See TS 36.211. [1], Section 6.8A.1.	Integer
`NECCEPerPRB`	Number of ECCE per PRB pair	Integer

Parameter Field	Description	Values
NEREGPerECCE	Number of EREG per ECCE	Integer
NECCEPerEPDCCH	Number of ECCES per EPDCCH transmission (equivalently the EPDCCH aggregation level L) as given by TS 36.211 [1] ,Table 6.8A.1-2	Integer
EPDCCHCase	Case number (1,2,3). See TS 36.213 [2], Section 9.1.4	Integer
NECCE	One or two element vector contianing the number of ECCE available for transmission of EPDCCHs in the PRB pair set	Integer

Data Types: `struct`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteEPDCCH` | `lteEPDCCHDecode` | `lteEPDCCHIndices` | `lteEPDCCHPRBS` | `lteEPDCCHSearch`

Introduced in R2016b

lteEPDCCHIndices

Enhanced physical downlink control channel (EPDCCH) resource element indices

Syntax

```
[ind,info] = lteEPDCCHIndices(enb,chs)
[ind,info] = lteEPDCCHIndices(enb,chs,opts)
```

Description

`[ind,info] = lteEPDCCHIndices(enb,chs)` returns the subframe resource element (RE) indices for the Enhanced Physical Downlink Control Channel (EPDCCH) and information related to EPDCCH indices, given the cell-wide settings structure, `enb`, and the EPDCCH transmission configuration, `chs`.

`[ind,info] = lteEPDCCHIndices(enb,chs,opts)` allows control of the format of the returned indices with a cell array of options, `opts`.

Examples

Generate RE Indices of Localized Transmission

This example generates RE Indices of localized transmission in default and subscripted formats.

Specify the cell-wide settings in parameter structure, `enb`.

```
enb.NDLRB = 6;
enb.NSubframe = 0;
enb.NCellID = 0;
enb.CellRefP = 1;
enb.CyclicPrefix = 'Normal';
enb.DuplexMode = 'FDD';
enb.NFrame = 0;
enb.CSIRSPeriod = 'Off';
enb.ZeroPowerCSIRSPeriod = 'Off';
```

Specify the channel transmission configuration in parameter structure, `chs`.

```
chs.EPDCCHECCE = [0 7];
chs.EPDCCHType = 'Localized';
chs.EPDCCHPRBSet = 2:3;
chs.EPDCCHStart = 2;
chs.RNTI = 1;
```

Generate 1-based linear resource element indices of a localized transmission.

```
[ind,info] = lteEPDCCHIndices(enb,chs);
size(ind)
```

```
ans =

   228     1
```

Display the size and the first 10 indices of `ind`.

```
ind(1:10)
```

```
ans =

  10×1 uint32 column vector

   1177
   1178
   1179
   1180
   1181
   1182
   1183
   1184
   1185
   1186
```

Generate 1-based resource element indices in the subscript format [`subcarrier`, `symbol`, `antenna`].

```
[ind,info] = lteEPDCCHIndices(enb,chs,'sub');
size(ind)
```

```
ans =
```

```
   228     3
```

Display the size and the first 10 indices of `ind`.

```
ind(1:10,:)
```

```
ans =

  10×3 uint32 matrix

   25    3    2
   26    3    2
   27    3    2
   28    3    2
   29    3    2
   30    3    2
   31    3    2
   32    3    2
   33    3    2
   34    3    2
```

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Parameter Field	Required or Optional	Values	Description
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
The following parameter is only read when `chs.EPDCCHStart` is absent.			
`CFI`	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following: • `'FDD'` — Frequency division duplex (default) • `'TDD'` — Time division duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
`NFrame`	Optional	0 (default), nonnegative scalar integer	Frame number
`CSIRSPeriod`	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.

Parameter Field	Required or Optional	Values	Description
The following CSI-RS resource parameters apply only when `CSIRSPeriod` sets one or more CSI-RS subframe configurations to any value other than `'Off'`. Each parameter length must be equal to the number of CSI-RS resources required.			
`CSIRSConfig`	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
`CSIRefP`	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
`ZeroPowerCSIRS`	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is only applicable if one or more of the above zero power subframe configurations are set to any value other than `'Off'`.			
`ZeroPowerCS`	Required	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

chs — EPDCCH-specific channel transmission configuration

structure

EPDCCH-specific channel transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
EPDCCHECCE	Required	1- or 2- element vector specifying the zero-based ECCE index or inclusive [`begin`, `end`] ECCE index range according to the aggregation level `L` (`L = end – begin + 1`). The number of ECCEs in the candidate must be a power of 2. If no transmission is required, leave this parameter empty.	The set of one of several consecutive ECCEs defining the EPDCCH transmission candidate in the overall EPDCCH set.
EPDCCHType	Required	`'Localized'`, `'Distributed'`	EPDCCH transmission type
EPDCCHPRBSet	Required	Vector of zero-based indices for the PRB pairs corresponding to the EPDCCH PRB set. The number of PRB pair indices must be a power of 2. If no transmission is required, leave this parameter empty.	EPDCCH PRB pair indices
EPDCCHStart	Optional	integer from 0 to 4 If this parameter is not present, then the cell-	EPDCCH starting symbol

Parameter Field	Required or Optional	Values	Description
		wide CFI parameter is used for the starting symbol.	
The following parameters apply when `EPDCCHType` is set to `'Localized'`.			
`RNTI`	Required only for the `'Localized'` transmission type	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

`opts` — Index generation options

character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'sub'`	Style for the returned indices, specified as one of the following options. • `'ind'` — returns the indices in linear index form as a column vector (default) • `'sub'` — returns the indices in `[subcarrier, symbol, antenna]` subscript row style. The number of rows in the output, `ind`, is the number of resource elements (N_{RE}). Thus, `ind` is an N_{RE}-by-3 matrix.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.

Whether in linear or subscript format style, the indices are always formed out of `[subcarrier, symbol, antenna]` subscripts. These subscripts identify the used resource elements in each subframe resource grid per antenna port.

For the EPDCCH, the antenna subscripts have the possible range 1...4 (if index is one-based), which represents antenna ports p = 107...110. For a localized EPDCCH transmission, the antenna subscripts are a single value out of 1...4, dependent on the RNTI and ECCEs selected. For a distributed EPDCCH transmission, the antenna subscripts alternate between one of two values: {1,3} (p = 107,109) for normal cyclic

prefix, and {1,2} (p = 107,108) for extended cyclic prefix. See TS 36.211 [1], Section 6.8A.5. Use these indices to index the subframe grid directly. The grid comprises the four possible EPDCCH antenna ports (p = 107...110) and is represented as an.N_{SC}-by-N_{SYM}-by-4 array.

Data Types: `char` | `cell`

Output Arguments

`ind` — Subframe EPDCCH RE indices

integer column vector | 3-column integer matrix

EPDCCH subframe resource element indices, returned by default in one-based linear indexing form as a numeric column vector of length N_{RE}-by-1. N_{RE} is the number of subframe resource elements. Optionally, for subscript-specific indexing style [`subcarrier`, `symbol`, `antenna`], `ind` is returned as a numeric matrix of size N_{RE}-by-3. The grid comprises the four possible EPDCCH antenna ports (p = 107,...,110) and is represented as an N_{SC}-by-N_{SYM}-by-4 array. N_{SC} is the number of subcarriers, N_{SYM} is the number of symbols, and `4` is the number of antenna ports.

The indices are for a single transmission instance of the EPDCCH. The order of the indices is the same as required for the complex EPDCCH symbols mapping. Generate these symbols using `lteEPDCCH`. The indices are parameterized in terms of a configured PRB pair set that defines:

- the overall set of possible EPDCCH candidates and
- the aggregation of one or more consecutive enhanced control channel elements (ECCE). This aggregation identifies the specific EPDCCH instance within the set of EPDCCH candidates.

The EPDCCH can use either localized or distributed transmission, differing in the mapping of ECCEs to REs, active PRB pairs, and antenna ports.

Data Types: `double`

`info` — Information related to EPDCCH indices

scalar structure

Dimensional information related to EPDCCH indices, returned as a scalar structure. The structure `info` contains the following fields.

Parameter Field	Description	Values	Data Type
`EPDCCHG`	EPDCCH data bit capacity	Integer	int32
`EPDCCHGd`	EPDCCH QPSK symbol capacity	Integer	int32
`nEPDCCH`	Number of REs in a PRB pair configured for possible EPDCCH transmission. See TS 36.211. [1], Section 6.8A.1.	Integer	int32
`NECCE`	Number of ECCE available for transmission of EPDCCHs in the PRB pair set	Integer	int32
`NECCEPerPRB`	Number of ECCE per PRB pair	Integer	int32
`NEREGPerECCE`	Number of EREG per ECCE	Integer	int32
`EPDCCHPorts`	A vector indicating the set of antenna subscripts used by REs for this transmission instance of the EPDCCH. The subscripts are one-based (default) or zero-based according to the option charcater vectors, `opts`.	Vector of integers	int32

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteEPDCCH` | `lteEPDCCHDMRSIndices` | `lteEPDCCHIndices`

Introduced in R2014b

lteEPDCCHPRBS

EPDCCH pseudorandom scrambling sequence

Syntax

```
seq = lteEPDCCHPRBS(enb,chs,n)
seq = lteEPDCCHPRBS(enb,chs,n,mapping)
```

Description

`seq = lteEPDCCHPRBS(enb,chs,n)` returns the first `n` outputs of the Enhanced Physical Downlink Control Channel (EPDCCH) scrambling sequence. The function is initialized according to the cell-wide settings structure, `enb`, and the channel transmission configuration structure, `chs`.

`seq = lteEPDCCHPRBS(enb,chs,n,mapping)` allows additional control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Generate the EPDCCH Scrambling Sequence

Specify the cell-wide settings and channel transmission configuration in parameter structures `enb` and `chs`.

```
enb.NSubframe = 0;
chs.EPDCCHNID = 0;
```

Create the codeword and generate the EPDCCH scrambling sequence.

```
cw = randi([0 1],100,1);
prbs = lteEPDCCHPRBS(enb,chs,length(cw));
```

Scramble the DCI coded bits.

```
scrambled = xor(prbs,cw);
```

```
prbs(1:20)
```

```
ans =

  20×1 logical array

   0
   0
   0
   0
   0
   0
   1
   0
   0
   0
   0
   1
   1
   0
   1
   0
   0
   0
   0
   1
```

Generate the EPDCCH scrambling sequence using the `'signed'` sequence format.

```
prbs = lteEPDCCHPRBS(enb,chs,length(cw),'signed');
prbs(1:20)
```

```
ans =

     1
     1
     1
     1
     1
     1
    -1
     1
```

```
     1
     1
     1
    -1
    -1
     1
    -1
     1
     1
     1
     1
    -1
```

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure. This argument contains the following parameter field.

`NSubframe` — Subframe number

nonnegative scalar integer

Subframe number, specified as a nonnegative scalar integer.

Data Types: `double`

Data Types: `struct`

`chs` — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure. This argument contains the following parameter field.

`EPDCCHNID` — EPDCCH scrambling sequence initialization

nonnegative scalar integer

EPDCCH nID parameter for scrambling sequence initialization, specified as a nonnegative scalar integer.

Data Types: `double`

Data Types: `struct`

`n` — Number of elements in returned sequence

numeric scalar

Number of elements in returned sequence `seq`, specified as a numeric scalar.

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — EPDCCH pseudorandom scrambling sequence

logical column vector | numeric column vector

EPDCCH pseudorandom scrambling sequence, returned as a logical column vector or a numeric column vector. This argument contains the first `n` outputs of the EPDCCH scrambling sequence, when initialized according to the cell-wide settings structure `enb` and the channel transmission configuration `chs`. If you set `mapping` to `'signed'`, the output data type is `double`. Otherwise, the output data type is `logical`.

Data Types: `logical` | `double`

See Also

See Also

`lteEPDCCH` | `lteEPDCCHIndices`

Introduced in R2014b

lteEVM

Error vector magnitude calculation

Syntax

```
evm = lteEVM(x,r)
evm = lteEVM(ev)
```

Description

`evm = lteEVM(x,r)` returns a structure, `evm`, containing error vector magnitude (EVM) information for the input vector, `x`, given the reference signal vector, `r`. The EVM is defined using the error, or difference, between the input values, `x`, and the reference signal, `r`.

The EVM values in the `RMS` and `Peak` structure fields are linear EVM, not EVM as a percentage. To obtain EVM as a percentage, multiply the value of the `RMS` and `Peak` structure fields by 100.

`evm = lteEVM(ev)` returns a structure, `evm`, for the input vector, `ev`, which is taken to be the normalized error vector given by the expression `ev=(x-r)/sqrt(mean(abs(r.^2)))`. This syntax allows for peak and RMS EVM calculation for preexisting normalized error vectors. For example, it can be used to calculate the EVM across an array of previous EVM results, by extracting and concatenating the EV fields from the array to form the `ev` input vector.

Examples

Measure LTE Symbol EVM

Generate a random QPSK constellation at a defined EVM level. Measure and confirm the added EVM.

Generate a stream of QPSK symbols.

```
txSym = lteSymbolModulate(randi([0,1],10000,1),'QPSK');
```

Add noise at a defined EVM level, `evmPercent`.

```
evmPercent = 14.0;
N0 = complex(randn(size(txSym)),randn(size(txSym)));
noise = N0 * (evmPercent/100)/sqrt(2);
rxSym = txSym + noise;
```

Measure and display the root mean square EVM level in percent.

```
evm = lteEVM(rxSym,txSym)
evm.RMS*100
```

```
evm =

  struct with fields:

    Peak: 0.4260
     RMS: 0.1382
      EV: [5000×1 double]


ans =

   13.8234
```

Input Arguments

x — Input vector

numeric column vector

Input vector, specified as a numeric column vector.

Data Types: `double` | `single`
Complex Number Support: Yes

r — Reference signal vector

numeric column vector

Reference signal vector, specified as a numeric column vector.

Data Types: `double` | `single`

Complex Number Support: Yes

ev — Normalized error vector

numeric column vector

Normalized error vector, specified as a numeric column vector.

Data Types: `double | single`
Complex Number Support: Yes

Output Arguments

evm — EVM information

structure

EVM information, returned as structure. `evm` contains the following fields.

RMS — Root mean square (RMS) EVM

positive numeric scalar

Root mean square (RMS) EVM, specified as a positive numeric scalar. It is the square root of the mean of the squares of all the values of the EVM.

Data Types: `double | single`

Peak — Peak EVM

positive numeric scalar

Peak EVM, returned as a positive numeric scalar. It is the largest single EVM value calculated across all input values.

Data Types: `double | single`

EV — Normalized error vector

numeric column vector

Normalized error vector, returned as a numeric column vector.

Data Types: `double | single`
Complex Number Support: Yes

Data Types: `struct`

See Also

See Also

`lteSymbolDemodulate`

Introduced in R2014a

lteEqualizeMIMO

MMSE-based joint downlink equalization and combining

Syntax

```
[out,csi] = lteEqualizeMIMO(enb,chs,in,hest,noiseest)
```

Description

`[out,csi] = lteEqualizeMIMO(enb,chs,in,hest,noiseest)` performs joint equalization and combining of the received PDSCH symbols in `in`, given cell-wide settings structure, `enb`, PDSCH configuration structure, `chs`, channel estimate, `hest`, and noise power estimate, `noiseest`. MMSE equalization is performed on the product of the channel matrix and precoding matrices. Thus, it performs MMSE equalization between transmit and receive layers and returns the result, `out`.

Examples

Equalize and Deprecode PDSCH Symbols

Equalize and deprecode the PDSCH symbols for RMC R.11 in a MIMO configuration. The PDSCH symbols are extracted from a transmit resource grid. An ideal (identity) channel estimate and ideal (zero) noise estimate are created. The channel and noise estimates are used to equalize and deprecode the PDSCH symbols.

Initialize cell-wide configuration structure, `enb`. Generate and populate transmit resouce grid for RMC R.11.

```
rmccfg.RC = 'R.11';
ncodewords = 2;
enb = lteRMCDL(rmccfg, ncodewords);
enb.TotSubframes = 1;
[~,txGrid] = lteRMCDLTool(enb, {[1;0] [0;1]});
```

Extract the PDSCH symbols from this transmit grid.

```
[ind,indInfo] = ltePDSCHIndices(enb, enb.PDSCH, enb.PDSCH.PRBSet);
pdschSym = txGrid(ind);
```

Create an ideal, or identity, channel estimate and an ideal, or zero, noise estimate.

```
hest = permute(repmat(eye(enb.CellRefP), [1 1 indInfo.Gd]), [3 1 2]);
nest = 0.0;
```

Equalize and deprecode the PDSCH symbols, using the channel and noise estimates.

```
[out,csi] = lteEqualizeMIMO(enb, enb.PDSCH, pdschSym, hest, nest);
deprecoded = lteDLDeprecode(enb,enb.PDSCH,out);
```

Input Arguments

enb — Cell-wide settings

structure

Cell-wide settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. ($N_{\mathrm{RB}}^{\mathrm{DL}}$)
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `enb.DuplexMode` is set to `'TDD'`.			

Parameter Field	Required or Optional	Values	Description
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter fields are dependent upon the condition that `chs.TxScheme` is set to `'SpatialMux'` or `'MultiUser'`.			
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)

Data Types: `struct`

chs — PDSCH configuration

structure

PDSCH configuration, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
NLayers	Required	Integer from 1 to 8	Number of transmission layers (downlink modulation)
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
TxScheme	Required	`'CDD'`, `'SpatialMux'`, `'MultiUser'`	Transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'CDD'`	Large delay cyclic delay diversity
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO

Parameter Field	Required or Optional	Values	Description
The following parameters are dependent upon the condition that `TxScheme` is set to `'SpatialMux'` or `'MultiUser'`.			
`PMISet`	Required	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.
`PRBSet`	Required	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.

Data Types: `struct`

`in` — Received PDSCH input symbols

numeric matrix

Received PDSCH input symbols, specified as a numeric matrix of size *M*-by-`NRxAnts`, where *M* is the number of received symbols for each of `NRxAnts` receive antennas.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array

Channel estimate, specified as a 3-D numeric array of size *M*-by-`NRxAnts`-by-`enb.CellRefP`, where:

- *M* is the number of received symbols in `in`,
- `NRxAnts` is the number of receive antennas,
- `enb.CellRefP` is the number of cell-specific reference signal antenna ports.

Data Types: `double`

`noiseest` — Noise power estimate

numeric scalar

Noise power estimate, specified as a numeric scalar. This argument is an estimate of the noise power spectral density per RE on `rxgrid`. Such an estimate is provided by the `lteDLChannelEstimate` function.

Data Types: `double`

Output Arguments

`out` — Equalized output symbols

numeric matrix

Equalized output symbols, returned as a numeric matrix of size *M*-by-*NU*, where

- *M* is the number of received symbols for each receive antenna
- *NU* is the number of transmit layers

Data Types: `double`
Complex Number Support: Yes

`csi` — Soft channel state information

numeric matrix

Soft channel state information, returned as a numeric matrix of size *M*-by-`NU`, the same size as `out`. This argument contains soft channel state information and provides an estimate, via MMSE, of the received gain for each received layer.

Data Types: `double`

See Also

See Also

`lteDLChannelEstimate` | `lteDLPrecode` | `lteEqualizeMMSE` | `lteEqualizeULMIMO` | `lteEqualizeZF` | `ltePDSCHDecode`

Introduced in R2014a

lteEqualizeMMSE

MMSE equalization

Syntax

```
[out,csi] = lteEqualizeMMSE(rxgrid,channelest,noiseest)
```

Description

`[out,csi] = lteEqualizeMMSE(rxgrid,channelest,noiseest)` returns equalized data in multidimensional array, `out`. MMSE equalization is applied to the received data resource grid in the matrix, `rxgrid`, using the channel information in the `channelest` matrix. `noiseest` is an estimate of the received noise power spectral density.

Alternatively, the input `channelest` can be provided as a 3-D array of size *NRE*-by-`NRxAnts`-by-*P*, and the input `rxgrid` can be provided as a matrix of size *NRE*-by-`NRxAnts`. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel. The outputs, `out` and `csi`, are of size (*N*×*M*)-by-*P*.

Examples

Equalize MMSE for RMC R.4

Equalize the received signal for RMC R.4 after channel estimation. Use the MMSE equalizer.

Create cell-wide configuration structure and generate transmit signal. Configure propagation channel.

```
enb = lteRMCDL('R.4');
[txSignal,~,info] = lteRMCDLTool(enb,[1;0;0;1]);
```

```
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 1;
chcfg.DopplerFreq = 70;
chcfg.MIMOCorrelation = 'Low';
chcfg.SamplingRate = info.SamplingRate;
chcfg.Seed = 1;
chcfg.InitPhase = 'Random';
chcfg.InitTime = 0;

txSignal = [txSignal; zeros(15,1)];
N = length(txSignal);
noise = 1e-3*complex(randn(N,chcfg.NRxAnts),randn(N,chcfg.NRxAnts));
rxSignal = lteFadingChannel(chcfg,txSignal)+noise;
```

Perform synchronization and OFDM demodulation.

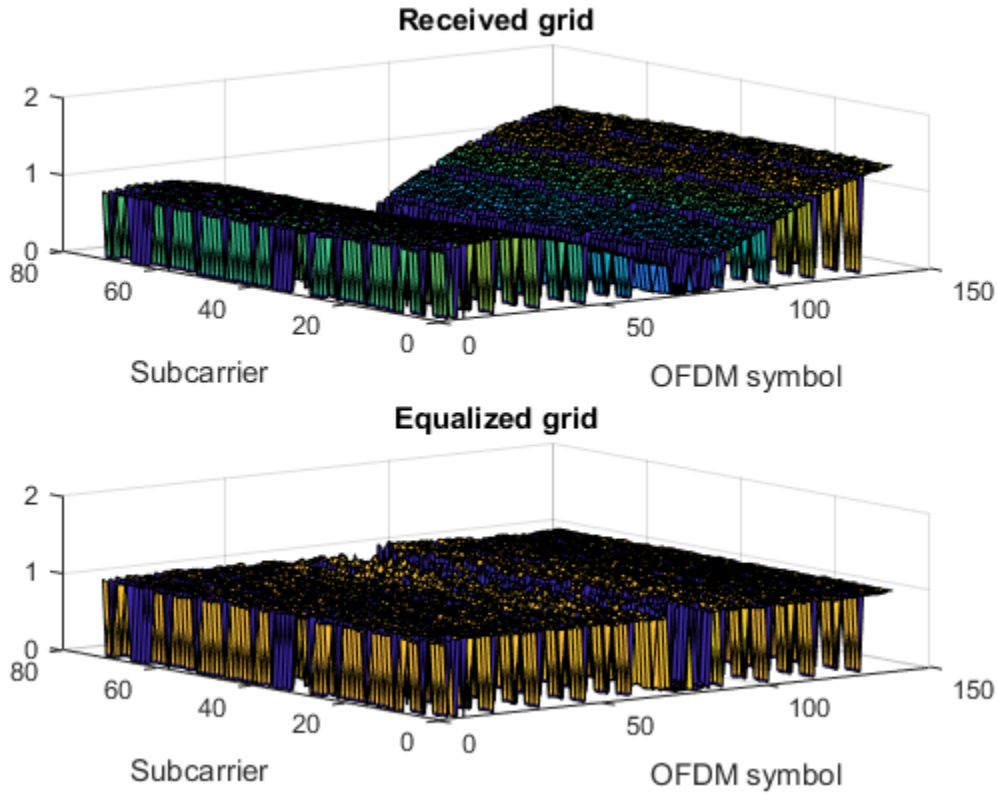
```
offset = lteDLFrameOffset(enb,rxSignal);
rxGrid = lteOFDMDemodulate(enb,rxSignal(1+offset:end,:));
```

Create channel estimation configuration structure and perform channel estimation.

```
cec.FreqWindow = 9;
cec.TimeWindow = 9;
cec.InterpType = 'Cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 3;
cec.InterpWindow = 'Causal';
[hest,noiseEst] = lteDLChannelEstimate(enb, cec, rxGrid);
```

Equalize and plot received and equalized grids.

```
eqGrid = lteEqualizeMMSE(rxGrid, hest, noiseEst);
subplot(2,1,1)
surf(abs(rxGrid))
title('Received grid')
xlabel('OFDM symbol')
ylabel('Subcarrier')

subplot(2,1,2)
surf(abs(eqGrid))
title('Equalized grid')
xlabel('OFDM symbol')
ylabel('Subcarrier')
```



Equalize MMSE for RMC R.5

This example applies MMSE equalization on the received signal for reference measurement channel (RMC) R.5, after channel estimation.

Set the DL reference measurement channel to R.5

```
enb = lteRMCDL('R.5');
```

Set channel estimator configuration `PilotAverage` field to `UserDefined`. as follows: averaging window of 9 resource elements in both frequency and time domain, cubic interpolation with a casual window.

```
cec = struct('FreqWindow',9,'TimeWindow',9,'InterpType','cubic');
```

```
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 1;
cec.InterpWindow = 'Causal';
```

Generate the `txWaveform`.

```
txWaveform = lteRMCDLTool(enb,[1;0;0;1]);
n = length(txWaveform);
```

Apply some random noise to the transmitted signal and save as the `rxWaveform`.

```
rxWaveform = repmat(txWaveform,1,2)+complex(randn(n,2),randn(n,2))*1e-3;
```

Next, demodulate the received data.

```
rxGrid = lteOFDMDemodulate(enb,rxWaveform);
```

Then, perform channel estimation.

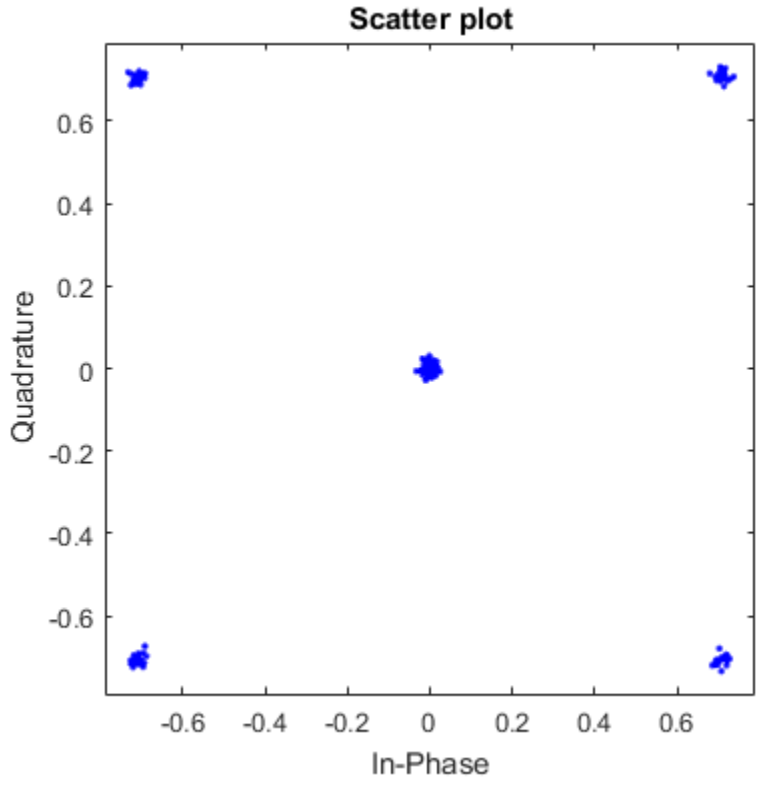
```
[hest,nO] = lteDLChannelEstimate(enb,cec,rxGrid);
```

Finally, apply the MMSE equalization.

```
out = lteEqualizeMMSE(rxGrid,hest,nO);
```

Show scatter plot of one component carrier.

```
scatterplot(out(:,1))
```



Input Arguments

`rxgrid` — Received data resource grid

3-D numeric array | 2-D numeric matrix

Received data resource grid, specified as a 3-D numeric array or a 2-D numeric matrix. As a 3-D numeric array, it has size *N*-by-*M*-by-`NRxAnts`, where *N* is the number of subcarriers, *M* is the number of OFDM symbols, and `NRxAnts` is the number of receive antennas.

Alternatively, as a 2-D numeric matrix, it has size *NRE*-by-`NRxAnts`. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing

through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`
Complex Number Support: Yes

`channelest` — Channel information

4-D numeric array | 3-D numeric array

Channel information, specified as a 4-D numeric array or a 3-D numeric array. As a 4-D numeric array, it has size *N*-by-*M*-by-`NRxAnts`-by-*P*. *N* is the number of subcarriers, *M* is the number of OFDM symbols, `NRxAnts` is the number of receive antennas, and *P* is the number of transmit antennas. Each element is a complex number representing the narrowband channel for each resource element and for each link between transmit and receive antennas. This matrix can be obtained using the channel estimation command `lteDLChannelEstimate`.

Alternatively, as a 3-D numeric array, it has size *NRE*-by-`NRxAnts`-by-*P*. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Noise power estimate

numeric scalar

Noise power estimate, specified as a numeric scalar. It is an estimate of the received noise power spectral density per RE on `rxgrid`.

Data Types: `double`

Output Arguments

`out` — Equalized output data

3-D numeric array | 2-D numeric matrix

Equalized output data, returned as a 3-D numeric array or a 2-D numeric matrix. As a 3-D numeric array, it has size *N*-by-*M*-by-*P*, where *N* is the number of subcarriers, *M* is the number of OFDM symbols, and *P* is the number of transmit antennas.

Alternatively, if `channelest` is provided as a 3-D array, `out` is a 2-D numeric matrix of size ($N \times M$)-by-P. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`
Complex Number Support: Yes

`csi` — Soft channel state information

3-D numeric array | 2-D numeric matrix

Soft channel state information, returned as a 3-D numeric array of the same size as `out`. As a 3-D numeric array, it has size N-by-M-by-P, where N is the number of subcarriers, M is the number of OFDM symbols, and P is the number of transmit antennas. `csi` provides an estimate (via MMSE) of the received RE gain for each received RE.

Alternatively, if `channelest` is provided as a 3-D array, `csi` is a 2-D numeric matrix of size ($N \times M$)-by-P. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`

See Also

See Also

`lteDLChannelEstimate` | `lteEqualizeMIMO` | `lteEqualizeULMIMO` | `lteEqualizeZF` | `lteOFDMDemodulate` | `lteSCFDMADemodulate` | `lteULChannelEstimate`

Introduced in R2014a

lteEqualizeULMIMO

MMSE-based joint uplink equalization and combining

Syntax

```
[out,csi] = lteEqualizeULMIMO(ue,chs,in,hest,noiseest)
```

Description

`[out,csi] = lteEqualizeULMIMO(ue,chs,in,hest,noiseest)` performs joint equalization and combining of the received PUSCH symbols in `in`, given UE-specific settings structure, `ue`, PUSCH configuration structure, `chs`, channel estimate, `hest` and noise power estimate, `noiseest`. MMSE equalization is performed on the product of the channel matrix and precoding matrices, thus performing MMSE equalization between transmit and receive layers and returning the result in `out`.

Examples

Equalize and Deprecode PUSCH Symbols

Extract, equalize, and deprecode PUSCH symbols from an RMC A3-2 grid.

Generate a resource grid using multiple antennas to transmit a single PUSCH codeword.

```
ue = lteRMCUL('A3-2');
ue.TotSubframes = 1;
ue.NTxAnts = 2;
ue.PUSCH.NLayers = 2;
[~,txGrid] = lteRMCULTool(ue,[1;0;0;1]);
```

Extract the PUSCH symbols from this transmit grid.

```
[ind,indInfo] = ltePUSCHIndices(ue,ue.PUSCH);
puschSym = txGrid(ind);
```

Create an ideal, or identity, channel estimate and an ideal, or zero, noise estimate.

```
hest = permute(repmat(eye(ue.NTxAnts),[1,1,indInfo.Gd]),[3,1,2]);
nest = 0.0;
```

Equalize and deprecode the PUSCH symbols, using the channel and noise estimates.

```
[out,csi] = lteEqualizeULMIMO(ue,ue.PUSCH,puschSym,hest,nest);
NPRB = size(ue.PUSCH.PRBSet,1);
deprecoded = lteULDeprecode(out,NPRB);
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.

Data Types: `struct`

chs — PUSCH configuration structure

structure

PUSCH configuration structure, specified as a structure that can contain the following fields. The `PMI` parameter field is only required if `ue.NTxAnts` is set to 2 or 4.

Parameter Field	Required or Optional	Values	Description
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.
The following parameter is required only when `ue.NTxAnts` is set to 2 or 4.			
`PMI`	Required	Nonnegative scalar integer from 0 (default) to 23	Precoder matrix indication. This PMI is to be used during precoding of the DRS reference symbols. For more information, see `lteULPMIInfo`.

Data Types: `struct`

`in` — Received PUSCH input symbols

numeric matrix

Received PUSCH input symbols, specified as a numeric matrix of size *M*-by-`NRxAnts`, where *M* is the number of received symbols for each of the `NRxAnts` receive antennas.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array

Channel estimate, specified as a 3-D numeric array of size *M*-by-`NRxAnts`-by-`NTxAnts`, where *M* is the number of received symbols in `in`, `NRxAnts` is the number of receive antennas, and `NTxAnts` is the number of transmit antenna ports, given by `ue.NTxAnts`.

Data Types: `double`

`noiseest` — Noise power estimate

numeric scalar

Noise power estimate as power spectral density per RE on `rxgrid`, specified as a numeric scalar. Such an estimate is provided by the `lteULChannelEstimate` function.

Data Types: `double`

Output Arguments

`out` — Equalized output symbols

complex-valued numeric matrix

Equalized output symbols, returned as a complex-valued numeric matrix of size *M*-by-*NU*, where *M* is the number of received symbols for each receive antenna and *NU* is the number of transmit layers.

Data Types: `double`
Complex Number Support: Yes

`csi` — Soft channel state information

numeric matrix

Soft channel state information, returned as a numeric matrix of the same size as `out`, *M*-by-*NU*. This output provides an estimate, via MMSE, of the received gain for each received layer.

Data Types: `double`

See Also

See Also

`lteEqualizeMIMO` | `lteEqualizeMMSE` | `lteEqualizeZF` | `ltePUSCHDecode` | `ltePUSCHPrecode` | `lteULChannelEstimate`

Introduced in R2013b

lteEqualizeZF

Zero-forcing equalization

Syntax

```
[out,csi] = lteEqualizeZF(rxgrid,channelest)
```

Description

`[out,csi] = lteEqualizeZF(rxgrid,channelest)` returns equalized data in multidimensional array, `out`, by applying MIMO zero-forcing equalization to the received data resource grid in matrix `rxgrid`, using the channel information in the `channelest` input matrix.

For each resource element, the function calculates the pseudoinverse of the channel and equalizes the corresponding received signal.

Alternatively, the `channelest` input can be provided as a 3-D array of size *NRE*-by-*NRxAnts*-by-*P* and the `rxgrid` input can be provided as a matrix of size *NRE*-by-*NRxAnts*. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel. The outputs, `out` and `csi`, are of size ($N \times M$)-by-*P*.

Examples

Perform Zero-Forcing Equalization for RMC R.4

Equalize the received signal for RMC R.4 after channel estimation. Use the zero forcing equalizer.

Create cell-wide configuration structure and generate transmit signal. Configure propagation channel.

```
enb = lteRMCDL('R.4');
[txSignal,~,info] = lteRMCDLTool(enb,[1;0;0;1]);
```

```
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 1;
chcfg.DopplerFreq = 70;
chcfg.MIMOCorrelation = 'Low';
chcfg.SamplingRate = info.SamplingRate;
chcfg.Seed = 1;
chcfg.InitPhase = 'Random';
chcfg.InitTime = 0;

txSignal = [txSignal; zeros(15,1)];
N = length(txSignal);
noise = 1e-3*complex(randn(N,chcfg.NRxAnts),randn(N,chcfg.NRxAnts));
rxSignal = lteFadingChannel(chcfg,txSignal)+noise;
```

```
Warning: Using default value for parameter field ModelType (GMEDS)
Warning: Using default value for parameter field NTerms (16)
Warning: Using default value for parameter field NormalizeTxAnts (On)
Warning: Using default value for parameter field NormalizePathGains (On)
```

Perform synchronization and OFDM demodulation.

```
offset = lteDLFrameOffset(enb,rxSignal);
rxGrid = lteOFDMDemodulate(enb,rxSignal(1+offset:end,:));
```

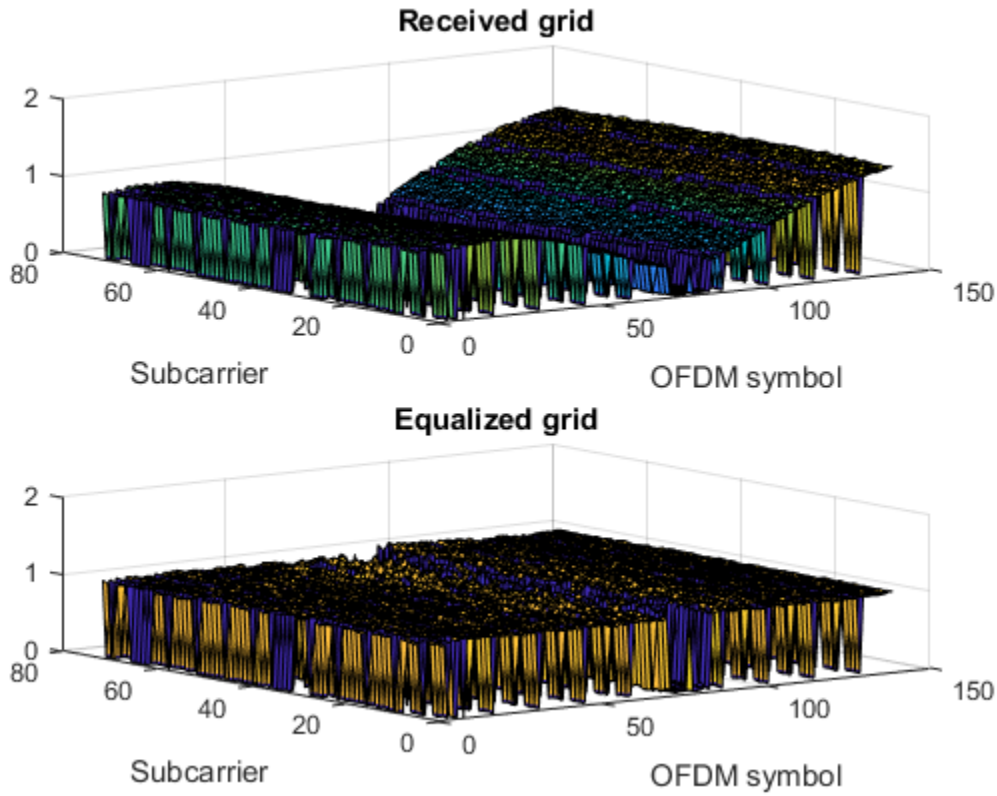
Create channel estimation configuration structure and perform channel estimation.

```
cec.FreqWindow = 9;
cec.TimeWindow = 9;
cec.InterpType = 'Cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 3;
cec.InterpWindow = 'Causal';
hest = lteDLChannelEstimate(enb,cec,rxGrid);
```

Equalize and plot received and equalized grids.

```
eqGrid = lteEqualizeZF(rxGrid,hest);

subplot(2,1,1);
surf(abs(rxGrid));
title('Received grid');
xlabel('OFDM symbol');
ylabel('Subcarrier');

subplot(2,1,2);
```

```
surf(abs(eqGrid));
title('Equalized grid');
xlabel('OFDM symbol');
ylabel('Subcarrier');
```



Input Arguments

`rxgrid` — Received data resource grid

3-D numeric array | 2-D numeric matrix

Received data resource grid, specified as a 3-D numeric array or a 2-D numeric matrix. As a 3-D numeric array, it has size *N*-by-*M*-by-`NRxAnts`, where *N* is the number of

subcarriers, *M* is the number of OFDM symbols, and `NRxAnts` is the number of receive antennas.

Alternatively, as a 2-D numeric matrix, it has size *NRE*-by-`NRxAnts`. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`
Complex Number Support: Yes

`channelest` — Channel information

4-D numeric array | 3-D numeric array

Channel information, specified as a 4-D numeric array or a 3-D numeric array. As a 4-D numeric array, it has size *N*-by-*M*-by-`NRxAnts`-by-*P*. *N* is the number of subcarriers, *M* is the number of OFDM symbols, `NRxAnts` is the number of receive antennas, and *P* is the number of transmit antennas. Each element is a complex number representing the narrowband channel for each resource element and for each link between transmit and receive antennas. This matrix can be obtained using a channel estimation function, such as `lteDLChannelEstimate`.

Alternatively, as a 3-D numeric array, it has size *NRE*-by-`NRxAnts`-by-*P*. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`out` — Equalized output data

3-D numeric array | 2-D numeric matrix

Equalized output data, returned as a 3-D numeric array or a 2-D numeric matrix. As a 3-D numeric array, it has size *N*-by-*M*-by-*P*. *N* is the number of subcarriers, *M* is the number of OFDM symbols, and *P* is the number of transmit antennas.

Alternatively, if `channelest` is provided as a 3-D array, `out` is a 2-D numeric matrix of size ($N \times M$)-by-*P*. In this case, the first two dimensions have been reduced to one

dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`
Complex Number Support: Yes

`csi` — Soft channel state information

3-D numeric array | 2-D numeric matrix

Soft channel state information, returned as a 3-D numeric array or a 2-D numeric matrix of the same size as `out`. As a 3-D numeric array, it has size *N*-by-*M*-by-*P*. *N* is the number of subcarriers, *M* is the number of OFDM symbols, and *P* is the number of transmit antennas. `csi` provides an estimate of the received RE gain for each received RE.

Alternatively, if `channelest` is provided as a 3-D array, `csi` is a 2-D numeric matrix of size (*N*×*M*)-by-*P*. In this case, the first two dimensions have been reduced to one dimension by appropriate indexing through the frequency and time locations of the resource elements of interest, typically for a single physical channel.

Data Types: `double`

See Also

See Also

`lteDLChannelEstimate` | `lteEqualizeMIMO` | `lteEqualizeMMSE` | `lteEqualizeULMIMO` | `lteOFDMDemodulate` | `lteSCFDMADemodulate` | `lteULChannelEstimate`

Introduced in R2014a

lteExtractResources

Resource elements extraction

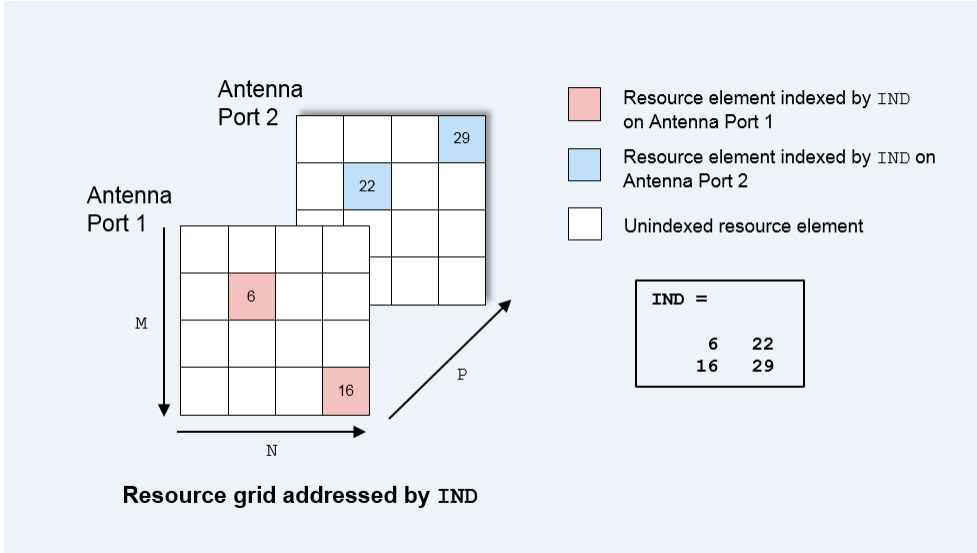
Syntax

```
[re,reind] = lteExtractResources(ind,grid)
[re1, re2,...,reN,reind1, reind2, ...,reindN]= lteExtractResources(
ind,grid1,grid2, ....,gridN)
re = lteExtractResources(....,opts)
```

Description

`[re,reind] = lteExtractResources(ind,grid)` returns resource elements `re` and indices of the extracted resource elements `reind` from a resource array, `grid`, using resource elements indices `ind`. You can extract resource elements from a resource grid with different dimensionality than the resource grid addressed by the indices. The indices specified and returned are in 1–based linear indexing form. Other indexing options are available. The resource extraction process is further explained in “Algorithms” on page 1-400.

In LTE System Toolbox, indices are generated for mapping sequences of physical channel and signal symbols to a resource grid. These indices are generated using channel-or signal-specific functions and address resource elements in an array sized, *M*-by-*N*-by-*P*. *M* is the number of subcarriers, *N* is the number of OFDM or SC-FDMA symbols and *P* is the number of planes. The diagram highlights the resource elements of a resource grid addressed by indices, `ind`. The indices are in a 1–based linear indexing form. *P = 2* is the number of antenna ports.



Typically the resource array extracts resource elements from one of the following:

- A 3-D received grid, sized *M*-by-*N*-by-*NRxAnts*. *NRxAnts* is the number of receive antennas. This grid is created after OFDM or SC-FDMA demodulation.
- A 4-D channel estimation grid, sized *M*-by-*N*-by-*NRxAnts*-by-*P*. This grid is created by channel estimation functions (refer “Channel Estimation”).

You can describe the size of the 3D received grid as a 4D grid that has a trailing singleton dimension.

`[re1, re2,...,reN,reind1, reind2, ...,reindN]= lteExtractResources( ind,grid1,grid2, ....,gridN)` extracts resource elements from multiple resource arrays using the indices `ind`.

`re = lteExtractResources(....,opts)` enables control over the format of the indices and the extraction method used with a cell array of options, `opts`.

Examples

Extract PDCCH Symbols and Channel Estimates for Decoding

Extract PDCCH symbols from a received grid and associated channel estimates in preparation for decoding.

Create a transmit waveform for one subframe.

```
enb = lteRMCDL('R.12');
enb.TotSubframes = 1;
txWaveform = lteRMCDLTool(enb,[1;0;0;1]);
```

Receive sum of transmit antenna waveforms on three receive antennas.

```
NRxAnts = 3;
rxWaveform = repmat(sum(txWaveform,2),1,NRxAnts);
rxGrid = lteOFDMDemodulate(enb,rxWaveform);
```

Compute the channel estimation.

```
cec.FreqWindow = 1;
cec.TimeWindow = 1;
cec.InterpType = 'cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 3;
cec.InterpWindow = 'Causal';
[hEstGrid,nEst] = lteDLChannelEstimate(enb,cec,rxGrid);
```

Generate PDCCH indices and extract symbols from received and channel estimate grids in preparation for PDCCH decoding.

```
ind = ltePDCCHIndices(enb);
[pdcchRxSym,pdcchHestSym] = lteExtractResources(ind,rxGrid,hEstGrid);
```

pdcchRxSym is sized `NRE-by-NRxAnts` and `pdcchHestSym` is sized `NRE-by-NRxAnts-by-CellRefP`.

```
rxSymSize = size(pdcchRxSym)
hestSymSize = size(pdcchHestSym)
```

```
rxSymSize =
```

```
   212     3

hestSymSize =

   212     3     4
```

Decode PDCCH with extracted resource elements.

```
pdcchBits = ltePDCCHDecode(enb,pdcchRxSym,pdcchHestSym,nEst);
```

Extract Resources From 3D Receive Grid and 4D Channel Estimate Grid

Extract resources from a 3D receive grid and 4D channel estimate grid. Show the location of the indices within the grid.

Setup sizes of the grids: [M N P] and [M N NRxAnts P], where M is the number of subcarriers, N is the number of OFDM symbols, NRxAnts is the number of rx antennas, and P is the number of tx antennas.

```
M = 4;
N = 4;
P = 2;
NRxAnts = 3;
```

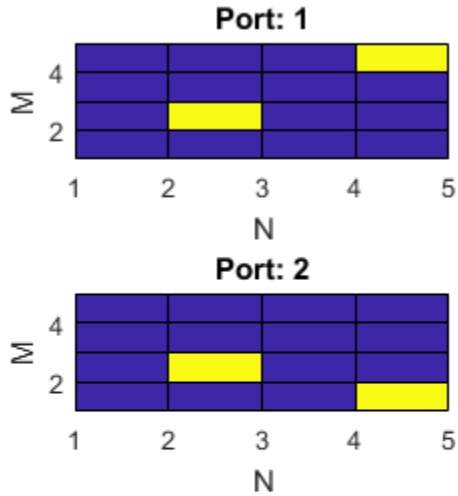
Create indices and show the locations within the transmit grid addressed by these indices. As you will notice, different resource elements are addressed on each antenna port. Addressed resource element locations contain 1.

```
ind = [6 22; 16 29];
txGrid = zeros(M,N,P);
txGrid(ind) = 1;
```

Visualize locations of indexed resource elements in the transmit grid.

```
visualizeGrid = zeros(M+1,N+1,P);
visualizeGrid(1:M,1:N,:) = txGrid;

figure

subplot(321)
pcolor(visualizeGrid(:,:,1))
```

```
title('Port: 1')
xlabel('N')
ylabel('M')

subplot(323)
pcolor(visualizeGrid(:,:,2))
title('Port: 2')
xlabel('N')
ylabel('M')
```

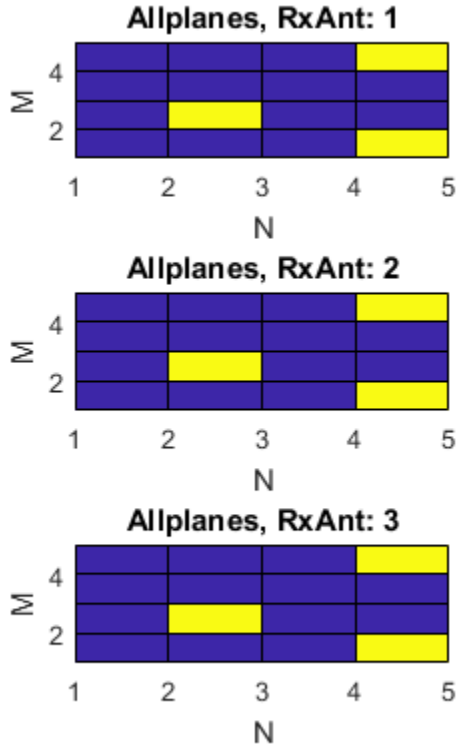


Create a 3D received grid to extract resource elements. Extract resource elements from the received grid. Show the locations of these extracted resource elements. Addressed resource element locations contain 1.

```
rxGrid = zeros(M,N,NRxAnts);

[re, indOut] = lteExtractResources(ind,rxGrid);
rxGrid(indOut) = 1;
```

Visualize locations of indexed resource elements in the receive grid.

```
figure
visualizeGrid = zeros(M+1,N+1,NRxAnts);
visualizeGrid(1:M,1:N,:) = rxGrid;

subplot(321)
pcolor(visualizeGrid(:,:,1))
title('Allplanes, RxAnt: 1');
xlabel('N')
ylabel('M')

subplot(323)
pcolor(visualizeGrid(:,:,2))
title('Allplanes, RxAnt: 2')
xlabel('N')
ylabel('M')

subplot(325)
pcolor(visualizeGrid(:,:,3))
title('Allplanes, RxAnt: 3')
xlabel('N')
ylabel('M')
```



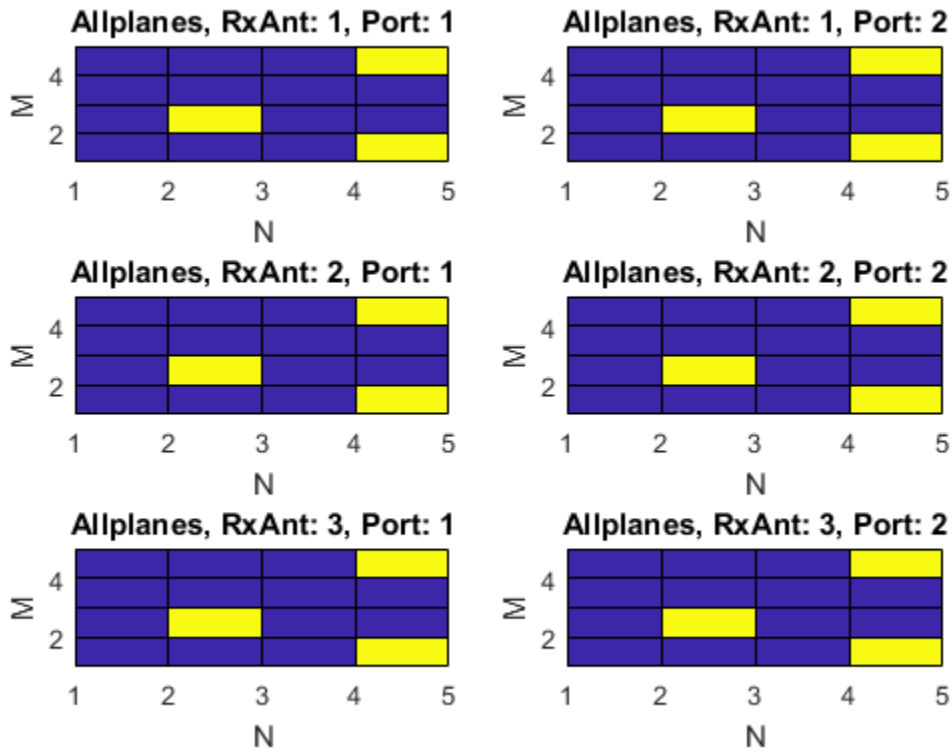
Create a 4D channel estimate grid to extract resource elements. Extract resource elements from the channel estimate grid. Show the locations of these extracted resource elements. Addressed resource element locations contain 1.

```
hEstGrid = zeros(M,N,NRxAnts,P);

[re, indOut] = lteExtractResources(ind,hEstGrid);
hEstGrid(indOut) = 1;
```

Visualize locations of the resource elements extracted using `'allplanes'` mode from 3D receive grid.

```
figure;
visualizeGrid = zeros(M+1,N+1,NRxAnts,P);
```

```
visualizeGrid(1:M,1:N,:,:) = hEstGrid;

subplot(321)
pcolor(visualizeGrid(:,:,1,1))
title('Allplanes, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')

subplot(323)
pcolor(visualizeGrid(:,:,2,1))
title('Allplanes, RxAnt: 2, Port: 1')
xlabel('N')
ylabel('M')

subplot(325)
pcolor(visualizeGrid(:,:,3,1))
title('Allplanes, RxAnt: 3, Port: 1')
xlabel('N')
ylabel('M')

subplot(322)
pcolor(visualizeGrid(:,:,1,2))
title('Allplanes, RxAnt: 1, Port: 2')
xlabel('N')
ylabel('M')

subplot(324)
pcolor(visualizeGrid(:,:,2,2))
title('Allplanes, RxAnt: 2, Port: 2')
xlabel('N')
ylabel('M')

subplot(326)
pcolor(visualizeGrid(:,:,3,2))
title('Allplanes, RxAnt: 3, Port: 2')
xlabel('N')
ylabel('M')
```



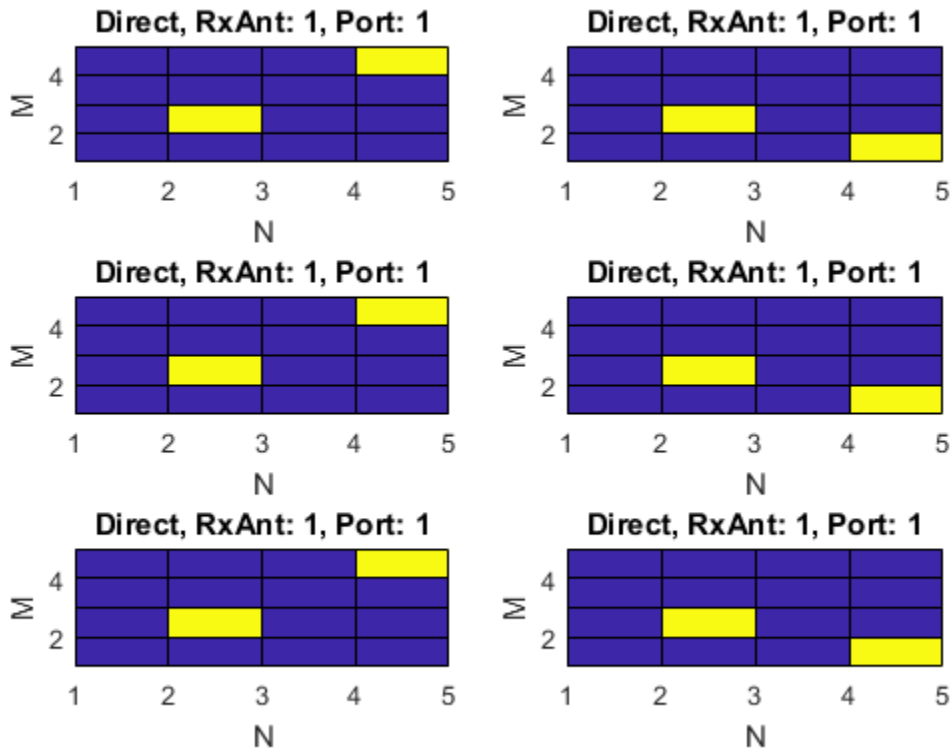
Create a 4D channel estimate grid to extract resource elements. Extract resource elements from the channel estimate grid using `'direct'` extraction mode. Show the locations of these extracted resource elements. Addressed resource element locations contain 1.

```
hEstGridDirect = zeros(M,N,NRxAnts,P);

[re, indOut] = lteExtractResources(ind,hEstGridDirect,'direct');
hEstGridDirect(indOut) = 1;
```

Visualize locations of the resource elements extracted using `'direct'` mode from 4D channel estimate grid.

```
figure
```

```
visualizeGrid = zeros(M+1,N+1,NRxAnts,P);
visualizeGrid(1:M,1:N,:,:) = hEstGridDirect;

subplot(321)
pcolor(visualizeGrid(:,:,1,1))
title('Direct, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')

subplot(323)
pcolor(visualizeGrid(:,:,2,1))
title('Direct, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')

subplot(325)
pcolor(visualizeGrid(:,:,3,1))
title('Direct, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')

subplot(322)
pcolor(visualizeGrid(:,:,1,2))
title('Direct, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')

subplot(324)
pcolor(visualizeGrid(:,:,2,2))
title('Direct, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')

subplot(326)
pcolor(visualizeGrid(:,:,3,2))
title('Direct, RxAnt: 1, Port: 1')
xlabel('N')
ylabel('M')
```



Extract Cell-Specific Reference Signal (CRS) Symbols

Use `'direct'` and `'allplanes'` extraction methods and subscript indices to extract cell-specific reference signal (CRS) symbols in subcarrier 7 from `grid`.

Generate a resource grid and CRS indices in the subscript form: [subcarrier, OFDM symbol, CRS port].

```
enb = lteRMCDL('R.12');
enb.TotSubframes = 1;
enb.CellRefP = 2;
enb.PDSCH.NLayers = 2;
[waveform,grid] = lteRMCDLTool(enb,[1;0;0;1]);
crsInd = lteCellRSIndices(enb,'sub');
```

There are 2 resource elements used on CRS ports 1 & 2; all are on different OFDM symbols (1, 5, 8, 12).

```
crsIndSC7 = crsInd(crsInd(:,1)==7,:)
```

```
crsIndSC7 =

  4×3 uint32 matrix

    7    1    1
    7    8    1
    7    5    2
    7   12    2
```

Use `'direct'` method to extract resource elements. The extracted resource element indices are same as the generated CRS indices as the resource array indexed by `crsInd` in `grid`.

```
[dirREs,dirInd] = lteExtractResources(crsInd,grid,{'direct','sub'});
directIndSC7 = dirInd(dirInd(:,1)==7,:)
```

```
directIndSC7 =

  4×3 uint32 matrix

    7    1    1
    7    8    1
    7    5    2
    7   12    2
```

Use `'allplanes'` method to extract resource elements. There are 4 extracted CRS indices as per the CRS port on subcarrier 7. Indices addressing unique OFDM symbols in the indexed resource grid are used to extract resource elements from all the CRS ports in `'grid`. Therefore indices are extracted at OFDM symbols (1, 5, 8,12) on both CRS ports.

```
[apREs,apInd] = lteExtractResources(crsInd,grid,{'allplanes','sub'});
allPlanesIndSC7 = apInd(apInd(:,1)==7,:)
```

```
allPlanesIndSC7 =
```

```
8×3 uint32 matrix

   7    1    1
   7    8    1
   7    5    1
   7   12    1
   7    1    2
   7    8    2
   7    5    2
   7   12    2
```

Input Arguments

`ind` — Resource elements indices

numeric array

Resource elements indices, specified as a numeric array. The indices address elements of a *N*-by-*M*-by-*P* resource array. *M* is the number of subcarriers, *N* is the number of OFDM or SC-FDMA symbols, and *P* is the number of planes.

`grid` — Resource array

3–D numeric array (default) | 4–D numeric array

Resource array, specified as a 3-D or 4-D numeric array. Typically the resource array to extract resource elements from in one of the following:

- A 3–D received grid, sized *M*-by-*N*-by-*NRxAnts*. *NRxAnts* is the number of receive antennas. This grid is created after OFDM or SC-FDMA demodulation.
- A 4–D channel estimation grid, sized *M*-by-*N*-by-*NRxAnts*-by-*P*. This grid is created by channel estimation functions (refer “Channel Estimation”).

You can describe the size of the 3D received grid as a 4D grid that has a trailing singleton dimension.

Data Types: `double`

`opts` — Resource elements extraction options

character vector | cell array of character vectors

Resource elements extraction options, specified as a character vector or cell array of character vectors. `opts` can contain the following values:

Parameter Field	Required or Optional	Values	Description
`Indexing Style`	Required	`'ind'` (default) or `'sub'`	Indexing style of the specified or returned indices, `ind` and `reind`, specified as one of the following options: • `'ind'` — linear index form • `'sub'` — subscript form
`Index Base`	Required	`'1based'` (default) or `'0based'`	Base value of the specified or returned indices, `ind` and `reind`, specified as one of the following options: • `'1based'` — the first value of index sequence is one • `'0based'` — the first value of the index sequence is zero
`Extraction Method`	Required	`'allplanes'` (default) or `'direct'`	Resource element extraction methods. The methods are described in "Algorithms" on page 1-400. • `'allplanes'` — uses indices addressing unique subcarrier and symbol location over all planes of the indexed resource array for extraction. • `'direct'` — only resource elements relevant to each plane of the indexed resource grid are extracted.

Output Arguments

`re` — Extracted resource elements

column vector | numeric array

Extracted resource elements, returned as a column vector or numeric array.

When `'allplanes'` extraction method is used, the extracted resource elements array is of size N_{RE}-by-*NRxAnts*-by-*P* where:

- N_{RE} is the number of resource elements per *M*-by-*N* plane of `grid`.
- *M* is the number of subcarriers.
- *N* is the number of OFDM or SC-FDMA symbols.
- *P* is the number of planes.

When using `'direct'` extraction method, the size of the extracted resource elements array, `re`, depends on the number of indices addressing each plane of the indexed source grid:

- If the same number of indices address each plane then `re` is of size N_{RE}-by-*NRxAnts*-by-*P*.
- If a different number of indices address each plane then `re` is a column vector containing all extracted resource elements.

`reind` — Indices of extracted resource elements
numeric array

Indices of extracted resource elements within `grid`, returned as numeric array. `reind` is the same size as extracted resource elements array `re`.

Algorithms

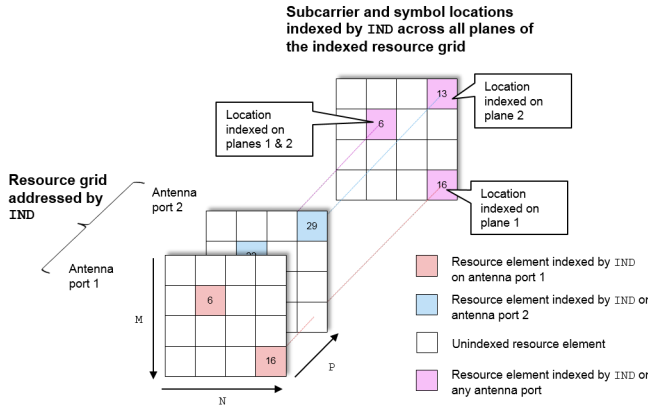
`lteExtractResources` can extract resource elements using one of two methods. The `'allplanes'` method is used by default. You can optionally specify `'direct'` extraction method.

All Planes Extraction Method

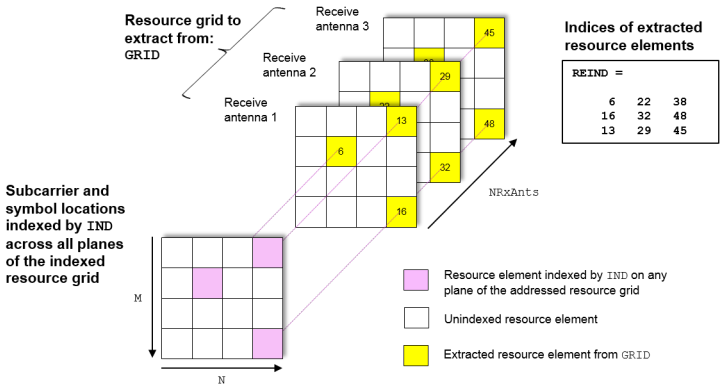
The `'allplanes'` method extracts resource elements from each *M*-by-*N* plane within `grid` using indices that address unique subcarrier and symbol locations over all the planes of the indexed resource array.

The following diagrams illustrate the resource extraction process for a 3D received grid and a 4D channel estimation grid. The example, “Extract Resources From 3D Receive Grid and 4D Channel Estimate Grid” on page 1-389 recreates these diagrams.

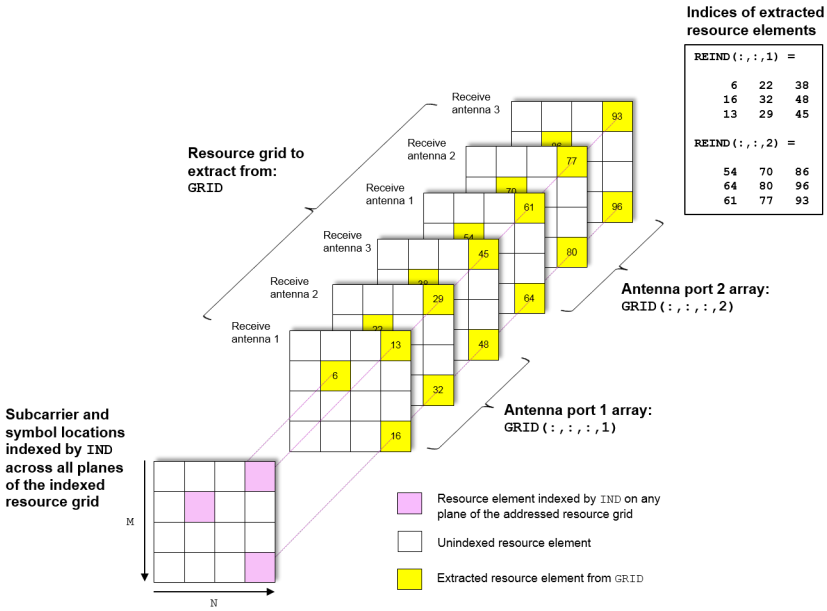
Indices addressed by unique subcarrier and symbol locations across all planes of the indexed resource gird are used for the extraction. The diagram highlights the indices used to extract resource elements address the resource grid with *P* = *2*. In this case, *P* is the number of antenna ports.



Resource elements are extracted from `grid` at the symbol and subcarrier locations. The following diagrams illustrate the resource element extraction from a 3D received grid, `grid`, with *NRxAnts* = *3*.



The following diagram shows the extraction process for a 4D channel estimate grid, `grid`, with *NRxAnts* = *3* and *P*= *2*. In this case, *P* is the number for antenna ports. The 4D resource grid consists of *P* *M*-by-*N*-by-*NRxAnts* arrays, each associated with an antenna port. Resource elements are extracted from all planes within these arrays.



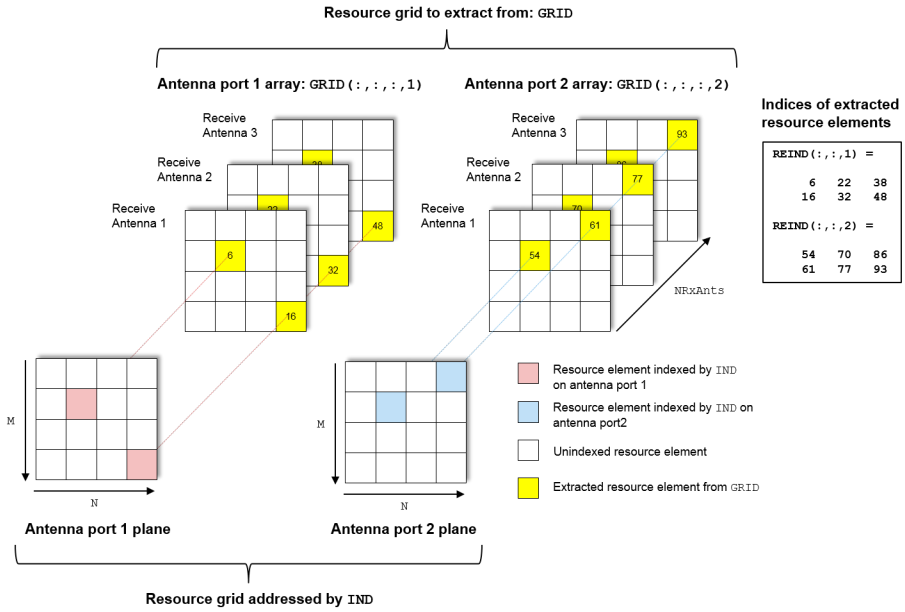
Direct Extraction Method

The `'direct'` method extracts resource elements from `grid` with the assumption that third and fourth dimension of the `grid` represents the same property as the planes of the indexed resource array such as antenna ports, layers, transmit antennas. Therefore the only resource elements relevant to each plane of the indexed resource grid are extracted:

- For a 3D `grid`, the `'direct'` method extracts elements from each *M*-by-*N* plane of `grid` using indices addressing the same plane of the indexed resource array. This is the same as the standard MATLAB operation `re = grid(ind)`. Therefore `reind = ind`.
- For a 4D `grid`, the `'direct'` method extracts elements from each *M*-by-*N*-by-*NRxAnts* array of `grid` using indices addressing the same plane of the indexed resource array. Therefore it is assumed the property represented by the planes of the indexed resource array is the same as the fourth dimension of `grid`.

The extraction of a 4D estimation grid, `grid`, using the `'direct'` method is illustrated in the following diagram with *NRxAnts* = *3* and *P*= *2*, which is the number of antenna ports. The 4D resource grid consists of *P* *M*-by-*N*-by-*NRxAnts* arrays, each associated

with an antenna port. Therefore the indices corresponding to each individual antenna port in the indexed resource array are used to extract resource elements from each of these arrays. The example, “Extract Resources From 3D Receive Grid and 4D Channel Estimate Grid” on page 1-389 creates a version of this diagram.



See Also

See Also

lteCellRSIndices | lteDLChannelEstimate | lteDLResourceGrid | lteOFDMDemodulate | ltePBCHDecode | ltePBCHIndices | ltePCFICHDecode | ltePCFICHIndices | ltePDCCHDecode | ltePDCCHDecode | ltePDCCHIndices | ltePDCCHIndices | ltePDSCHDecode | ltePDSCHIndices | ltePHICHDecode | ltePHICHIndices | ltePUCCH1Decode | ltePUCCH1Indices | ltePUCCH2Decode | ltePUCCH2Indices | ltePUCCH3Decode | ltePUCCH3Indices | ltePUSCHDecode | ltePUSCHIndices | lteSCFDMADemodulate | lteULChannelEstimate | lteULChannelEstimatePUCCH1 | lteULChannelEstimatePUCCH2 | lteULChannelEstimatePUCCH3 | lteULResourceGrid

Introduced in R2014b

lteFadingChannel

Multipath fading MIMO channel propagation conditions

Syntax

```
[out,info] = lteFadingChannel(model,in)
```

Description

`[out,info] = lteFadingChannel(model,in)` returns the channel output signal matrix and an information structure, given the multipath Rayleigh fading channel model and input waveform. For more information, see “Fading Channel Model Delay” on page 1-414.

Examples

Transmit Multiple Subframes over Fading Channel

Transmit a number of subframes through a fading channel using a `for`-loop.

Define the channel configuration structure.

```
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 1;
chcfg.DopplerFreq = 5;
chcfg.MIMOCorrelation = 'Low';
chcfg.Seed = 1;
chcfg.InitPhase = 'Random';
chcfg.ModelType = 'GMEDS';
chcfg.NTerms = 16;
chcfg.NormalizeTxAnts = 'On';
chcfg.NormalizePathGains = 'On';
```

Define the transmission waveform configuration structure, initialized to RMC `'R.10'` and one subframe.

```
rmc = lteRMCDL('R.10');
rmc.TotSubframes = 1;
```

Within a `for`-loop, generate ten subframes, one subframe at a time.

- Outside the `for`-loop, define `delay`, which accounts for a combination of implementation delay and channel delay spread.
- Set the subframe number and initialize the subframe start time, allocating 1 ms per subframe.
- Generate a transmit waveform.
- Initialize the number of transmit antennas and the waveform sampling rate.
- Send the waveform through the channel. Append `delay` zeros to the generated waveform prior to channel filtering.

```
delay = 25;
for subframeNumber = 0:9

    rmc.NSubframe = mod(subframeNumber,10);
    chcfg.InitTime = subframeNumber/1000;

    [txWaveform,txGrid,info] = lteRMCDLTool(rmc,[1;0;1;1]);

    numTxAnt = size(txWaveform,2);
    chcfg.SamplingRate = info.SamplingRate;

    rxWaveform = lteFadingChannel(chcfg,[txWaveform; zeros(delay,numTxAnt)]);
end
```

Transmit Two Consecutive Frames over Fading Channel

Transmit two consecutive frames over fading channel while maintaining continuity between the fading process between the end of the first frame and the beginning of the second.

The first frame is transmitted at time t = 0 s. Hence the channel is initialized with `InitTime` set to 0 s. The second frame is transmitted at time t = 10 ms. Hence the channel fading process has to be initialized to that value.

Initialize a resource grid to RMC R.10 and generate a transmit waveform for the first frame. Initialize a propagation channel configuration structure and set the start time for the first frame. Pass the first frame through the channel.

```
rmc = lteRMCDL('R.10');
[txWaveform,txGrid,info] = lteRMCDLTool(rmc,[1;0;1]);

chcfg.DelayProfile = 'EPA';
```

```
chcfg.NRxAnts = 1;
chcfg.DopplerFreq = 5;
chcfg.MIMOCorrelation = 'Low';
chcfg.SamplingRate = info.SamplingRate;
chcfg.Seed = 1;
chcfg.InitPhase = 'Random';
chcfg.ModelType = 'GMEDS';
chcfg.NTerms = 16;
chcfg.NormalizeTxAnts = 'On';
chcfg.NormalizePathGains = 'On';
chcfg.InitTime = 0;

numTxAnt = size(txWaveform,2);
```

Define `delay` and append zeros to the generated waveform prior to channel filtering. `delay` accounts for a combination of implementation delay and channel delay spread.

```
delay = 25;

rxWaveform = lteFadingChannel(chcfg,[txWaveform; zeros(delay,numTxAnt)]);
```

Update the frame number and generate a transmit waveform for the second frame. Set the start time for the second frame to 10 ms. Pass the second frame through the channel.

```
rmc.NFrame = 1;
[txWaveform,txGrid] = lteRMCDLTool(rmc,[1;0;1]);

chcfg.InitTime = 10e-3;
rxWaveform = lteFadingChannel(chcfg,[txWaveform; zeros(delay,numTxAnt)]);
```

Input Arguments

`model` — Multipath fading channel model

structure

Multipath fading channel model, specified as a structure. `model` must contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NRxAnts`	Required	Positive scalar integer	Number of receive antennas

Parameter Field	Required or Optional	Values	Description
MIMOCorre	Required	`'Low'`, `'Medium'`, `'UplinkMedium'`, `'High'`, `'Custom'`	Correlation between UE and eNodeB antennas • `'Low'` correlation is equivalent to no correlation between antennas. • `'Medium'` correlation level is defined in TS 36.101 [1] Annex B.2.3.2 and applicable to tests defined in TS 36.101. • `'UplinkMedium'` correlation level is defined in TS 36.104 [2] Annex B.5.2 and is applicable to tests defined in TS 36.104 . • `'High'` correlation is equivalent to strong correlation between antennas. • `"Custom'` correlation apllies user defined `TxCorrelationMatrix` and `RxCorrelationMatrix` **Note:** The `'Low'` and `'High'` correlation levels are the same for both uplink and downlink and are therefore applicable to tests defined in both TS 36.101 and TS 36.104.

Parameter Field	Required or Optional	Values	Description
`Normalize`	Optional	`'On'` (default), `'Off'`	Transmit antenna number normalization, specified as. • `'On'` — `lteFadingChannel` normalizes the model output by `1/sqrt(P)`, where P is the number of transmit antennas. Normalization by the number of transmit antennas ensures that the output power per receive antenna is unaffected by the number of transmit antennas. • `'Off'` — Normalization is not performed.
`DelayProf`	Required	`'EPA'`, `'EVA'`, `'ETU'`, `'Custom'`, `'Off'`	Delay profile model. For more information, see "Propagation Channel Models". Setting `DelayProfile` to `'Off'` switches off fading completely and implements a static MIMO channel model. In this case, the antenna geometry corresponds to the number of transmit antennas (that is, the number of columns in the input `in`), the number of receive antennas, `model.NRxAnts`, and the MIMO correlation, `model.MIMOCorrelation`. The temporal part of the model for each link between transmit and receive antennas consists of a single path with zero delay and constant unit gain.
The following fields are applicable when `DelayProfile` is set to a value other than `'Off'`.			

Parameter Field	Required or Optional	Values	Description
Doppler	Required	Scalar value	Maximum *Doppler* frequency, in Hz.
Samplin	Required	Numeric scalar	Input signal sampling rate, the rate of each sample in the rows of the input matrix, `in`.
InitTim	Required	Numeric scalar	Fading process time offset, in seconds.
NTerms	Optional	16 (default) scalar power of 2	Number of oscillators used in fading path modeling.
ModelTy	Optional	`'GMEDS'` (default), `'Dent'`	Rayleigh fading model type. • `'GMEDS'` — The Rayleigh fading is modeled using the Generalized Method of Exact Doppler Spread (GMEDS), as described in [4]. • `'Dent'` — The Rayleigh fading is modeled using the modified Jakes fading model described in [3]. **Note:** `ModelType = 'Dent'` is not recommended. Use `ModelType = 'GMEDS'` instead.
Normali	Optional	`'On'` (default), `'Off'`	Model output normalization. • `'On'` — The model output is normalized such that the average power is unity. • `'Off'` — The average output power is the sum of the powers of the taps of the delay profile.

Parameter Field	Required or Optional	Values	Description

`InitPha`	Optional	`'Random'` (default), a scalar value (in radians), or a numeric array	Phase initialization for the sinusoidal components of the model, specified as:
			• The value `'Random'` — The phases are randomly initialized according to `Seed`.
			• A scalar value — Assumed to be in radians, is used to initialize the phases of all components.
			• An *N*-by-*L*-by-*P*-by-`NRxAnts` numeric array — Used to initialize the phase in radians of each component explicitly.
			  • *N* is the number of phase initialization values per path.
			  • *L* is the number of paths.
			  • *P* is the number of transmit antennas.
			  • `NRxAnts` is the number of receive antennas.
			Note:
			• When `ModelType` is set to `'GMEDS'`, $N = 2 \times$ `NTerms`.
			• When `ModelType` is set to `'Dent'`, $N =$ `NTerms`.

The following field is applicable when `DelayProfile` is set to a value other than `'Off'` and `InitPhase` is set to `'Random'`.			

Parameter Field	Required or Optional	Values	Description
`Seed`	Required	Scalar value	Random number generator seed. To use a random seed, set `Seed` to zero. **Note:** • To produce distinct results, use `Seed` values in the range $0 \ldots 2^{31} \quad 1 \quad (\frac{K(K \quad 1)}{2})$ $K = P \times$ `model.NRxAnts`, which is the product of the number of transmit and receive antennas. Avoid using `Seed` values outside of this recommended range, as they may result in random sequences that repeat results produced using `Seed` values inside the recommended range. • The fading channel random seed behavior is not affected by the state of MATLAB random number generators, `rng`.
The following fields are applicable when `DelayProfile` is set to `'Custom'`.			
`Average`	Required	Vector	Average gains of the discrete paths, expressed in dB.

Parameter Field	Required or Optional	Values	Description
`PathDel`	Required	Vector	Delays of the discrete paths, expressed in seconds. This vector must have the same size as `AveragePathGaindB`. If these delays are not a multiple of the sampling period, fractional delay filters are used internally to implement them.
The following fields are applicable when `MIMOCorrelation` is set to `'Custom'`.			
`TxCorre`	Required	Matrix	Correlation between each of the transmit antennas, specified as a *P*-by-*P* complex matrix.
`RxCorre`	Required	Matrix	Correlation between each of the receive antennas, specified as a complex matrix of size `NRxAnts`-by-`NRxAnts`.

Data Types: `struct`

`in` — Input samples

numeric matrix

Input samples, specified as a numeric *T*-by-*P* matrix. *T* is the number of time-domain samples and *P* is the number of transmit antennas. Each column of `in` corresponds to the waveform at each of the transmit antennas.

Data Types: `double | single`
Complex Number Support: Yes

Output Arguments

`out` — Channel output signal

numeric matrix

Channel output signal, returned as a numeric matrix. Each column of `out` corresponds to the waveform at each of the receive antennas. `out` has the same number of rows as the input, `in`.

Data Types: `double` | `single`
Complex Number Support: Yes

`info` — Channel modeling information

structure

Channel modeling information, returned as a structure. `info` contains the following fields.

Parameter Field	Values	Description
`ChannelFilt`	Scalar value	The implementation delay of the internal channel filtering, in samples.
`PathGains`	Numeric array	Complex gain of the discrete channel paths, specified as a numeric array of size *T*-by-*L*-by-*P*-by-`NRxAnts`. • *T* is the number of output samples. • *L* is the number of paths. • *P* is the number of transmit antennas. • `NRxAnts` is the number of receive antennas.
`PathSampleD`	Row vector	Delays of the discrete channel paths. The delays are expressed in samples at the sampling rate specified in `model.SamplingRate`.

Data Types: `struct`

Definitions

Fading Channel Model Delay

The function implements the MIMO multipath fading channel model, as specified in TS 36.101 [1] and TS 36.104 [2]. The transmitted waveform passes through the multipath Rayleigh fading channel model specified by the input structure `model`. The delay profile of `model` is resampled to match the input signal sampling rate. When

the path delays are not a multiple of the sampling rate, fractional delay filters are used internally to implement them. These filters introduce an implementation delay of `info.ChannelFilterDelay` samples. The signal passing through the channel, passes through these filters and incurs the `ChannelFilterDelay`, regardless of the value of the path delays.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.104. "Base Station (BS) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] Dent, P., G. E. Bottomley, and T. Croft. "Jakes Fading Model Revisited." *Electronics Letters*. Vol. 29, Number 13, 1993, pp. 1162–1163.

[4] Pätzold, Matthias, Cheng-Xiang Wang, and Bjørn Olav Hogstad. "Two New Sum-of-Sinusoids-Based Methods for the Efficient Generation of Multiple Uncorrelated Rayleigh Fading Waveforms." *IEEE Transactions on Wireless Communications*. Vol. 8, Number 6, 2009, pp. 3122–3131.

See Also

See Also

`lteDLPerfectChannelEstimate` | `lteHSTChannel` | `lteMovingChannel` | `lteOFDMModulate` | `lteSCFDMAModulate`

Introduced in R2013b

lteFrequencyCorrect

Frequency offset correction

Syntax

```
out = lteFrequencyCorrect(cfg,in,foffset)
```

Description

`out = lteFrequencyCorrect(cfg,in,foffset)` corrects for a specified frequency offset, `foffset`, in the time-domain waveform, `in`, by performing simple frequency modulation (FM). The parameters of the waveform, `in`, are specified in a settings structure, `cfg`, which must contain either the field `NDLRB` or `NULRB` to control whether a downlink or uplink signal is expected in `in`.

The input, `foffset` is the frequency offset, in hertz, present on the waveform, `in`. Therefore, the correction applied is FM modulation by –`foffset`.

Examples

Correct for Specified Frequency Offset

Perform frequency offset estimation and correction on an uplink signal, to which a frequency offset has been applied.

Generate uplink RMC A3-2.

```
[txWaveform,rgrid,cfg] = lteRMCULTool('A3-2',[1;0;0;1],'Fdd',2);
```

Apply an arbitrary frequency offset of 51.2 Hz.

```
t = (0:length(txWaveform)-1).'/cfg.SamplingRate;
txWaveform = txWaveform .* exp(1i*2*pi*51.2*t);
```

Estimate and display the frequency offset.

```
offset = lteFrequencyOffset(cfg,txWaveform);
```

```
disp(['Frequency offset: ' num2str(offset) ' Hz'])
```

```
Frequency offset: 51.2 Hz
```

Correct for the frequency offset.

```
rxWaveform = lteFrequencyCorrect(cfg,txWaveform,offset);
```

Finally, perform SC-FDMA demodulation.

```
rxGrid = lteSCFDMADemodulate(cfg,rxWaveform);
```

Input Arguments

`cfg` — Waveform parameter settings

structure

Waveform parameter settings, specified as a structure. `cfg` must contain either the field `NDLRB`, to specify a downlink configuration, or the field `NULRB`, to specify an uplink configuration.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Positive scalar integer	Number of downlink resource blocks. (N_{RB}^{DL}) Set this parameter field to specify a downlink configuration.
`CyclicPre`	Required	`'Normal'` (default), `'Extended'`	Cyclic prefix length in the downlink Only set this parameter field if you are specifying a downlink configuration.
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL}) Set this parameter field to specify an uplink configuration.

Parameter Field	Required or Optional	Values	Description
`CyclicPre`	Required	`'Normal'` (default), `'Extended'`	Uplink cyclic prefix length. Only set this parameter field if you are specifying an uplink configuration.

Data Types: `struct`

`in` — Time-domain waveform

numeric column vector

Time-domain waveform, specified as a numeric column vector.

Data Types: `double | single`
Complex Number Support: Yes

`foffset` — Waveform frequency offset

scalar value

Waveform frequency offset, specified as a scalar value expressed in Hertz. The correction applied to `in` is FM modulation by –`foffset`.

Data Types: `double`

Output Arguments

`out` — Offset-corrected waveform

numeric column vector

Offset-corrected waveform, returned as a numeric column vector.

Data Types: `double | single`
Complex Number Support: Yes

See Also

See Also

`lteCellSearch | lteDLFrameOffset | lteFrequencyOffset | lteOFDMDemodulate | lteSCFDMADemodulate | lteULFrameOffset`

Introduced in R2014a

lteFrequencyOffset

Frequency offset estimation using cyclic prefix

Syntax

```
foffset = lteFrequencyOffset(cfgdl,waveform)
foffset = lteFrequencyOffset(cfgul,waveform)
[foffset, corr] = lteFrequencyOffset( ___ )
[foffset, corr] = lteFrequencyOffset( ___ ,toffset)
```

Description

`foffset = lteFrequencyOffset(cfgdl,waveform)` estimates the average frequency offset, `foffset`, of the time-domain waveform, `waveform`, by calculating correlation of the cyclic prefix. The parameters of `waveform` are given in the downlink settings structure, `cfgdl`. `cfgdl` must contain the field `NDLRB` to specify that a downlink signal is expected in `waveform`.

`foffset = lteFrequencyOffset(cfgul,waveform)` estimates the average frequency offset, `foffset`, of the time-domain waveform, `waveform`, by calculating correlation of the cyclic prefix. The parameters of `waveform` are given in the uplink settings structure, `cfgul`. `cfgul` must contain the field `NULRB` to specify that an uplink signal is expected in `waveform`.

`[foffset, corr] = lteFrequencyOffset( ___ )` also returns a complex matrix, `corr`, spanning one slot and containing the same number of antennas, or columns, as `waveform`. `corr` is the signal used to extract the timing of the correlation for the estimation of the frequency offset.

`[foffset, corr] = lteFrequencyOffset( ___ ,toffset)` provides control over the position in the correlator output used to estimate the frequency offset. When present `toffset` is the timing offset in samples from the start of the correlator output to the position used for the frequency offset estimation. This input allows a timing offset to be calculated externally on a signal of longer duration than the input `waveform`. Which allows a short-term frequency offset estimate to be obtained while retaining the benefit of a longer-term timing estimate.

Note: If `toffset` is absent, the quality of the internal timing estimate is subject to the length and signal quality of the input `waveform` and, therefore, it may result in inaccurate frequency offset measurements.

Examples

Estimate Frequency Offset

Perform frequency offset estimation and correction on an uplink signal, to which a frequency offset has been applied.

Generate uplink RMC A3-2.

```
[txWaveform,rgrid,cfg] = lteRMCULTool('A3-2',[1;0;0;1],'Fdd',2);
```

Apply an arbitrary frequency offset of 51.2 Hz.

```
t = (0:length(txWaveform)-1).'/cfg.SamplingRate;
txWaveform = txWaveform .* exp(1i*2*pi*51.2*t);
```

Estimate and display the frequency offset.

```
offset = lteFrequencyOffset(cfg,txWaveform);
disp(['Frequency offset: ' num2str(offset) ' Hz'])
```

```
Frequency offset: 51.2 Hz
```

Correct for frequency offset.

```
rxWaveform = lteFrequencyCorrect(cfg,txWaveform,offset);
```

Perform SC-FDMA demodulation.

```
rxGrid = lteSCFDMADemodulate(cfg,rxWaveform);
```

Input Arguments

`cfgdl` — Downlink configuration

structure

Downlink configuration, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following apply when `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NSubframe	Optional	0 (default), nonnegative scalar integer	Subframe number

Data Types: `struct`

`cfgUl` — Uplink configuration

structure

Uplink configuration, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
CyclicPrefixUL	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Parameter Field	Required or Optional	Values	Description
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following apply when `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
`NSubframe`	Optional	0 (default), nonnegative scalar integer	Subframe number

Data Types: `struct`

`waveform` — Input time-domain waveform

numeric column vector

Input time-domain waveform, specified as a numeric column vector.

Data Types: `double | single`
Complex Number Support: Yes

`toffset` — Timing offset

scalar value

Timing offset, specified as a scalar value expressed in samples. Use `toffset` to control the position in the correlator output used to estimate the frequency offset. If `toffset` is absent, or empty, the position of the peak magnitude of the correlator output is used.

Data Types: `double | single`

Output Arguments

`foffset` — Average frequency offset estimate

scalar value

Average frequency offset estimate, returned as a scalar value expressed in Hertz. This function can only accurately estimate frequency offsets of up to ±7.5 kHz (a range of 15 kHz, the subcarrier spacing).

Data Types: `double` | `single`

`corr` — Correlation timing signal

numeric matrix

Correlation timing signal, returned as a numeric matrix. `corr` is a complex matrix that spans one slot and contains the same number of antennas, or columns, as `waveform`. It is the signal used to extract the timing of the correlation for the frequency offset estimation.

Data Types: `double` | `single`
Complex Number Support: Yes

See Also

See Also

`lteCellSearch` | `lteDLFrameOffset` | `lteFrequencyCorrect` | `lteOFDMDemodulate` | `lteSCFDMADemodulate` | `lteULFrameOffset`

Introduced in R2014a

lteHSTChannel

High-speed train MIMO channel propagation conditions

Syntax

```
out = lteHSTChannel(model,in)
```

Description

`out = lteHSTChannel(model,in)` implements the high-speed train (HST) MIMO channel model specified in TS 36.101 [1] and TS 36.104 [2]. The high-speed train propagation condition is composed of a non-fading single path of unit amplitude and zero phase with a changing Doppler shift. The columns of matrix `in` correspond to the channel input waveforms at each transmit antenna. The channel model filters `in` with the characteristics specified in structure `model`. The matrix `out` stores the filtered waveform. Each column of `out` corresponds to the waveform at one of the receive antennas.

Examples

Model High-Speed Train Propagation Channel

Generate a frame and filter it with the high-speed train channel model.

Create a reference channel configuration structure initialized to `'R.10'`. Generate a waveform.

```
rmc = lteRMCDL('R.10');
[txWaveform,txGrid,info] = lteRMCDLTool(rmc,[1;0;1]);
```

Initialize a propagation channel configuration structure for high-speed train profile. Pass the transmission waveform through the propagation channel.

```
chcfg.NRxAnts = 1;
```

```
chcfg.Ds = 100;
chcfg.Dmin = 500;
chcfg.Velocity = 350;
chcfg.DopplerFreq = 5;
chcfg.SamplingRate = info.SamplingRate;
chcfg.InitTime = 0;

rxWaveform = lteHSTChannel(chcfg,txWaveform);
```

Input Arguments

`model` — High-speed train propagation channel model

structure

High-speed train propagation channel model, specified as a structure. `model` must contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NRxAnts`	Required	Positive scalar integer	Number of receive antennas
`Ds`	Required	Numeric scalar	Train-to-eNodeB double initial distance, in meters. `Ds`/2 is initial distance between train and eNodeB, in meters
`Dmin`	Required	Scalar value	eNodeB to railway track distance, in meters
`Velocity`	Required	Scalar value	Train velocity, in kilometers per hour
`DopplerFr`	Required	Scalar value	Maximum *Doppler* frequency, in Hz.
`SamplingF`	Required	Scalar value	Input signal sampling rate, the rate of each sample in the rows of the input matrix, `in`.
`InitTime`	Required	Scalar value	*Doppler* shift timing offset, in seconds

Parameter Field	Required or Optional	Values	Description
`Normalize`	Optional	`'On'` (default), `'Off'`	Transmit antenna number normalization, specified as: • `'On'`, `lteHSTChannel` normalizes the model output by `1/sqrt(P)`, where P is the number of transmit antennas. Normalization by the number of transmit antennas ensures that the output power per receive antenna is unaffected by the number of transmit antennas. • `'Off'`, normalization is not performed.

Data Types: `struct`

`in` — Channel input waveforms at transmit antennas

numeric matrix

Channel input waveforms at transmit antennas, specified as a numeric matrix. `in` has size T-by-P, where P is the number of antennas and T is the number of time-domain samples. These waveforms are filtered with the high-speed train channel model with the Doppler shift as specified in parameter structure `model`.

Data Types: `double | single`
Complex Number Support: Yes

Output Arguments

`out` — Filtered waveform

numeric matrix

Filtered waveform, returned as a numeric matrix. Each column of `out` corresponds to the waveform at one of the receive antennas.

Data Types: `double | single`
Complex Number Support: Yes

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteFadingChannel` | `lteMovingChannel` | `lteOFDMDemodulate` | `lteSCFDMADemodulate`

Introduced in R2013b

lteLayerDemap

Layer demapping onto scrambled and modulated codewords

Syntax

```
out = lteLayerDemap(in,ncw)
out = lteLayerDemap(in,ncw,txscheme)
out = lteLayerDemap(chs,in)
```

Description

`out = lteLayerDemap(in,ncw)` performs the layer demapping required to undo the processing described in TS 36.211, Sections 5.3.2A and 6.3.3 [1]. The function returns `out`, a cell array containing one, or two vectors of modulation symbols, one for each codeword. The function demaps the `NU` layers specified in the input matrix, `in`, into `ncw` codewords using `'Port0'` transmission scheme if `NU = 1` and `'SpatialMux'` transmission scheme otherwise.

`out = lteLayerDemap(in,ncw,txscheme)` performs the layer demapping using the transmission scheme, `txscheme`.

`out = lteLayerDemap(chs,in)` performs layer demapping according to the parameters specified in the channel transmission configuration structure, `chs`.

Examples

Demap Codeword for Transmit Diversity

Map a codeword onto four symbols for 'TxDiversity' transmission scheme. Recover the codeword by demapping the four layers onto one codeword.

```
nCodewords = 1;
codeword = ones(16,1);
nLayers = 4;
txScheme = 'TxDiversity';

layerMap = lteLayerMap(codeword,nLayers,txScheme);
```

```
out = lteLayerDemap(layerMap,nCodewords,txScheme);
```

Input Arguments

in — Modulation symbols

numeric matrix

Modulation symbols, specified as an *M*-by-*NU* numeric matrix consisting of *M* modulation symbols for *NU* transmission layers. You can generate this matrix using `lteDLDeprecode` or `ltePUSCHDeprecode`.

Data Types: `double`
Complex Number Support: Yes

ncw — Number of codewords

1 | 2

Number of codewords, specified as 1 or 2.

Data Types: `double`

txscheme — Transmission scheme

`'Port0' | 'TxDiversity' | 'CDD' | 'SpatialMux' | 'MultiUser' | 'Port5' | 'Port7-8' | 'Port8' | 'Port7-14'`

PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.

Transmission scheme	Description
'Port8'	Single-antenna port, port 8
'Port7-14'	Up to eight layer transmission, ports 7–14

When provided as an optional input this setting overrides any setting provided in `chs.TxScheme`.

Data Types: `char`

chs — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
TxScheme	Optional	'Port0', 'TxDiversity', 'CDD', 'Spatia 'Multiu 'Port5' 'Port7- 'Port8' 'Port7- The defa TxSchem 'Port0' NLayers 'Spatia otherwis	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
'Port0'	Single antenna port, port 0
'TxDiversity'	Transmit diversity
'CDD'	Large delay cyclic delay diversity scheme
'SpatialMux'	Closed loop spatial multiplexing
'MultiUser'	Multi-user MIMO
'Port5'	Single-antenna port, port 5
'Port7-8'	Single-antenna port, port 7, when **NLayers** = 1. Dual layer transmission, ports 7 and 8, when **NLayers** = 2.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table><tr><th>Transmission scheme</th><th>Description</th></tr><tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr><tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr></table></td></tr>
<tr><td colspan="4">Also specify one of these fields:</td></tr>
<tr><td>Modulation</td><td>Required, if NCodewords is not set</td><td>'QPSK', '16QAM', '64QAM', or '256QAM'</td><td>Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.</td></tr>
<tr><td>NCodewords
(see 1)</td><td>Required, if Modulation is not set</td><td>1, 2</td><td>Number of codewords</td></tr>
<tr><td colspan="4">1 The number of codewords is established from the number of modulation formats in the Modulation field. This allows the correct number of codewords to be returned by using the channel transmission configuration structure chs as provided to the ltePDSCH or ltePUSCH function on the transmit side. Alternatively the number of codewords can be directly specified in the NCodewords field. The NCodewords field takes precedence if present.</td></tr>
</table>

Output Arguments

out — Modulation symbols

cell array of one or two vectors

Modulation symbols, specified as a cell array of one or two vectors. The cell array contains one or two vectors of symbols, one for each codeword.

Data Types: cell

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLDeprecode` | `lteLayerMap` | `ltePHICHDeprecode` | `ltePUSCHDeprecode` | `lteSymbolDemodulate` | `lteULDeprecode`

Introduced in R2014a

lteLayerMap

Layer mapping of modulated and scrambled codewords

Syntax

```
out = lteLayerMap(in,nu)
out = lteLayerMap(in,nu,txscheme)
out = lteLayerMap(chs,in)
```

Description

`out = lteLayerMap(in,nu)` performs layer mapping of the codeword or codewords, `in`, onto `nu` layers. It carries out the layer mapping according to TS 36.211 [1], Sections 5.3.2A and 6.3.3. The function returns an *M*-by-`nu` matrix consisting of the modulation symbols for transmission upon `nu` layers. These transmission layers are formed by multiplexing the modulation symbols from either one or two codewords. The overall operation of the layer mapper is the transpose of that defined in the specification. In other words, the symbols for layers lie in columns rather than rows.

`out = lteLayerMap(in,nu,txscheme)` performs layer mapping using the transmission scheme, `txscheme`.

`out = lteLayerMap(chs,in)` performs layer mapping of the codeword or codewords, `in`, according to the parameters in the channel transmission configuration structure, `chs`.

Examples

Map Codeword for Spatial Multiplexing

Map one codeword to four layers for the spatial multiplexing transmission scheme.

When no transmission scheme is specified, the default layer mapping is spatial multiplexing.

```
out = lteLayerMap(ones(40,1),4);
sizeOut = size(out)
```

```
sizeOut =

    10     4
```

Map Codeword for Transmit Diversity

Map one codeword to four layers for the transmit diversity transmission scheme.

```
out = lteLayerMap(ones(40,1),4,'TxDiversity');
sizeOut = size(out)
```

```
sizeOut =

    10     4
```

Input Arguments

`in` — Scrambled and modulated codeword or codewords

numeric vector | cell array of numeric vectors

Scrambled and modulated codeword or codewords, specified as a numeric vector or a cell array of numeric vectors. As a cell array, `in` contains one or two vectors of modulation symbols that result from the scrambling and modulation of DL-SCH or UL-SCH codewords.

`nu` — Number of transmission layers

integer from 1 to 8

Number of transmission layers, specified as a scalar integer from 1 to 8.

Data Types: `double`

`txscheme` — Transmission scheme

`'Port0'` | `'TxDiversity'` | `'CDD'` | `'SpatialMux'` | `'MultiUser'` | `'Port5'` | `'Port7-8'` | `'Port8'` | `'Port7-14'` | optional

PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

This optional input takes precedence over `chs.TxScheme`.

Data Types: `char`

`chs` — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`NLayers`	Required	Integer from 1 to 8	Number of transmission layers.

`TxScheme`	Optional	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, `'MultiUser'`, `'Port5'`, `'Po`
		`'Port8'`, `'Po`
		
		The default `Tx`
		is `'Port0'` for
			PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity

Parameter Field	Required or Optional	Values	Description
		`NLayers` = 1, a `'SpatialMux` otherwise.	

Transmission scheme	Description
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

Output Arguments

`out` — Modulation symbols

numeric matrix

Modulation symbols, returned as a numeric matrix. `out` is an *M*-by-`nu` matrix consisting of *M* modulation symbols for transmission upon `nu` layers.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLPrecode` | `lteLayerDemap` | `ltePHICHPrecode` | `ltePUSCHPrecode` | `lteSymbolModulate` | `lteULPrecode`

Introduced in R2014a

lteMCS

Modulation and code scheme lookup

Use `lteMCS` to look up the Modulation and Coding Scheme (MCS) information as defined by MCS index mapping to modulation and TBS index tables in TS 36.213 [1] Table 7.1.7.1-1, Table 7.1.7.1-1A, and Table 8.6.1-1.

Syntax

```
[itbs,mod,rv]=lteMCS()
[itbs,mod,rv]=lteMCS(imcs)

[itbs,mod,rv]= lteMCS(table)
[itbs,mod,rv]=lteMCS(imcs,table)
```

Description

`[itbs,mod,rv]=lteMCS()` returns the MCS information for the PDSCH for all 32 `imcs` entries in TS 36.213 [1], Table 7.1.7.1-1.

`[itbs,mod,rv]=lteMCS(imcs)` returns the MCS information for the PDSCH for one or more rows of the TS 36.213 [1], Table 7.1.7.1-1 as specified by the `imcs` vector.

`[itbs,mod,rv]= lteMCS(table)` returns the MCS information associated with `table` specified.

The columns of the indexed MCS table entries are returned as separate outputs given by the transport block size index `itbs` (0,...,33), modulation type `mod` ('QPSK','16QAM','64QAM','256QAM') and in the case of PUSCH, the redundancy version index `rv`. Reserved values of `itbs` are returned as `NaN` and reserved values of `mod` are returned as the empty character vector. The `rv` index is not defined in the PDSCH tables and this value is set to 0 in these cases.

`[itbs,mod,rv]=lteMCS(imcs,table)` returns one or more rows of the specified `table` as indicated in the vector `imcs`. The values of `imcs` must be in the range 0, ..., 31. If `imcs = –1`, the function interprets the value as a discontinuous transmission (DTX),

indicating no data should be sent. See TS 36.101 [2], Annex A.4. For `imcs = -1`, values of `itbs = -1` (for which `lteTBS` yields `tbs = 0`) and `mod = 'QPSK'` are returned. For convenience, if `imcs` is scalar then `mod` is returned as a single character vector rather than a single element cell array of character vectors.

Examples

Return the Transport Block Size Modulation Order

Return the Transport Block Size index and modulation order for IMCS=17.

```
[ITBS,Modulation] = lteMCS(17)
```

```
ITBS =

    15


Modulation =

    '64QAM'
```

Get MCS from PDSCH Table 2

Return the PDSCH transport block size index and modulation scheme for the set of indices `imcs` = 20,...,27 used to configure a first transport block transmission with Release 12 256QAM modulation.

```
[ITBS,Modulation] = lteMCS(20:27,'PDSCHTable2')
```

```
ITBS =

    25    27    28    29    30    31    32    33


Modulation =

  1×8 cell array

  Columns 1 through 6
```

```
    '256QAM'    '256QAM'    '256QAM'    '256QAM'    '256QAM'    '256QAM'

  Columns 7 through 8

    '256QAM'    '256QAM'
```

Input Arguments

`imcs` — Modeling and coding scheme indices

vector | 0, ..., 31 | –1

Modeling and coding scheme indices, specified as a vector of values from 0 through 31.

If `imcs = –1`, the function interprets the value as a discontinuous transmission (DTX) where `itbs=-1` and `mod='QPSK'`. If `imcs` is scalar, `mod` is returned as a single character vector instead of a single element cell array of character vectors.

Data Types: `double`

`table` — MCS index mapping table

`'PDSCH' | 'PDSCHTable2' | 'PUSCH'`

MCS index mapping table, specified as a character vector, identifying the desired table from TS 36.213 [1]:

- `'PDSCH'` indicates PDSCH, Table 7.1.7.1-1
- `'PDSCHTable2'` indicates Table 2 for PDSCH, Table 7.1.7.1-1A, which was added in 3GPP Release 12.
- `'PUSCH'` indicates PUSCH, Table 8.6.1-1

Output Arguments

`itbs` — Transport block size indices

column vector | 0,...,33 | -1

Transport block size indices, returned as a column vector of values from 0 through 33 or -1. If `imcs = -1`, the function interprets the value as a discontinuous transmission (DTX), where `itbs = -1`, for which `lteTBS` yields `tbs = 0`.

`mod` — Modulation orders
'QPSK' | '16QAM' | '64QAM' | '256QAM'

Modulation orders, returned as a single column cell array of character vectors. `imcs = -1`, is interpreted as a discontinuous transmission (DTX), and the value of `mod= 'QPSK'`. If `imcs` is a scalar, `mod` is returned as a single character vector instead of a single element cell array of character vectors.

`rv` — Redundancy version
column vector | 0 | 1 | 2 | 3

Redundancy version, returned as a column vector, specified as `(0, 1, 2, or 3)`, associated with specified `imcs` from TS 36.213 [1], Table 8.6.1-1.

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.101. "User Equipment (UE) radio transmission and reception" *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also
`lteDLSCH` | `lteDLSCHDecode` | `lteTBS` | `lteULSCH` | `lteULSCHDecode`

Introduced in R2014b

lteMIB

Master information block encoding and decoding

Syntax

```
mib = lteMIB(enb)
enb = lteMIB(mib)
enb = lteMIB(mib,enb)
```

Description

`mib = lteMIB(enb)` allows encoding and decoding of the master information block (MIB) broadcast control channel (BCCH) message from cell-wide settings.

It creates the 24-bit-long MIB message, `mib`, from the fields of cell-wide settings structure, `enb`. See TS 36.331 [1], Sections 5.2.1.1 and 6.2.2 for further description of the MIB.

`enb = lteMIB(mib)` performs the inverse processing of the preceding syntax, taking as input the MIB message bits, `mib`, and creating the cell-wide settings structure, `enb`.

`enb = lteMIB(mib,enb)` includes in the `enb` output structure any fields contained in the `enb` input structure. For any of the fields already present in the input structure, the value decoded from the MIB replaces the existing value.

Note: Within the MIB, the system frame number (SFN) is stored as `floor(SFN/4)`. Therefore, when `enb` is created from an MIB bit sequence, `enb.NFrame` satisfies `mod(enb.NFrame,4)==0` and the frame number modulo 4 must be established by other means. For example, this can be done by using the `nfmod4` output of `ltePBCHDecode`.

Examples

Decode MIB Message Bits

Decode a set of master information block (MIB) message bits.

Decode the MIB message bits in the column vector `mib`.

```
mib = [0,1,0,0,1,0,1,1,0,0,1,1,1,1,0,0,0,0,0,0,0,0,0,0].';
enb = lteMIB(mib)
```

```
enb =

  struct with fields:

           NDLRB: 25
    PHICHDuration: 'Normal'
              Ng: 'One'
          NFrame: 828
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` can contain the following fields.

`NDLRB` — Number of downlink resource blocks

scalar value (6...110)

Number of downlink resource blocks, specified as a positive integer scalar value. `NDLRB` must be between 6 and 110.

Note: If `NDLRB` is a nonstandard bandwidth, not one of the set {6,15,25,50,75,100}, all ones are inserted into the first 3 bits, the *dl-Bandwidth* bit field, of the MIB message, `mib`.

Data Types: `double`

`Ng` — HICH group multiplier

`'Sixth'` (default) | optional | `'Half'` | `'One'` | `'Two'`

HICH group multiplier, specified as `'Sixth'`, `'Half'`, `'One'`, or `'Two'`.

Data Types: `char`

`NFrame` — Frame number

0 (default) | optional | nonnegative scalar integer

Frame number, specified as a nonnegative scalar integer.

Data Types: `double`

`PHICHDuration` — PHICH duration

`'Normal'` (default) | optional | `'Extended'`

PHICH duration, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

`mib` — MIB message bit sequence

24-bit column vector

MIB message bit sequence, specified as a 24-bit column vector.

Note: If the first 3 bits, the *dl-Bandwidth* bit field, of the MIB message do not contain the equivalent of a decimal between 0 and 5 (MSB first, corresponding to the RB set {6,15,25,50,75,100}), the returned `NDLRB` is 0.

Data Types: `double` | `int8` | `logical`

Output Arguments

`mib` — MIB message

24-bit column vector

MIB message, returned as a 24-bit column vector.

Note: If the `enb.NDLRB` input parameter field is a nonstandard bandwidth, not one of the set {6,15,25,50,75,100}, the first 3 bits of `mib`, the *dl-Bandwidth* bit field, are all ones.

Data Types: `int8`

`enb` — Cell-wide settings created from MIB

structure

Cell-wide settings created from MIB, returned as a structure. `enb` contains the following fields.

`NDLRB` — Number of downlink resource blocks

nonnegative scalar integer

Number of downlink resource blocks, returned as a nonnegative scalar integer.

Note: If the first 3 bits, the *dl-Bandwidth* bit field, of the input MIB message, `mib`, do not contain the equivalent of a decimal between 0 and 5 (MSB first, corresponding to the RB set {6,15,25,50,75,100}), `NDLRB` is 0. The MIB message should have 24 bits. Longer messages are truncated to 24 elements, while shorter messages are zero padded.

Data Types: `int32`

`PHICHDuration` — PHICH duration

`'Normal' | 'Extended'`

PHICH duration, returned as `'Normal'` or `'Extended'`.

Data Types: `char`

`Ng` — HICH group multiplier

`'Sixth' | 'Half' | 'One' | 'Two'`

HICH group multiplier, specified as `'Sixth'`, `'Half'`, `'One'`, or `'Two'`.

Data Types: `char`

`NFrame` — Frame number

scalar value

Frame number, specified as a scalar value.

Data Types: `int32`

Data Types: `struct`

References

[1] 3GPP TS 36.331. “Radio Resource Control (RRC); Protocol specification.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCH` | `lteBCHDecode` | `lteSLMIB`

Introduced in R2014a

lteMovingChannel

Moving channel propagation conditions

Syntax

```
out = lteMovingChannel(model,in)
```

Description

`out = lteMovingChannel(model,in)` implements the moving propagation conditions specified in TS 36.104 [1]. The filtered waveform is stored in matrix `out`, where each column corresponds to the waveform at each of the receive antennas. The columns of matrix `in` correspond to the channel input waveforms at each transmit antenna. The input waveforms are filtered with the delay profiles as specified in the parameter structure `model`. The delay profiles are resampled to match the input signal sampling rate. The modeling process introduces delay on top of the channel group delay.

The time difference between the first multipath component and the reference time (assumed to be 0) follows a sinusoidal characteristic.

$$\Delta\tau = \frac{A}{2}(1+\sin(\Delta\omega(t+t_0)))$$

Where the offset t_0 is

$$t_0 = InitTime + \frac{3\pi}{2(\Delta\omega)}$$

If `model.InitTime` is 0, the delay of the first multipath component is 0. If $t = 0$, $\Delta\tau = 0$. Relative delay between all multipath components is fixed.

Two moving propagation scenarios are specified in TS 36.104 [1], Annex B.4:

- Scenario 1 implements an extended typical urban with 200 Hz Doppler shift (ETU200) Rayleigh fading model with changing delays. The Rayleigh fading model

can be modeled using two different methods as described in `model.ModelType`. For Scenario 1, `model.InitTime` also controls the fading process timing offset. Changing this value produces parts of the fading process at different points in time.

- Scenario 2 consists of a single non-fading path with unit amplitude and zero phase degrees with changing delay. No AWGN is introduced internally in this model.

Examples

Model Moving Propagation Channel

Generate a frame and filter it with the LTE moving propagation channel.

```
rmc = lteRMCDL('R.10');
[txWaveform,txGrid,info] = lteRMCDLTool(rmc,[1;0;1]);
chcfg.Seed = 1;
chcfg.NRxAnts = 1;
chcfg.MovingScenario = 'Scenario1';
chcfg.SamplingRate = 100000;
chcfg.InitTime = 0;
rxWaveform = lteMovingChannel(chcfg,txWaveform);
```

Input Arguments

`model` — Moving channel model

structure

Moving channel model, specified as a structure. `model` must contain the following fields.

Parameter Field	Required or Optional	Values	Description
`Seed`	Required	Scalar value	Random number generator seed. To use a random seed, set `Seed` to zero. **Note:**

Parameter Field	Required or Optional	Values	Description
			• To produce distinct results, use `Seed` values in the range $0 \ldots 2^{31} \quad 1 \quad (\frac{K(K \quad 1)}{2})$ Where $K = P \times$ `model.NRxAnts`, the product of the number of transmit and receive antennas. `Seed` values outside of this recommended range should be avoided as they may result in random sequences that repeat results produced using Seed values inside the recommended range. • The moving channel random seed behavior is not affected by the state of MATLAB random number generators, `rng`.
`NRxAnts`	Required	Positive scalar integer	Number of receive antennas
`MovingSce`	Required	`'Scenario1'`, `'Scenario2'`	Moving channel scenario
`SamplingR`	Required	Numeric scalar	Input signal sampling rate, the rate of each sample in the rows of the input matrix, `in`.
`InitTime`	Required	Scalar value	Fading process and timing adjustment offset, in seconds

Parameter Field	Required or Optional	Values	Description
Normalize	Optional	`'On'` (default), `'Off'`	Transmit antenna number normalization, specified as: • `'On'`, `lteFadingChannel` normalizes the model output by `1/sqrt(P)`, where P is the number of transmit antennas. Normalization by the number of transmit antennas ensures that the output power per receive antenna is unaffected by the number of transmit antennas. • `'Off'`, normalization is not performed.
The following fields are required or optional (as indicated) only if `MovingScenario` is set to `'Scenario1'`.			
NTerms	Optional	16 (default) scalar power of 2	Number of oscillators used in fading path modeling.
ModelTy	Optional	`'GMEDS'` (default), `'Dent'`	Rayleigh fading model type. • `'GMEDS'`, the Rayleigh fading is modeled using the Generalized Method of Exact Doppler Spread (GMEDS), as described in [3]. • `'Dent'`, the Rayleigh fading is modeled using the modified Jakes fading model described in [2] **Note:** `ModelType = 'Dent'` is not recommended. Use `ModelType = 'GMEDS'` instead.

Parameter Field	Required or Optional	Values	Description
`Normali`	Optional	`'On'` (default), `'Off'`	Model output normalization. • `'On'`, the model output is normalized such that the average power is unity. • `'Off'`, the average output power is the sum of the powers of the taps of the delay profile.

Data Types: `struct`

`in` — Input samples

numeric matrix

Input samples, specified as a numeric matrix. `in` has size T-by-P, where P is the number of transmit antennas and T is the number of time-domain samples. These waveforms are filtered with the delay profiles as specified in the parameter structure `model`. These delay profiles are resampled to match the input signal sampling rate. Each column of `in` corresponds to the waveform at each of the transmit antennas.

Data Types: `double | single`
Complex Number Support: Yes

Output Arguments

`out` — Filtered waveform

numeric matrix

Filtered waveform, returned as a numeric matrix. Each column of `out` corresponds to the waveform at each of the receive antennas.

Data Types: `double | single`
Complex Number Support: Yes

References

[1] 3GPP TS 36.104. “Base Station (BS) radio transmission and reception.” *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

[2] Dent, P., G. E. Bottomley, and T. Croft. "Jakes Fading Model Revisited." *Electronics Letters*. Vol. 29, 1993, Number 13, pp. 1162–1163.

[3] Pätzold, Matthias, Cheng-Xiang Wang, and Bjørn Olav Hogstad. "Two New Sum-of-Sinusoids-Based Methods for the Efficient Generation of Multiple Uncorrelated Rayleigh Fading Waveforms." *IEEE Transactions on Wireless Communications*. Vol. 8, 2009, Number 6, pp. 3122–3131.

See Also

See Also

`lteFadingChannel` | `lteHSTChannel` | `lteOFDMModulate` | `lteSCFDMAModulate`

Introduced in R2013b

lteOFDMDemodulate

OFDM demodulation

Syntax

```
grid = lteOFDMDemodulate(enb,waveform)
grid = lteOFDMDemodulate(enb,waveform,cpfraction)
```

Description

`grid = lteOFDMDemodulate(enb,waveform)` performs OFDM demodulation of the time-domain waveform, `waveform`, given the cell-wide settings structure, `enb`.

The demodulation performs one FFT operation per received OFDM symbol to recover the received subcarrier values. These values are then used to construct each column of the output resource array, `grid`. The FFT is positioned partway through the cyclic prefix to allow for a certain degree of channel delay spread while avoiding the overlap between adjacent OFDM symbols. The particular position of the FFT chosen here avoids the OFDM symbol overlapping used in `lteOFDMModulate`. Since the FFT is performed away from the original zero-phase point on the transmitted subcarriers, a phase correction is applied to each subcarrier after the FFT. Then, the received subcarriers are extracted from the FFT bins, skipping unused frequency bins at either end of the spectrum and the central DC frequency bin. These extracted subcarriers form the columns of the output `grid`.

The sampling rate of the time-domain waveform, `waveform`, must be the same as used in `lteOFDMModulate` for the specified number of resource blocks, `NDLRB`. `waveform` must also be time-aligned such that the first sample is the first sample of the cyclic prefix of the first OFDM symbol in a subframe. This alignment can be achieved by using `lteDLFrameOffset`.

`grid = lteOFDMDemodulate(enb,waveform,cpfraction)` allows specification of the position of the demodulation through the cyclic prefix.

Examples

Perform OFDM Demodulation

Perform modulation and demodulation of Test Model 1.1 5MHz.

```
cfg = lteTestModel('1.1','5MHz');
txWaveform = lteTestModelTool(cfg);
rxGrid = lteOFDMDemodulate(cfg,txWaveform);
```

Input Arguments

`enb` — Cell-wide settings
structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

`waveform` — Time-domain waveform
numeric matrix

Time-domain waveform, specified as a numeric matrix of size T-by-P, where P is the number of antennas and T is the number of time-domain samples. $T = K \times 30720 / 2048 \times N_{\text{fft}}$, where N_{fft} is the IFFT size and K is the number of subframes in the input, `grid`. `waveform` must be time-aligned such that the first sample is the first sample of the cyclic prefix of the first OFDM symbol in a subframe.

Data Types: `double`
Complex Number Support: Yes

`cpfraction` — Demodulation position

0.55 (default) | scalar value

Demodulation position, specified as a scalar from 0 through 1, with 0 representing the start of the cyclic prefix and 1 representing the end of the cyclic prefix. The default value, 0.55, allows for the default level of windowing in `lteOFDMModulate`

Data Types: `double`

Output Arguments

`grid` — Resource elements

3-D numeric array

Resource elements, returned as a 3-D numeric array. `grid` stores the resource elements for a number of subframes across all configured antenna ports. It is an *M*-by-*N*-by-*P* array, where *M* is the number of subcarriers, *N* is the number of OFDM symbols, and *P* is the number of antennas.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`lteDLChannelEstimate` | `lteDLFrameOffset` | `lteDLPerfectChannelEstimate` | `lteOFDMInfo` | `lteOFDMModulate`

Introduced in R2014a

lteOFDMModulate

OFDM modulation

Syntax

```
[waveform,info] = lteOFDMModulate(enb,grid)
[waveform,info] = lteOFDMModulate(enb,grid,windowing)
```

Description

`[waveform,info] = lteOFDMModulate(enb,grid)` performs DC subcarrier insertion, inverse fast Fourier transform (IFFT) calculation, cyclic prefix insertion, and optional raised cosine windowing and overlapping of adjacent OFDM symbols of the complex symbols in the resource array, `grid`. `grid` is a 3-D array containing the resource elements (REs) for a number of subframes across all configured antenna ports, as described in "Data Structures". It could also be multiple concatenated matrices to give multiple subframes, using concatenation across the columns or second dimension. The antenna planes in `grid` are each OFDM modulated to yield the columns of the output `waveform`.

`grid` can span multiple subframes. Windowing and overlapping are applied between all adjacent OFDM symbols, including the last of one subframe and the first of the next. Therefore, a different result is obtained than if `lteOFDMModulate` is called on individual subframes and then those time-domain waveforms are concatenated. In that case, the resulting waveform has discontinuities at the start or end of each subframe. It is recommended that all subframes for OFDM modulation first be concatenated before calling `lteOFDMModulate` on the resulting multi-subframe array. However, individual subframes can be OFDM modulated and the resulting multi-subframe time-domain waveform created by manual overlapping.

`[waveform,info] = lteOFDMModulate(enb,grid,windowing)` allows control of the number of windowed and overlapped samples used in the time-domain windowing, specified by the `windowing` parameter. The value of `enb.Windowing`, if present, is ignored, and the output, `info.Windowing` is set to `windowing`.

Examples

Perform OFDM Modulation

Perform OFDM modulation of one subframe of random uniformly-distributed noise using a 10 MHz two-antenna configuration.

```
enb = struct('NDLRB',50,'CyclicPrefix','Normal','CellRefP',2);
dims = lteDLResourceGridSize(enb);
regrid = reshape(lteSymbolModulate(randi([0,1],prod(dims)*2,1), ...
    'QPSK'),dims);
waveform = lteOFDMModulate(enb,regrid);
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Windowing`	Optional	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied See Note:

Note: If `enb.Windowing` is absent, a default value for the number of windowed and overlapped samples is used. The default value is chosen as a function of `enb.NDLRB` to compromise between the effective duration of cyclic prefix, and thus

the channel delay spread tolerance, and the spectral characteristics of the transmitted signal, not considering any additional FIR filtering. The value used is returned in `info.Windowing`. If `enb.Windowing` is present, it must be even. The issues concerning concatenation of subframes before OFDM modulation do not apply when `enb.Windowing` is zero.

Data Types: `struct`

`grid` — Resource elements

3-D numeric array

Resource elements, specified as a 3-D numeric array. `grid` stores the resource elements for a number of subframes across all configured antenna ports. `grid` is an *M*-by-*N*-by-*P* array, where *M* is the number of subcarriers, *N* is the number of OFDM symbols, and *P* is the number of antennas.

M must be 12 ×`enb.NDLRB`, where `enb.NDLRB` must be from 6 through 110. *N* must be a multiple of the number of symbols in a subframe, *L*, where *L* is 14 for normal cyclic prefix and 12 for extended cyclic prefix.

Data Types: `double`
Complex Number Support: Yes

`windowing` — OFDM sample span

even scalar integer

OFDM sample span, specified as an even scalar integer. This input argument controls the number of windowed and overlapped samples used in the time-domain windowing. This value overwrites the value of the parameter field `enb.Windowing`, if present.

Data Types: `double`

Output Arguments

`waveform` — OFDM modulated waveform

numeric matrix

OFDM modulated waveform, returned as a numeric matrix of size *T*-by-*P*, where *P* is the number of antennas and *T* is the number of time-domain samples.

$T = K \times 30720 / 2048 \times N_{\text{fft}}$ where N_{fft} is the IFFT size and K is the number of subframes in the input `grid`. N_{fft} is a function of the number of resource blocks (NRB), as shown in the following table.

NRB	N_{fft}
6	128
15	256
25	512
50	1024
75	2048
100	2048

In general, N_{fft} is the smallest power of 2 greater than or equal to `12*NRB/0.85`. It is the smallest FFT that spans all subcarriers and results in a bandwidth occupancy, `12*NRB/Nfft`, of no more than 85%.

Data Types: `double`
Complex Number Support: Yes

`info` — OFDM modulated waveform information

structure

OFDM modulated waveform information, returned as a structure. `info` contains the following fields.

`SamplingRate` — Time-domain waveform sampling rate

scalar value

Time-domain waveform sampling rate, returned as a scalar value.
`SamplingRate` = 30.72 MHz / 2048 × N_{fft}.

Data Types: `double`

`Nfft` — Number of FFT points

scalar power of 2

Number of FFT points, returned as a scalar power of 2. `Nfft` is the smallest power of 2 greater than or equal to 12 × `NDLRB` / 0.85. It is the smallest FFT that spans all

subcarriers and results in a bandwidth occupancy (12 × NDLRB / N_{fft}) of no more than 85%.

Data Types: uint32

Windowing — OFDM sample span

even integer scalar

OFDM sample span, returned as an even integer scalar. This parameter is the number of time-domain samples over which windowing and overlapping of OFDM symbols are applied.

Data Types: int32

CyclicPrefixLengths — Cyclic prefix length

even integer scalar

Cyclic prefix length (in samples) of each OFDM symbol in a subframe.

info.Nfft	CyclicPrefixLengths	
	for CyclicPrefix = 'Normal'	for CyclicPrefix = 'Extended'
2048	[160 144 144 144 144 144 144 160 144 144 144 144 144 144]	[512 512 512 512 512 512 512 512 512 512 512 512]
1024	[80 72 72 72 72 72 72 80 72 72 72 72 72 72]	[256 256 256 256 256 256 256 256 256 256 256 256]
512	[40 36 36 36 36 36 36 40 36 36 36 36 36 36]	[128 128 128 128 128 128 128 128 128 128 128 128]
256	[20 18 18 18 18 18 18 20 18 18 18 18 18 18]	[64 64 64 64 64 64 64 64 64 64 64 64]
128	[10 9 9 9 9 9 9 10 9 9 9 9 9 9]	[32 32 32 32 32 32 32 32 32 32 32 32]

Note: For info.Nfft < 2048, info.CyclicPrefixLengths are the CyclicPrefixLengths for info.Nfft = 2048 scaled by info.Nfft / 2048.

Data Types: uint32

Data Types: `struct`

Algorithms

Windowing

The use of the IFFT within the OFDM modulator constitutes the use of a rectangular pulse shape. This use of the IFFT means that discontinuities occur from one OFDM symbol to the next, resulting in out of band emissions. (Alternatively, considering the frequency domain, the frequency response of this rectangular pulse shape is a sinc pulse.) The discontinuities between OFDM symbols can be reduced by using windowing, which smooths the transitions between OFDM symbols. Within LTE System Toolbox, the windowing is performed as follows:

For **`Windowing`** = N samples, the cyclic prefix added to the nominal OFDM symbol extends by N additional samples.

This extended waveform is windowed by pointwise multiplication in the time domain with a raised cosine window, which applies a taper to the first N and last N samples, with all other values being 1. The y values in the first N samples are:

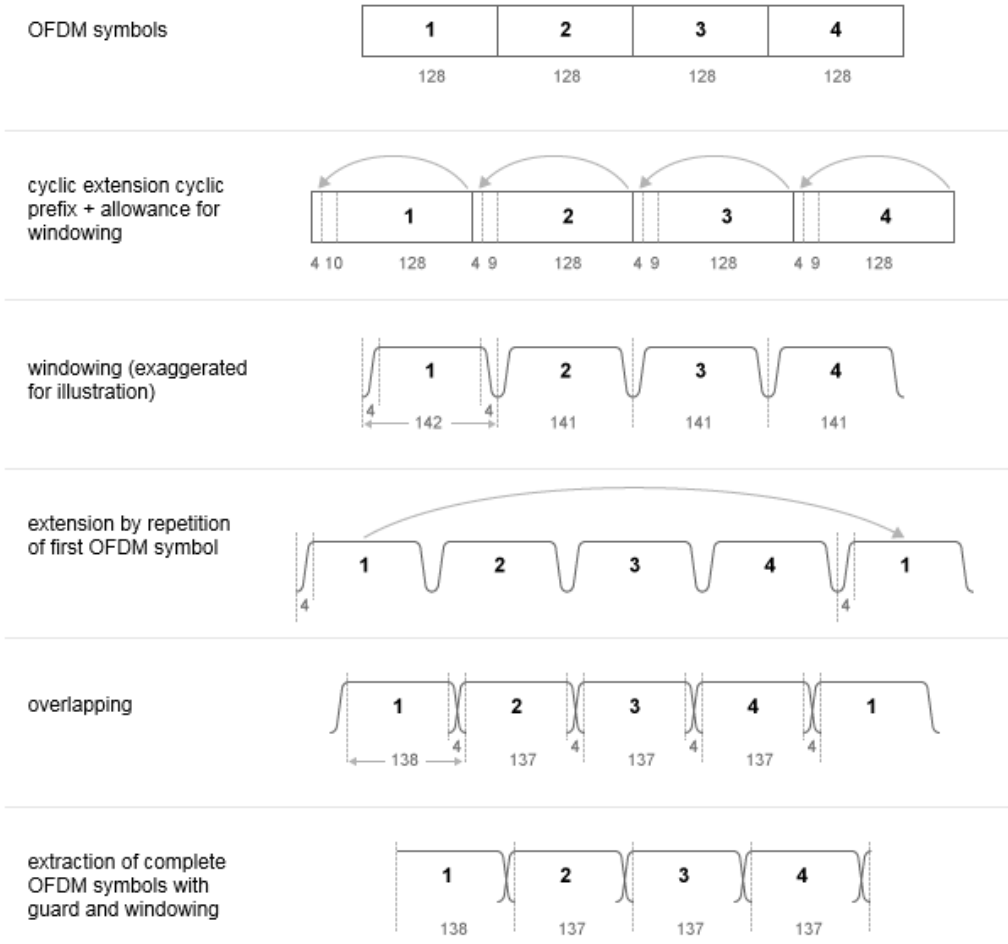
$$y = \frac{1}{2}\left(1 - \sin\left(\pi \frac{N + 1 - 2i}{2N}\right)\right), \text{ where } i = 1 \ldots N$$

The values in the last N samples are the same values in reverse order.

The windowed OFDM symbols are then overlapped by commencing transmission of each windowed OFDM symbol N samples before the end of the previous OFDM symbol. This overlapping ensures that the time between OFDM symbols is maintained as required by the standard. The taper at the start of the first OFDM symbol for transmission is removed and is overlapped with the taper at the end of the last OFDM symbol.

Processing

The processing performed by this function is illustrated in the following diagram.



The number of samples used for windowing depends on the number of resource blocks and whether the cyclic prefix length is normal or extended. The number of samples is chosen in accordance with the *maximum* values implied by TS 36.101 [1], Tables F.5.3-1, and F.5.4-1.

Number of resource blocks (NRB)	Windowing samples for normal cyclic prefix	Windowing samples for extended cyclic prefix
6	4	4
15	6	6
25	4	4
50	6	6
75	8	8
100	8	8

The number of windowing samples is a compromise between the effective duration of cyclic prefix, and therefore the channel delay spread tolerance, and the spectral characteristics of the transmitted signal, not considering any additional FIR filtering. For a larger amount of windowing, the effective duration of the cyclic prefix is reduced but the transmitted signal spectrum has smaller out-of-band emissions.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLResourceGrid` | `lteFadingChannel` | `lteHSTChannel` | `lteMovingChannel` | `lteOFDMDemodulate` | `lteOFDMInfo`

Introduced in R2014a

lteOFDMInfo

OFDM modulation related information

Syntax

```
info = lteOFDMInfo(enb)
```

Description

`info = lteOFDMInfo(enb)` provides information related to the OFDM modulation performed by `lteOFDMModulate`, given the cell-wide settings structure, `enb`.

Examples

Get Information Related to OFDM Modulation

Find the sampling rate of a 50RB, corresponding to 10 MHz waveform after OFDM modulation.

```
enb = struct('NDLRB',50,'CyclicPrefix','Normal');
lteOFDMInfo(enb)
```

```
ans =

  struct with fields:

          SamplingRate: 15360000
                  Nfft: 1024
             Windowing: 6
    CyclicPrefixLengths: [80 72 72 72 72 72 72 80 72 72 72 72 72 72]
```

Input Arguments

enb — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Windowing`	Optional	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied

Data Types: `struct`

Output Arguments

`info` — OFDM information

structure

OFDM information, returned as a structure. `info` contains the following fields.

`SamplingRate` — Sampling rate of the OFDM modulator

integer scalar value

Sampling rate of the OFDM modulator, returned as an integer scalar value.

Data Types: `double`

`Nfft` — Number of FFT points

scalar power of 2

Number of FFT points used in the OFDM modulator, returned as a scalar power of 2.

Data Types: `uint32`

`Windowing` — OFDM sample span

even integer scalar

OFDM sample span, returned as an even integer scalar Number of time-domain samples over which windowing and overlapping of OFDM symbols are applied.

If `enb.Windowing` is absent, `info.Windowing` returns a default value chosen as a function of `enb.NDLRB` to compromise between the effective duration of cyclic prefix (and therefore the channel delay spread tolerance) and the spectral characteristics of the transmitted signal (not considering any additional FIR filtering). See `lteOFDMModulate` for details.

Data Types: `int32`

`CyclicPrefixLengths` — Cyclic prefix length

even integer scalar

Cyclic prefix length (in samples) of each OFDM symbol in a subframe.

info.Nfft	CyclicPrefixLengths	
	for `CyclicPrefix = 'Normal'`	for `CyclicPrefix = 'Extended'`
2048	[160 144 144 144 144 144 144 160 144 144 144 144 144 144]	[512 512 512 512 512 512 512 512 512 512 512 512]
1024	[80 72 72 72 72 72 72 80 72 72 72 72 72 72]	[256 256 256 256 256 256 256 256 256 256 256 256]
512	[40 36 36 36 36 36 36 40 36 36 36 36 36 36]	[128 128 128 128 128 128 128 128 128 128 128 128]
256	[20 18 18 18 18 18 18 20 18 18 18 18 18 18]	[64 64 64 64 64 64 64 64 64 64 64 64]
128	[10 9 9 9 9 9 9 10 9 9 9 9 9 9]	[32 32 32 32 32 32 32 32 32 32 32 32]

Note: For `info.Nfft` < 2048, `info.CyclicPrefixLengths` are the `CyclicPrefixLengths` for `info.Nfft` = 2048 scaled by `info.Nfft` / 2048.

Data Types: `uint32`

Data Types: `struct`

See Also

See Also

`lteDLResourceGridSize` | `lteOFDMModulate`

Introduced in R2014a

ltePBCH

Physical broadcast channel

Syntax

```
sym = ltePBCH(enb,cw)
```

Description

`sym = ltePBCH(enb,cw)` returns a matrix containing the complex symbols of the Physical Broadcast Channel (PBCH) for cell-wide settings structure, `enb`, and codeword, `cw`. The function performs all physical channel processing steps, including the stages of scrambling, QPSK modulation, layer mapping, and precoding as defined in TS 36.211 [1], Section 6.6.

The BCH transport channel consumes information bits every 40 ms. The coded transport block is then passed to PBCH for physical channel processing. The PBCH is transmitted in the first subframe of every frame, so four successive frames are required to transmit one transport block. As the scrambling sequence is initialized at the boundary of every 40 ms, this function expects 40 ms worth of data. For example, it expects 1920 bits for normal cyclic prefix, or 1728 bits for extended cyclic prefix. Demultiplex the output of this function into quarter length blocks for carriage on the first subframe in each 10 ms frame.

Examples

Generate PBCH Symbols

Generate physical broadcast channel (PBCH) symbols using the master information block (MIB).

Create cell-wide configuration structure initialized to RMC R.0. Generate the MIB. Pass the MIB through broadcast channel (BCH) transport channel coding.

```
enb = lteRMCDL('R.0');
mib = lteMIB(enb);
```

```
bchCoded = lteBCH(enb,mib);
```

Generate and display the PBCH symbols.

```
pbchSymbols = ltePBCH(enb,bchCoded);
pbchSymbols(1:10)
```

```
ans =

   0.7071 + 0.7071i
   0.7071 - 0.7071i
   0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 - 0.7071i
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` must contain the following fields.

`NCellID` — Physical layer cell identity

scalar integer

Physical layer cell identity, specified as a scalar integer.

Data Types: `double`

`CellRefP` — Number of cell-specific reference signal antenna ports

1 | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

Data Types: `double`

Data Types: `struct`

cw — PBCH codeword

vector

PBCH codeword, specified as a vector. `cw` contains the bit values of the PBCH codeword for modulation.

Data Types: `double` | `single` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

Output Arguments

sym — PBCH symbols

numeric matrix

PBCH symbols, returned as a numeric matrix. `sym` contains the complex symbols of the Physical Broadcast Channel (PBCH) for cell-wide settings, `enb`, and codeword, `cw`. Its size is *N*-by-`CellRefP`, where *N* is the number of modulation symbols for one antenna port and `CellRefP` is the number of antenna ports.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCH` | `ltePBCHDecode` | `ltePBCHIndices` | `ltePBCHPRBS`

Introduced in R2014a

ltePBCHDecode

Physical broadcast channel decoding

Syntax

```
[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,sym)
[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,sym,hest,
noiseest)
[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,sym,hest,
noiseest,alg)
```

Description

`[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,sym)` returns a vector of soft bits, `bits`, a vector of received constellation complex symbols, `symbols`, frame number (modulo 4), `nfmod4`, decoded BCH information bits, `trblk`, and number of cell-specific reference signal antenna ports, `cellrefp`. For more information, see "PBCH Decoding" on page 1-477.

`[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,sym,hest, noiseest)` decodes the complex PBCH symbols, `sym`, using cell-wide settings, `enb`, the channel estimate, `hest`, and the noise estimate, `noiseest`. For more information, see "PBCH Decoding" on page 1-477.

`[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,sym,hest, noiseest,alg)` provides control over weighting the output soft bits, `bits`, with channel state information (CSI) calculated during the equalization stage using the algorithmic configuration structure, `alg`. For more information, see "PBCH Decoding" on page 1-477.

Examples

Decode CellRefP from MIB

This example shows use of `ltePBCHDecode` to decode the number of cell-specific reference ports from the Master Information Block (MIB):

Initialize cell-wide configuration structure, `enb`, with RMC R.14. Generate MIB and the broadcast channel bits

```
enb = lteRMCDL('R.14');
mib = lteMIB(enb);
bchBits = lteBCH(enb,mib);
```

`lteBCH` generates bits for a 40ms period, intended for 4 frames. Since PBCH is transmitted every frame, one quarter of these bits are encoded and transmitted each frame. In this example we encode the PBCH for a single frame. So, we only map and encode one quarter of the `bchbits` to PBCH. We then decode the PBCH symbols specifying `cellrefp` as an output. Looking at the number of cell-specific reference ports, `cellrefp`, we see it matches number of antenna ports specified in TS 36.101 Annex 3.3.2 for RMC `R.14`

```
quarterLen = length(bchBits)/4;
pbchSymbols = ltePBCH(enb,bchBits(1:quarterLen));
[bits,symbols,nfmod4,trblk,cellrefp] = ltePBCHDecode(enb,pbchSymbols);

cellrefp
```

```
cellrefp =

  uint32

   4
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity

Parameter Field	Required or Optional	Values	Description
`CellRefP`	Optional	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports The default is to establish `cellrefp` by decoding the input symbols, `sym`
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

`sym` — Complex modulated PBCH symbols

numeric matrix

Complex modulated PBCH symbols, specified as an `NRE`-by-`NRxAnts` numeric matrix. `NRE` is the number of QPSK symbols per antenna assigned to the PBCH and `NRxAnts` is the number of receive antennas. `sym` can contain 1–4 subframes with PBCH data.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D array

Channel estimate is a 3-D array of size `NRE`-by-`NRxAnts`-by-*P*, where

- `NRE` is the number of PBCH resource elements (frequency and time locations).
- `NRxAnts` is the number of receive antennas.
- *P* is the number of cell-specific reference signal antennas.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Noise estimate

numeric scalar

Noise estimate, specified as a numeric scalar. It is an estimate of the noise power spectral density per resource element on the received subframe. This estimate is provided by the `lteDLChannelEstimate` function.

Data Types: `double`

`alg` — Algorithmic configuration
structure

Algorithmic configuration, specified as a structure. The structure must have the following field.

Parameter Field	Required or Optional	Values	Description
`CSI`	Optional	`'On'` (default), `'Off'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.

Data Types: `struct`

Output Arguments

`bits` — Decoded PBCH soft bits
numeric column vector

Decoded PBCH soft bits, returned as a numeric column vector. If `alg.CSI` is `'On'`, `bits` gets scaled by channel state information (CSI) calculated during the equalization process.

Data Types: `double`

`symbols` — Received constellation of complex symbols
complex numeric column vector

Received constellation of complex symbols, returned as a numeric column vector.

Data Types: `double`
Complex Number Support: Yes

`nfmod4` — System frame number modulo 4

integer scalar

System frame number modulo 4, `mod(NFrame,4)`, returned as an integer scalar. `nfmod4` is obtained when determining the scrambling phase of the input PBCH symbols, `sym`.

Data Types: `double`

`trblk` — Decoded BCH information bits

24-by-1 numeric column vector

Decoded BCH information bits, returned as a 24-by-1 numeric column vector.

Data Types: `int8`

`cellrefp` — Number of cell-specific reference signal antenna ports

optional | 1 | 2 | 4

Number of cell-specific signal antenna ports, returned as 1, 2, or 4 as determined during the BCH decoding.

Data Types: `uint32`

Definitions

PBCH Decoding

TS 36.211 [1], Section 6.6 defines the inverse of Physical Broadcast Channel (PBCH) processing of `bits` and `symbols`. TS 36.212 [2], Section 5.3.1 defines the inverse Broadcast Channel (BCH) processing used to decode `nfmod4`, `trblk`, and `cellrefp`.

PBCH Decoding performs the inverse of PBCH processing (deprecoding, symbol demodulation, and descrambling) on the matrix of complex modulated PBCH symbols, `sym`, given a cell-wide settings structure, `enb`. It decodes PBCH data scrambled with any scrambling sequence phase. So although the scrambling sequence gets initialized every 40 ms, there is no restriction on the input `sym` to be aligned at the 40 ms boundary.

After successful synchronization with the scrambling sequence, `nfmod4`, `trblk`, and `cellrefp` are determined. The true number of transmitted cell-specific reference signals is returned in `cellrefp`, and is searched for by attempting decoding with `cellrefp` equal to 1, 2, or 4. If provided,`enb.CellRefP` is attempted first to ensure that

`symbols` contains the expected constellation and `bits` contains the expected soft bit estimates for the specified value. Under good conditions, successful decoding is possible with a different value of `cellrefp`, but results in unexpected `bits` and `symbols`. If `enb.CellRefP` is not provided, the search establishes the true number of transmitted cell-specific reference signals and returns it in `cellrefp`.

For the `TxDiversity` transmission scheme (`cellrefp` = 2 or `cellrefp` = 4), the reception is performed using an OSFBC (Orthogonal Space Frequency Block Code) decoder. For the `Port0` transmission scheme (`cellrefp` = 1), the reception is performed using MMSE equalization.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCHDecode` | `ltePBCH` | `ltePBCHIndices` | `ltePBCHPRBS`

Introduced in R2014a

ltePBCHIndices

PBCH resource element indices

Syntax

```
ind = ltePBCHIndices(enb)
ind = ltePBCHIndices(enb,opts)
```

Description

`ind = ltePBCHIndices(enb)` returns an *N*-by-`CellRefP` matrix of resource element (RE) indices for the Physical Broadcast Channel (PBCH) given the parameter fields of structure `enb`. By default, the indices are returned in 1-based linear indexing form that can directly index elements of a 3-D array representing the subframe resource grid for `CellRefP` antennas. These indices are ordered as the PBCH modulation symbols should be mapped. Alternative indexing formats can also be generated. The PBCH is only transmitted in first subframe of each frame.

`ind = ltePBCHIndices(enb,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PBCH RE Indices

Generate zero-based PBCH resource element indices in linear form for RMC R.14.

```
enb = lteRMCDL('R.14');
ind = ltePBCHIndices(enb,{'0based'});
ind(1:4,:)
```

```
ans =

  4×4 uint32 matrix

    4465   12865   21265   29665
```

```
4466   12866   21266   29666
4468   12868   21268   29668
4469   12869   21269   29669
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

`NDLRB` — Number of downlink resource blocks

scalar value

Number of downlink resource blocks, specified as a scalar value.

`NCellID` — Physical layer cell identity

scalar integer

Physical layer cell identity, specified as a scalar integer.

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

`CellRefP` — Number of cell-specific reference signal antenna ports

1 (default) | optional | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

`NSubframe` — Subframe number

0 (default) | optional | scalar integer

Subframe number, specified as a scalar integer.

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PBCH resource element indices

numeric matrix

PBCH resource element indices, returned as a numeric matrix of size *N*-by-`CellRefP`.

Data Types: `double`

See Also

See Also

`ltePBCH` | `ltePBCHDecode` | `ltePBCHPRBS`

Introduced in R2014a

ltePBCHPRBS

PBCH pseudorandom scrambling sequence

Syntax

```
seq = ltePBCHPRBS(enb,n)
seq = ltePBCHPRBS(enb,n,mapping)
```

Description

`seq = ltePBCHPRBS(enb,n)` returns a vector with the first `n` outputs of the Physical Broadcast Channel (PBCH) scrambling sequence when initialized with the structure `enb`.

`seq = ltePBCHPRBS(enb,n,mapping)` allows control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Scramble Broadcast Channel MIB Message

Scramble the MasterInformationBlock broadcast channel (BCCH) message.

Create a cell-wide configuration structure initialzed to RMC R.0. Generate the MIB and coded BCH.

```
enb = lteRMCDL('R.0');
mib = lteMIB(enb);
bchCoded = lteBCH(enb,mib);
```

Generate the required length of the PBCH scrambling sequence. Scramble the coded BCH.

```
pbchPrbsSeq = ltePBCHPRBS(enb,length(bchCoded));
scrambled = xor(pbchPrbsSeq, bchCoded);
```

Compare Pseudorandom Scrambling Sequences

Compare the PBCH scrambling sequence generated using both generic and PBCH-specific pseudorandom binary sequence generators.

Create a cell-wide configuration structure initialzed to RMC R.0. Generate the first 25 bits of the pseudorandom binary sequence for physical layer cell identity, `NCellID` using `ltePRBS` and `ltePBCHPRBS`.

```
enb = lteRMCDL('R.0');
prbsSeq = ltePRBS(enb.NCellID, 25);
pbchPrbsSeq = ltePBCHPRBS(enb,25);
isequal(prbsSeq,pbchPrbsSeq)
```

```
ans =

  logical

   1
```

The generic pseudorandom binary scrambling sequence equals the PBCH-specific pseudorandom binary scrambling sequence.

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` must contain the following field.

`NCellID` — Physical layer cell identity

scalar integer

Physical layer cell identity, specified as a scalar integer.

Data Types: `double`

Data Types: `struct`

`n` — Number of outputs

numeric scalar

Number of outputs, specified as a numeric scalar.

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — PBCH pseudorandom scrambling sequence

logical column vector | numeric column vector

PBCH pseudorandom scrambling sequence, specified as a logical column vector or a numeric column vector. `seq` contains the first `n` outputs of the physical broadcast channel (PBCH) scrambling sequence. If `mapping` is set to `'signed'`, `seq` is a vector of data type double. Otherwise, it is a vector of data type logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePBCH` | `ltePBCHDecode` | `ltePBCHIndices`

Introduced in R2014a

ltePCFICH

Physical control format indicator channel

Syntax

```
sym = ltePCFICH(enb,cw)
```

Description

`sym = ltePCFICH(enb,cw)` returns the matrix of complex modulation symbols generated by the Physical Control Format Indicator Channel (PCFICH). The channel processing includes the stages of scrambling, QPSK modulation, layer mapping, and precoding. Given input bit vector `cw`, each column of the 16-by-`CellRefP` matrix `sym` contains the 16 QPSK symbols carried by the PCFICH on each of `CellRefP` transmit antenna ports. The channel is parameterized by structure `enb`.

The PCFICH is intended to carry the 32-bit block encoding of the CFI. For more information, see `lteCFI`. The channel expects the input bit vector, `cw`, to be 32 elements in length. If `length(cw) < 32`, `cw` is padded with zeros before channel processing. If `length(cw) > 32`, only the first 32 elements are used.

Examples

Generate PCFICH Symbols

Modulate CFI=1 onto two antenna ports (transmit diversity). The generated PCFICH symbols are stored in a matrix.

Generate PCFICH symbols, using a control format indicator (CFI) value of one and using two antenna ports for transmit diversity.

```
cfiCodeword = lteCFI(struct('CFI',1));
enb = struct('CellRefP',2,'NCellID',0,'NSubframe',0);

pcfichSymbols = ltePCFICH(enb,cfiCodeword);
sizePCFICHSymbols = size(pcfichSymbols)
```

```
sizePCFICHSymbols =

    16     2
```

Since two antenna ports were configured, there are two columns in the output matrix.

Input Arguments

`enb` — Cell-wide settings structure

scalar structure

`enb` is a structure having the following fields.

`NCellID` — Physical layer cell identity

0...503

Physical layer cell identity, specified as an integer from 0 through 503.

`CellRefP` — Number of cell-specific reference signal (CRS) antenna ports

1 (default) | 2 | 4

Number of cell-specific reference signal (CRS) antenna ports, specified as one of the set (1, 2, 4).

`NSubframe` — Subframe number

scalar

Subframe number, specified as an integer.

Data Types: `struct`

`cw` — Input bit vector

vector

Input bit vector that is 32 elements in length, specified as a vector. If `length(cw) < 32`, `cw` is padded with zeros before channel processing. If `length(cw) > 32`, only the first 32 elements are used.

Example: `cw = lteCFI(struct('CFI',1));`

Data Types: `int8`

Output Arguments

`sym` — Complex modulation symbols generated by the PCFICH

numeric matrix

Complex modulation symbols generated by the PCFICH, returned as a numeric matrix of size 16-by-`CellRefP`. The channel processing includes the stages of scrambling, QPSK modulation, layer mapping, and precoding. Given input bit vector `cw`, each column of the 16-by-`CellRefP` matrix `sym` contains the 16 QPSK symbols carried by the PCFICH on each of the `CellRefP` transmit antenna ports. The channel is parameterized by structure `enb`.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`lteCFI` | `ltePCFICHDecode` | `ltePCFICHIndices` | `ltePCFICHInfo` | `ltePCFICHPRBS`

Introduced in R2014a

ltePCFICHDecode

Physical control format indicator channel decoding

Syntax

```
[bits,symbols] = ltePCFICHDecode(enb,sym)
[bits,symbols] = ltePCFICHDecode(enb,sym,hest,noiseest)
[bits,symbols] = ltePCFICHDecode(enb,sym,hest,noiseest,alg)
```

Description

`[bits,symbols] = ltePCFICHDecode(enb,sym)` performs the inverse of Physical Control Format Indicator Channel (PCFICH) processing on the matrix of complex modulated PCFICH symbols, `sym`, using cell-wide settings structure, `enb`. It returns a column vector of soft bits, `bits`, and received constellation of complex symbol vector, `symbols`. The channel inverse processing includes deprecoding, symbol demodulation, and descrambling. See TS 36.211, Section 6.7 [1] or `ltePCFICH` for details.

The input argument, `sym`, must be a matrix of `NRE`-by-`NRxAnts` complex modulated PCFICH symbols. `NRE` is the number of QPSK symbols per antenna assigned to the PCFICH (16) and `NRxAnts` is the number of receive antennas.

`[bits,symbols] = ltePCFICHDecode(enb,sym,hest,noiseest)` decodes the complex PCFICH symbols, `sym`, using cell-wide settings, `enb`, the channel estimate, `hest`, and the noise estimate, `noiseest`. For the `'TxDiversity'` transmission scheme, when `CellRefP` is 2 or 4, the reception is performed using an orthogonal space frequency block code (OSFBC) decoder. For the `'Port0'` transmission scheme, when `CellRefP` is 1, the reception is performed using MMSE equalization.

`hest` is a 3-D `NRE`-by-`NRxAnts`-by-`enb.CellRefP` array. `NRE` contains the frequency and time locations corresponding to the PCFICH RE positions for a total of `NRE` positions. `NRxAnts` is the number of receive antennas, and `enb.CellRefP` is the number of cell-specific reference signal antennas.

`noiseest` is an estimate of the noise power spectral density per RE in the received subframe. The `lteDLChannelEstimate` function produces this estimate.

`[bits,symbols] = ltePCFICHDecode(enb,sym,hest,noiseest,alg)` same as prior except this syntax provides control over weighting the output soft bits, `bits`. If `alg.CSI` is `'On'`, `bits` get scaled by the channel state information (CSI) calculated during the equalization stage.

Examples

Decode PCFICH Symbols

This example shows decoding of symbols to recover CFI value.

Initialize a cell wide configuration structure, `enb`. Encode a CFI value and perform phyiscal channel coding to create a vector of symbols, `pcfichSym`.

```
enb.NCellID = 0;
enb.NSubframe = 0;
enb.CellRefP = 1;
enb.CFI = 3;
cw = lteCFI(enb);
pcfichSym = ltePCFICH(enb,cw);
```

Demodulate and decode the symbols to recover the CFI value

```
cfiSoftBits = ltePCFICHDecode(enb,pcfichSym);
rxCFI = lteCFIDecode(cfiSoftBits)
```

```
rxCFI =

  int32

   3
```

Confirm recovered CFI value matches the setting in `enb`

```
enb.CFI
```

```
ans =

     3
```

Input Arguments

enb — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. enb contains the following fields.

Parameter Field	Required or Optional	Values	Description
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number

Data Types: struct

sym — Complex modulated PCFICH symbols

numeric matrix

Complex modulated PCFICH symbols, specified as a numeric matrix of size NRE-by-NRxAnts. NRE is the number of QPSK symbols per antenna assigned to the PCFICH (16). NRxAnts is the number of receive antennas.

Data Types: double
Complex Number Support: Yes

hest — Channel estimate

3-D numeric array

Channel estimate, specified as a 3-D numeric array of size NRE-by-NRxAnts-by-enb.CellRefP, where:

- NRE contains the frequency and time locations corresponding to the PCFICH RE positions (a total of NRE positions).
- NRxAnts is the number of receive antennas.

- `enb.CellRefP` is the number of cell-specific reference signal antennas.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Noise estimate

scalar

Estimate of the noise power spectral density per RE on received subframe. Such an estimate is provided by the `lteDLChannelEstimate` function.

Data Types: `double`

`alg` — Algorithmic configuration

structure

Algorithmic configuration, specified as a structure. It contains the following fields.

Parameter Field	Required or Optional	Values	Description
`CSI`	Optional	`'On'` (default), `'Off'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.

Data Types: `struct`

Output Arguments

`bits` — Soft bits

numeric column vector

Soft bits, returned as a numeric column vector. If the input `alg.CSI` field is `'On'`, `bits` gets scaled by channel state information (CSI) calculated during the equalization process.

Data Types: `double`

`symbols` — Received constellation symbols
complex numeric column vector

Received constellation symbols, returned as a complex numeric column vector.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteCFIDecode` | `ltePCFICH` | `ltePCFICHIndices` | `ltePCFICHInfo` | `ltePCFICHPRBS`

Introduced in R2014a

ltePCFICHIndices

PCFICH resource element indices

Syntax

```
ind = ltePCFICHIndices(enb)
ind = ltePCFICHIndices(enb,opts)
```

Description

`ind = ltePCFICHIndices(enb)` returns the 16-by-`CellRefP` matrix of subframe resource element (RE) indices for the physical control format indicator channel (PCFICH), given the `enb` input structure. By default, the indices are returned in 1-based linear indexing form that directly indexes elements of a 3-D array representing the subframe resource grid for `CellRefP` antenna ports. Each column of `ind` contains per-antenna indices for 16 resource elements in one of the `CellRefP` array planes. The rows are ordered as the PCFICH modulation symbols should be mapped. The indices can also be returned in a number of alternative indexing formats.

The PCFICH is always transmitted on 16 resource elements, or 4 resource element groups (REG), in the first OFDM symbol of a subframe however their locations depend on the `NCellID` and `NDLRB` parameters.

`ind = ltePCFICHIndices(enb,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PCFICH RE Indices

This example generates physical CFI channel (PCFICH) resource element (RE) indices for two different physical layer cell identity values.

To show the effects of the physical layer cell identity, `NCellID` on the indices, first set it to 0. Then, generate and display the PCFICH indices.

```
enb.NDLRB = 50;
enb.NCellID = 0;
enb.CyclicPrefix = 'Normal';
enb.CellRefP = 1;
ind = ltePCFICHIndices(enb,{'0based','reg'})
```

```
ind =

  4×1 uint32 column vector

     0
   150
   300
   450
```

```
Next, set the physical layer cell identity, |NCellID|, to 1. Regenerate
and display the PCFICH indices.

enb.NCellID = 1;
ind = ltePCFICHIndices(enb,{'0based','reg'})
```

```
ind =

  4×1 uint32 column vector

     6
   156
   306
   456
```

Input Arguments

enb — eNodeB cell-wide settings

scalar structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
CellRefP	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports

`opts` — Index generation options

character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'sub'`	Style for the returned indices, specified as one of the following options. • `'ind'` — returns the indices in linear index form as a column vector (default) • `'sub'` — returns the indices in `[subcarrier, symbol, antenna]` subscript row style. The number of rows in the output, `ind`, is the number of resource elements (N_{RE}). Thus, `ind` is an N_{RE}-by-3 matrix.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing unit	`'re'` (default), `'reg'`	Unit of the returned indices. Specify `'re'` to indicate that the returned values correspond to individual resource elements (REs). Specify `'reg'` to indicate that the

Option	Values	Description
		returned values correspond to resource element groups (REGs).

Data Types: `char` | `cell`

Output Arguments

`ind` — Subframe PCFICH RE indices

numeric matrix

Subframe PCFICH RE indices, returned as a numeric matrix of size 16-by-`CellRefP`. Each column of `ind` contains per-antenna indices for 16 resource elements in one of the `CellRefP` array planes. The rows are ordered as the PCFICH modulation symbols should be mapped.

See Also

See Also

`lteDLResourceGrid` | `ltePCFICH` | `ltePCFICHInfo` | `ltePDCCHIndices` | `ltePHICHIndices`

Introduced in R2014a

ltePCFICHInfo

PCFICH resource information

Syntax

```
info = ltePCFICHInfo
```

Description

`info = ltePCFICHInfo` returns a structure `info` containing the Physical Control Format Indicator Channel (PCFICH) subframe resources.

For the PCFICH, `NREG` = 4, and `NRE` = 16 = 4 × `NREG`. These values are fixed for the system.

Examples

Get PCFICH Resource Information

Display information about the PCFICH subframe resources.

```
info = ltePCFICHInfo
```

```
info =

  struct with fields:

    NREG: 4
     NRE: 16
```

Output Arguments

`info` — PCFICH resource information

scalar structure

PCFICH resource information, returned as a scalar structure. It can contain the following fields.

Parameter Field	Description	Values	Data Type
NRE	Number of resource elements (REs) assigned to PCFICH (4×NREG)	Nonnegative scalar integer	uint64
NREG	Number of resource element groups (REGs) assigned to PCFICH	Nonnegative scalar integer	uint64

See Also

See Also

ltePCFICH | ltePCFICHDecode | ltePCFICHIndices | ltePCFICHPRBS

Introduced in R2014a

ltePCFICHPRBS

PCFICH pseudorandom scrambling sequence

Syntax

```
seq = ltePCFICHPRBS(enb,n)
seq = ltePCFICHPRBS(enb,n,mapping)
```

Description

`seq = ltePCFICHPRBS(enb,n)` returns a vector containing the first `n` outputs of the physical control format indicator channel (PCFICH) scrambling sequence when initialized according to cell-wide settings structure, `enb`.

`seq = ltePCFICHPRBS(enb,n,mapping)` allows control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Scramble CFI Codeword

Scramble the CFI codeword.

Create cell-wide configuration structure, initialized to RMC R.14. Generate a CFI codeword and a pseudorandom scrambling sequence for the PCFICH the same length as the codeword.

```
enb = lteRMCDL('R.14');
cw = lteCFI(struct('CFI',2));
pcfichPrbsSeq = ltePCFICHPRBS(enb,length(cw));
size(pcfichPrbsSeq)
```

```
ans =

    32     1
```

Scramble the CFI codeword using the generated scrambling sequence.

```
scrambled = xor(pcfichPrbsSeq,cw);
```

Generate Signed PCFICH Pseudorandom Scrambling Sequence

Generate a signed pseudorandom scrambling sequence for the PCFICH. Each resource element (RE) in the PCFICH is QPSK-modulated, resulting in two bits-per-symbol mapping on each resource element.

Create cell-wide configuration structure, initialized to RMC R.14.

```
enb = lteRMCDL('R.14');
info = ltePCFICHInfo
pcfichPrbsSeq = ltePCFICHPRBS(enb,info.NRE*2,'signed');
size(pcfichPrbsSeq)
pcfichPrbsSeq(1:10)
```

```
info =

  struct with fields:

    NREG: 4
     NRE: 16


ans =

    32     1


ans =

     1
    -1
     1
     1
     1
     1
     1
    -1
    -1
```

```
1
```

The scrambling sequence contains a vector of 32 signed ones.

Input Arguments

`enb` — Cell-wide settings
scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

`NCellID` — Physical layer cell identity
0...503

Physical layer cell identity, specified as a nonnegative scalar integer in the range of 0 to 503.

Data Types: `double`

`NSubframe` — Subframe number
positive scalar integer

Subframe number, specified as a positive scalar integer greater than 0.

Data Types: `double`

Data Types: `struct`

`n` — Length of scrambling sequence
positive scalar integer

Length of scrambling sequence, specified as a positive scalar integer greater than 0. This argument determines the number of elements in the output vector, `seq`.

Data Types: `double`

`mapping` — Controls the format of the returned sequence
`'binary'` (default) | `'signed'`

Controls the format of the returned sequence, specified as either binary or signed. Valid formats are (`'binary'` (default), `'signed'`). `'binary'` maps true to 1 and false to 0, and `'signed'` maps true to –1 and false to 1.

Data Types: `char`

Output Arguments

`seq` — PCFICH pseudorandom scrambling sequence

logical column vector | numeric column vector

PCFICH pseudorandom scrambling sequence, returned as a logical column vector or a numeric column vector. This argument contains the first `n` outputs of the PCFICH scrambling sequence when initialized according to cell-wide settings structure, `enb`. If you set `mapping` to `'signed'`, the output is of data type double. Otherwise, it is of data type logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePCFICH` | `ltePCFICHDecode` | `ltePCFICHIndices` | `ltePCFICHInfo` | `ltePRBS`

Introduced in R2014a

ltePDCCH

Physical downlink control channel

Syntax

```
[sym,info] = ltePDCCH(enb,cw)
[sym,info] = ltePDCCH(enb,cw,NREG)
[sym,info] = ltePDCCH(enb,cw,NREG,CCEGAINS)
```

Description

`[sym,info] = ltePDCCH(enb,cw)` returns an `NRE`-by-`CellRefP` complex matrix, `sym`, of modulation symbols given the input bit vector `cw`.

The function returns a matrix (`sym`) of complex modulation symbols generated by the set of Physical Downlink Control Channels (PDCCH) in a subframe. The channel processing includes the stages of scrambling, QPSK modulation, layer mapping and precoding, followed by REG interleaving and cyclic shifting. For a given input bit vector (typically the PDCCH multiplex), the output matrix `sym` contains the QPSK symbols in column-wise antenna form. Any input bits with value < 0 are turned into `<NIL> ('0')` symbols. The optional structure `info` returns control resourcing information about the output symbols (see `ltePDCCHInfo` for details).

`[sym,info] = ltePDCCH(enb,cw,NREG)` returns matrix `sym`. sets the number of output QPSK symbols, `NRE`, based on the `NREG` input value (`NRE` = 4 × `NREG`) instead of calculating it from the parameters of the `enb` structure.

`[sym,info] = ltePDCCH(enb,cw,NREG,CCEGAINS)` returns matrix `sym`. `CCEGAINS` allows control of the QPSK symbol gains on a per control channel element (CCE) basis.

Examples

Generate PDCCH Symbols

Generate complex modulated symbols for the PDCCH. The PDCCH symbols are QPSK modulated. Each QPSK symbol represents two bits.

Create a cell-wide configuration structure, iniitialized for RMC R.0. Retrieve the PDCCH information.

```
enb = lteRMCDL('R.0');
pdcchInfo = ltePDCCHInfo(enb)
```

```
pdcchInfo =

  struct with fields:

        NREG: 113
         NRE: 452
        NCCE: 12
    NREGUsed: 108
     NREUsed: 432
        MTot: 904
    NSymbols: 3
```

The field `pdcch.MTot` indicates the maximum number of input bits that can be transmitted on the PDCCH.

Generate a codeword that is `MTot` bits long. Using the codeword, generate PDCCH symbols.

```
cw = randi([0,1],pdcchInfo.MTot,1);
[pdcchSym,info] = ltePDCCH(enb,cw);
numCodewordBits = length(cw)
numPDCCHSymbols = length(pdcchSym)
```

```
numCodewordBits =

   904


numPDCCHSymbols =

   452
```

Since there are two bits per symbol, the number of output PDCCH symbols is half length of the codeword bit stream.

Input Arguments

enb — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	Integer greater than 0	Subframe number
`NDLRB`	Required	Nonnegative scalar integer (6,...,110)	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPre`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CFI`	Required	1, 2, or 3	Control format indicator value
`Ng`	Required	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	PHICH group multiplier
`DuplexMod`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following field is required when `DuplexMode` is set to `'TDD'`.			
`TDDConf`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration

Data Types: `struct`

`cw` — Input bit vector

vector

Input bit vector that is 32 elements in length, specified as a vector. If `length(cw) < 32`, `cw` is padded with zeros before channel processing. If `length(cw) > 32`, only the first 32 elements are used.

Example: `cw = lteCFI(struct('CFI',1));`

Data Types: `int8`

`NREG` — Resource element groups (REGs) assigned to PDCCH

scalar

Resource element groups (REGs) assigned to PDCCH.

`CCEGAINS` — Vector that controls the QPSK symbol gains on a per CCE basis

vector

Vector that controls the QPSK symbol gains on a per CCE basis. Each CCE (Control Channel Element) is a group of 36 QPSK symbols (72 bits) and is the minimum unit that a single coded DCI can be mapped to. The number of complete CCE, NCCE = floor(NREG/9), is available via the `NCCE` field in `info`. Each element of `CCEGAINS` acts as a linear multiplier to all 36 symbols generated from the associated block of 72 input bits. If `CCEGAINS` does not cover all the `NREG` symbols, specifically length(`CCEGAINS`) < `NCCE`, then the uncovered CCE receives zero power. All symbols are interleaved before they are output.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`sym` — PDCCH modulation symbols

complex matrix

PDCCH modulation symbols, given the input bit vector `cw`, returned as a `NRE`-by-`CellRefP` complex matrix. `NRE` is the number of QPSK symbols per antenna and `CellRefP` is the number of TX antenna ports. `NRE` corresponds to the number of control region resource elements assigned to the PDCCH given the structure `enb`.

Data Types: `double`
Complex Number Support: Yes

`info` — Information for various PDCCH resourcing quantities

structure

Information for various PDCCH resourcing quantities, returned as a structure. It contains fields including `NRE`, `NREG`, and `MTot`.

`MTot` is the maximum number of input bits that can be transmitted on the `NRE` symbols (`MTot` = 2×`NRE` = 8×`NREG`). If `length(cw)<MTot`, the input is padded with (`MTot`-length(`cw`)) `<NIL>` elements which translate to zero valued symbols. Any elements of input vector `cw` valued < 0 are also treated as `<NIL>` elements. If length(`cw`) > `MTot` then only the first `MTot` bits are used.

Data Types: `struct`

See Also

See Also

`lteDCIEncode` | `ltePDCCHDecode` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHInterleave` | `ltePDCCHPRBS` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHDecode

Physical downlink control channel decoding

Syntax

```
[bits,symbols] = ltePDCCHDecode(enb,sym)
[bits,symbols] = ltePDCCHDecode(enb,sym,hest,noiseest)
[bits,symbols] = ltePDCCHDecode(enb,sym,hest,noiseest,alg)
```

Description

`[bits,symbols] = ltePDCCHDecode(enb,sym)` performs the inverse of Physical Downlink Control Channel (PDCCH) processing on the matrix of complex modulated PDCCH symbols, `sym`, and cell-wide settings structure, `enb`. The channel inverse processing includes resource element group deinterleaving and cyclic shifting, deprecoding, symbol demodulation, and descrambling.

The function returns a column vector of soft bits, `bits`, and received constellation of complex symbol vector, `symbols`, resulting from performing the inverse of PDCCH processing. See TS 36.211 [1], Section 6.8 and `ltePDCCH` for details.

`[bits,symbols] = ltePDCCHDecode(enb,sym,hest,noiseest)` decodes the complex PDCCH symbols, `sym`, using cell-wide settings, `enb`, the channel estimate, `hest`, and the noise estimate, `noiseest`. For the `TxDiversity` transmission scheme, when `CellRefP` is 2 or 4, the reception is performed using an orthogonal space frequency block code (OSFBC) decoder. For the `Port0` transmission scheme, when `CellRefP` is 1, the reception is performed using minimum mean square error (MMSE) equalization.

`[bits,symbols] = ltePDCCHDecode(enb,sym,hest,noiseest,alg)` provides control over weighting the output soft bits, `bits`, with channel state information (CSI) calculated during the equalization stage using algorithmic configuration structure, `alg`. When `alg.CSI` is `'On'`, `bits` is scaled by channel state information calculated during the equalization process.

Examples

Decode PDCCH Symbols

Generate and decode the complex PDCCH modulated symbols for RMC R.0 from cell-wide settings structure, `enb`.

```
enb = lteRMCDL('R.0');
pdcchInfo = ltePDCCHInfo(enb);
codewordBits = randi([0,1],pdcchInfo.MTot,1);
pdcchSym = ltePDCCH(enb,codewordBits);
[softBits,symbols] = ltePDCCHDecode(enb,pdcchSym);
```

Input Arguments

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number

Data Types: `struct`

`sym` — PDCCH modulation symbols

complex numeric matrix

PDCCH modulation symbols, specified as a complex numeric matrix of size `NRE`-by-`NRxAnts`. `NRE` is the number of QPSK symbols per antenna assigned to the PDCCH (that is, the number of control region resource elements) and `NRxAnts` is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array

Channel estimate, specified as a 3-D numeric array of size `NRE`-by-`NRxAnts`-by-`CellRefP`. `NRE` are the frequency and time locations corresponding to the PDCCH RE positions (a total of `NRE` positions). `NRxAnts` is the number of receive antennas, and `CellRefP` is the number of cell-specific reference signal antennas, given by `enb.CellRefP`.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Noise estimate

numeric scalar

Noise estimate, specified as a numeric scalar. This input argument is an estimate of the noise power spectral density per RE on received subframe. Produce this estimate using the `lteDLChannelEstimate` function.

Data Types: `double`

`alg` — Algorithmic configuration to calculate CSI for weighting soft bits

structure

Algorithmic configuration to calculate CSI for weighting soft bits, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
`CSI`	Optional	`'On'` (default), `'Off'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.

Data Types: `struct`

Output Arguments

`bits` — Soft bits

numeric column vector

Soft bits, returned as a numeric column vector. `bits` is the received PDCCH payload containing coded downlink control information (DCI) messages. It is optionally scaled by channel state information (CSI) calculated during the equalization process.

Data Types: `double`

`symbols` — Received constellation symbols

complex numeric column vector

Received constellation symbols, returned as a complex numeric column vector.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCIDecode` | `ltePDCCH` | `ltePDCCHDeinterleave` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHPRBS` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHDeinterleave

PDCCH deinterleaving and cyclic shifting

Syntax

```
out = ltePDCCHDeinterleave(enb,in)
```

Description

`out = ltePDCCHDeinterleave(enb,in)` performs the PDCCH Resource Element Groups (REGs) deinterleaving and cyclic shifting on PDCCH complex modulated symbols, `in` given cell-wide configuration structure, `enb` This function performs the inverse of the processing described in TS 36.211 [1], Section 6.8.5.

The cyclic shifting process is the reverse of the `NCellID` dependent cyclic shift carried out during PDCCH coding to avoid intercell interference. The de-interleaving is performed to reverse the permutation operation described in TS 36.212 [2], Section 5.1.4.2.1 with the exception that “symbol quadruplets” replace “bits”.

Examples

Deinterleave PDCCH Symbols

Perform PDCCH resource element group (REG) deinterleaving. A vector of PDCCH symbols is first interleaved. The output is then deinterleaved and compared with the input vector. Note that instead of actual PDCCH symbols, a range of values from 1 to NRE are used to highlight the interleaved order.

Create a cell-wide configuration structure initalized for RMC R.0. Instead of actual PDCCH symbols, a range of values from 1 to NRE are used to highlight the interleaved order. Interleave the PDCCH symbols, `pdcchSym`.

```
enb = lteRMCDL('R.0');
pdcchInfo = ltePDCCHInfo(enb);
pdcchSym = (1:pdcchInfo.NRE).';
startingSymbolOrder = pdcchSym(1:4)
```

```
interleavedSym = ltePDCCHInterleave(enb,pdcchSym);
interleavedSymbolOrder = interleavedSym(1:4)
```

```
startingSymbolOrder =

  4×1 uint64 column vector

   1
   2
   3
   4


interleavedSymbolOrder =

  4×1 uint64 column vector

   73
   74
   75
   76
```

Deinterleave symbols and view the first four.

```
deinterleavedSym = ltePDCCHDeinterleave(enb,interleavedSym);
deinterleavedSymbolOrder = deinterleavedSym(1:4)
```

```
deinterleavedSymbolOrder =

  4×1 uint64 column vector

   1
   2
   3
   4
```

Confirm deinteleaved symbol vector matches the input symbol vector.

```
isequal(pdcchSym,deinterleavedSym)
```

```
ans =

  logical

   1
```

Input Arguments

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` can contain the following fields.

`NCellID` — Physical layer cell identity

integer from 0 to 503

Physical layer cell identity, specified as an integer from 0 to 503.

Data Types: `struct`

`in` — PDCCH complex modulated input symbols

numeric matrix

PDCCH complex modulated input symbols, specified as an N_S-by-N_{TX} numeric matrix. N_S is the number of modulated symbols, and N_{TX} is the number of transmit antennas. The N_S modulated symbols specified in input matrix `in` must be a concatenation of symbol quadruplets. If the input `in` is a vector, it deinterleaves the elements of the vector. If `in` is a matrix, it deinterleaves the rows.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`out` — Deinterleaved output

numeric column vector

Deinterleaved output, returned as a numeric column vector.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHInterleave` | `ltePDCCHPRBS` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHIndices

PDCCH resource element indices

Syntax

```
ind = ltePDCCHIndices(enb)
ind = ltePDCCHIndices(enb,opts)
ind = ltePDCCHIndices(enb,exreg,opts)
```

Description

`ind = ltePDCCHIndices(enb)` returns a `NRE`-by-`CellRefP` matrix of one-based linear indexing RE indices given the structure `enb`. It returns the subframe resource element (RE) indices for the physical downlink control channels (PDCCH).

The `NRE` indices returned cover all PDCCH resources in the control region not already assigned to PCFICH or PHICH (see `ltePDCCHInfo`). They are ordered as the complete block of padded, interleaved, and shifted PDCCH modulation symbols that ready to be mapped, as described in TS 36.211 [1], Section 6.8.5.

`ind = ltePDCCHIndices(enb,opts)` allows control of the format of the returned indices through a cell array `opts`.

`ind = ltePDCCHIndices(enb,exreg,opts)` returns a matrix of indices, where the vector `exreg` explicitly defines resources not to be assigned to PDCCH. The `exreg` must contain valid resource element group (REG) indices but can be either zero-based or one-based throughout, and indices which do not fall within the control region are ignored.

Examples

Get PDCCH Resource Element Indices

Retrieve PDCCH resource element (RE) indices.

Create an RMC R.0 configuration structure and find its PDCCH RE indices. Display the size of the indices.

```
enb = lteRMCDL('R.0');
ind = ltePDCCHIndices(enb);
size(ind)
```

```
ans =

   452     1
```

Get PDCCH Indices and Exclude Resources

Explicitly exclude resources when retrieving PDCCH indices.

Create a cell-wide configuration structure initalized for RMC R.0. Generate RE indices for the PDCCH providing an empty matrix for the argument `exreg` so that no resources are excluded.

```
enb = lteRMCDL('R.0');
ind = ltePDCCHIndices(enb,[],'re');
numPDCCHwithNoExclusion = size(ind)
```

```
numPDCCHwithNoExclusion =

   480     1
```

All RE indices are returned in the required mapping order.

Explicitly exclude the PCFICH and PHICH indices.

```
enb = lteRMCDL('R.0');
exreg = [ltePCFICHIndices(enb,'reg'); ltePHICHIndices(enb,'reg')];
ind = ltePDCCHIndices(enb,exreg,'re');
numPDCCHwithExclusion = size(ind)
```

```
numPDCCHwithExclusion =

   452     1
```

This call returns the same result as the default syntax call, `ltePDCCHIndices(enb)`.

Input Arguments

`enb` — Cell-wide settings

structure

`enb` is a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Integer within the range (6,...,110)	Number of downlink resource blocks. (N_{RB}^{DL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`CyclicPre`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`CFI`	Required	1, 2, or 3	Control format indicator value
`Ng`	Required	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
`PHICHDura`	Optional	`'Normal'` (default), `'Extended'`	PHICH duration
`DuplexMod`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following field is required when `DuplexMode` is set to `'TDD'`.			
`TDDConf`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration

Parameter Field	Required or Optional	Values	Description
`NSubframe`	Required	Integer greater than 0	Subframe number

Data Types: `struct`

`opts` — Index generation options

character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'sub'`	Style for the returned indices, specified as one of the following options. • `'ind'` — returns the indices in linear index form as a column vector (default) • `'sub'` — returns the indices in `[subcarrier, symbol, antenna]` subscript row style. The number of rows in the output, `ind`, is the number of resource elements (N_{RE}). Thus, `ind` is an N_{RE}-by-3 matrix.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing unit	`'re'` (default), `'reg'`	Unit of the returned indices. Specify `'re'` to indicate that the returned values correspond to individual resource elements (REs). Specify `'reg'` to indicate that the returned values correspond to resource element groups (REGs).

Data Types: `char | cell`

`exreg` — Resources excluded from PDCCH

vector

Resources excluded from PDCCH, specified as a vector. This vector explicitly defines those resources not to be assigned to PDCCH. `exreg` must contain valid resource element group (REG) indices but can be either zero-based or one-based throughout. Indices which do not fall within the control region are ignored.

Data Types: `double`

Output Arguments

`ind` — PDCCH RE indices

numeric matrix

PDCCH RE indices, returned as an `NRE`-by-`CellRefP` numeric matrix by default. The matrix contains one-based linear indexing RE indices. Each column of `ind` identifies the same set of `NRE` subframe resource elements but with indices offset to select them in a different antenna "page" of the 3-D resource array.

The default matrix of indices in a one-based linear indexing style which can directly index elements of an *M*-by-*N*-by-`CellRefP` array, where *M* is the number of symbols, and *N* is the number of subcarriers representing the subframe grid across `CellRefP` antenna ports.

Data Types: `double`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHDeinterleave` | `ltePDCCHInfo` | `ltePDCCHInterleave` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHInfo

PDCCH resource information

Syntax

```
info = ltePDCCHInfo(enb)
```

Description

`info = ltePDCCHInfo(enb)` returns a structure `info` containing information about the Physical Downlink Control Channel (PDCCH) subframe resources.

Within a non-MBMS downlink subframe, the first `info.NSymbols` OFDM symbols represent its *control region* and carry the PCFICH, PHICH and PDCCH. `info.NRE` indicates the number of non-reference resource elements (RE), not assigned to the PCFICH or PHICH, that are associated with PDCCH transmission. These resources carry the set of PDCCH where each PDCCH carries a single encoded DCI message. Each PDCCH can be transmitted on 1,2,4, or 8 control channel elements (CCE), where 1 CCE = 9 REG = 36 RE = 72 bits. As such, not all the `NRE` elements can carry actual PDCCH instances, with (`info.NRE` – `info.NREUsed`) being unavailable for PDCCH transmission.

Examples

Get PDCCH Information

Get information about the PDCCH subframe resources for RMC R.0.

```
enb = lteRMCDL('R.0');
info = ltePDCCHInfo(enb)
```

```
info =

  struct with fields:

        NREG: 113
```

```
      NRE: 452
     NCCE: 12
 NREGUsed: 108
  NREUsed: 432
     MTot: 904
 NSymbols: 3
```

Input Arguments

enb — Cell-wide settings structure

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` is a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Integer within the range (6,...,110)	Number of downlink resource blocks. (N_{RB}^{DL})
`CyclicPre`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`CFI`	Required	1, 2, 3	Control format indicator value
`Ng`	Required	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	PHICH group multiplier
`DuplexMod`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number

Parameter Field	Required or Optional	Values	Description
The following field is required when `DuplexMode` is set to `'TDD'`.			
`TDDConf`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration

Data Types: `struct`

Output Arguments

`info` — PDCCH subframe resource information

structure

PDCCH subframe resource information, returned as a structure. `info` contains the following fields.

Parameter Field	Values	Description
`NRE`	Numeric scalar	Total number of resource elements (REs) associated with PDCCHs (4×`NREG`)
`NREG`	Numeric scalar	Total number of resource element groups (REGs) associated with PDCCHs (4×`NRE`)
`MTot`	Numeric scalar	Total number of bits associated with PDCCHs, returned as a numeric scalar (8×`NREG`). `MTot` is the maximum number of input bits that can be transmitted on the `NRE` symbols (`MTot` = 2 × `NRE` = 8 × `NREG`).
`NCCE`	Numeric scalar	Number of control channel elements available for actual PDCCH usage
`NREGUsed`	Numeric scalar	Number of resource element groups (REGs) available for actual PDCCH usage
`NREUsed`	Numeric scalar	Number of resource elements (REs) available for actual PDCCH usage
`NSymbols`	Numeric scalar	Total number of OFDM symbols spanned by the PDCCH

Data Types: `struct`

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHDeinterleave` | `ltePDCCHIndices` | `ltePDCCHInterleave` | `ltePDCCHPRBS` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHInterleave

PDCCH interleaving and cyclic shift

Syntax

```
out = ltePDCCHInterleave(enb,in)
```

Description

`out = ltePDCCHInterleave(enb,in)` performs the interleaving and cyclic shifting on PDCCH resource element groups (REGs) as described in TS 36.211 [1], Section 6.8.5.

The permutation, or interleaving, operation is performed as described in TS 36.212 [2], Section 5.1.4.2.1, with the exception that “symbol quadruplets” replace “bits”. Then, the block of PDCCH-modulated symbol quadruplets is cyclically shifted with `NCellID` to avoid intercell interference.

Examples

Perform PDCCH Interleaving

Interleave a sequential input sized to the number of resource elements.

```
enb = lteRMCDL('R.0');
pdcchInfo = ltePDCCHInfo(enb);
interleavedSym = ltePDCCHInterleave(enb,(1:pdcchInfo.NRE).');
size(interleavedSym)
interleavedSym(1:12)
```

```
ans =

   452     1


ans =
```

```
12×1 uint64 column vector

  73
  74
  75
  76
 201
 202
 203
 204
 329
 330
 331
 332
```

The sequential input is interleaved, resulting in the concatenation of input quadruplets.

Input Arguments

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

`NCellID` — Physical layer cell identity

integer from 0 to 503

Physical layer cell identity, specified as an integer from 0 to 503.

Data Types: `struct`

`in` — PDCCH complex modulated input symbols

complex-valued numeric matrix | numeric vector

PDCCH complex modulated input symbols, specified in a complex-valued numeric N_S-by-N_{TX} matrix, or a numeric vector. N_S is the number of modulated symbols, and N_{TX} is the number of transmit antennas. The N_S modulated symbols specified in input matrix, `in`, must be a concatenation of symbol quadruplets. If the input, `in`, is a vector, it interleaves the elements of the vector. If `in` is a matrix, it interleaves the rows.

Data Types: `double`

Complex Number Support: Yes

Output Arguments

`out` — Interleaved output

numeric vector

Interleaved output, returned as a numeric vector.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHDeinterleave` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHPRBS` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHPRBS

PDCCH pseudorandom scrambling sequence

Syntax

```
seq = ltePDCCHPRBS(enb,n)
seq = ltePDCCHPRBS(enb,n,mapping)
```

Description

`seq = ltePDCCHPRBS(enb,n)` returns a column vector containing the first `n` outputs of the Physical Downlink Control Channel (PDCCH) scrambling sequence when initialized according to cell-wide settings structure, `enb`.

`seq = ltePDCCHPRBS(enb,n,mapping)` allows control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Return Binary PDCCH Scrambling Sequence

Generate the first 7 outputs of the pseudorandom scrambling sequence for PDCCH in binary (default) format.

```
enb = lteRMCDL('R.0');
pdcchSeqBinary = ltePDCCHPRBS(enb,7)
```

```
pdcchSeqBinary =

  7×1 logical array

   0
   0
   0
   0
```

```
     0
     0
     1
```

Scramble Random PDCCH Codeword

Scramble a random PDCCH codeword.

Create a cell-wide configuration structure, initialized to RMC R.0. Generate a codeword. Use `MTot` to determine the total number of bits associated with PDCCHs. Generate a PDCCH pseudorandom scrambling sequence the same length as the codeword.

```
enb = lteRMCDL('R.0');

pdcchInfo = ltePDCCHInfo(enb)
cw = randi([0,1],pdcchInfo.MTot,1);

pdcchSeq = ltePDCCHPRBS(enb,length(cw));
```

```
pdcchInfo =

  struct with fields:

        NREG: 113
         NRE: 452
        NCCE: 12
    NREGUsed: 108
     NREUsed: 432
        MTot: 904
    NSymbols: 3
```

Scramble codeword with PDCCH PRBS.

```
scrambled = xor(pdcchSeq,cw);
```

Return Signed PDCCH Scrambling Sequence

Generate the first 7 outputs of the pseudorandom scrambling sequence for PDCCH in signed format.

```
enb = lteRMCDL('R.0');
pdcchSeqSigned = ltePDCCHPRBS(enb,7,'signed')
```

```
pdcchSeqSigned =

     1
     1
     1
     1
     1
     1
    -1
```

Input Arguments

`enb` — Cell-wide settings
structure

Cell-wide settings, specified as a structure. This argument contains the following fields.

`NCellID` — Physical layer cell identity
0,...,503

Physical layer cell identity, specified as a nonnegative scalar integer from 0 through 503.

Data Types: `double`

`NSubframe` — Subframe number
positive scalar integer

Subframe number, specified as a positive scalar integer greater than 0.

Data Types: `double`

Data Types: `struct`

`n` — Number of elements in returned sequence
numeric scalar

Number of elements in returned sequence, `seq`, specified as a numeric scalar.

Data Types: `double`

`mapping` — Output sequence formatting
`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`. `'binary'` maps true to 1 and false to 0. `'signed'` maps true to –1 and false to 1.

Data Types: `char`

Output Arguments

`seq` — PDCCH pseudorandom scrambling sequence

logical column vector | numeric column vector

PDCCH pseudorandom scrambling sequence, returned as a logical column vector or a numeric column vector. This argument contains the first `n` outputs of the PDCCH scrambling sequence when initialized according to cell-wide settings structure, `enb`. If you set `mapping` to `'signed'`, the output data type is double. Otherwise, the output data type is logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHDeinterleave` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHInterleave` | `ltePDCCHSearch` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHSearch

PDCCH downlink control information search

Syntax

```
[dcistr,dcibits] = ltePDCCHSearch(enb,chs,softbits)
```

Description

`[dcistr,dcibits] = ltePDCCHSearch(enb,chs,softbits)` recovers downlink control information (DCI) message structures, `dcistr`, and corresponding vectors of DCI message bits, `dcibits`, after blind decoding the multiplexed physical downlink control channels (PDCCHs) within the control region given by the `softbits` input vector, cell-wide configuration, `enb`, and UE-specific channel configuration, `chs`. For more information, see “PDCCH Search Processing” on page 1-552.

Examples

Get DCI Message Structure and Bits

Extract and decode the PDCCH symbols from the control region of a subframe grid created by the DL waveform generator, `lteRMCDLTool`. Use the blind search function, `ltePDCCHSearch`, to search the common and UE-specific spaces by demasking all PDCCH candidates with the configured RNTI.

Use a waveform generator to create a full subframe grid containing a reference PDSCH and associated DCI in UE-specific search space. Extract and decode all the PDCCH multiplex (control region) bits.

```
rmc = lteRMCDL('R.0');
[~,txGrid] = lteRMCDLTool(rmc,[1;0;0;1]);

pdcchSymbols = txGrid(ltePDCCHIndices(rmc));
rxPdcchBits = ltePDCCHDecode(rmc,pdcchSymbols);
```

Configure the UE-specific parameters that affect the DCI message lengths to match those of the reference UE.

```
ueConfig.RNTI = rmc.PDSCH.RNTI;
ueConfig.EnableCarrierIndication = 'Off';
ueConfig.EnableSRSRequest = 'Off';
ueConfig.EnableMultipleCSIRequest = 'Off';
ueConfig.NTxAnts = 1;
```

Use PDCCH blind search to find the DCI that schedules the PDSCH. Extract and display first DCI message structure from the search list. Compare the format of the DCI message returned in the previous step with the format used by the waveform generator.

```
[rxDCI,rxDCIBits] = ltePDCCHSearch(rmc,ueConfig,rxPdcchBits);

decDCI = rxDCI{1}
decDCIFormat = decDCI.DCIFormat
txDCIFormat = rmc.PDSCH.DCIFormat
```

```
decDCI =

  struct with fields:

          DCIFormat: 'Format1'
                CIF: 0
     AllocationType: 1
         Allocation: [1×1 struct]
          ModCoding: 14
             HARQNo: 0
            NewData: 1
                 RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
   HARQACKResOffset: 0


decDCIFormat =

    'Format1'


txDCIFormat =

    'Format1'
```

Get Two DCI Messages

Map a pair of format 0 uplink and format 1A downlink grants into a UE-specific search space in the PDCCH multiplex. Use the blind search function to recover them. Becasue the search space is UE-specific, you can extend the messages to include the Release 10 SRS request field and a 2-bit CSI request field for the format 0 DCI. For simplicity, the example does not include any PDCCH channel processing steps.

Create a vector containing the control region PDCCH multiplex bits.

```
enb = lteRMCDL('R.0');
pdcchinfo = ltePDCCHInfo(enb);
pdcchmux = zeros(1,pdcchinfo.MTot);
```

Configure the UE-specific parameters to control the DCI and encoding.

```
chs = struct('RNTI',1,'PDCCHFormat',2);
chs.ControlChannelType = 'PDCCH';
chs.SearchSpace = 'UESpecific';
chs.EnableCarrierIndication = 'Off';
chs.EnableSRSRequest = 'On';
chs.EnableMultipleCSIRequest = 'On';
chs.NTxAnts = 1;
```

List the formats to create and get the UE-specific search space candidate locations in the PDCCH multiplex.

```
formats = {'Format0','Format1A'};
candidates = ltePDCCHSpace(enb,chs);
```

For each DCI format, create the DCI info bits and encode them for PDCCH mapping. Demonstate setting of the `ModCoding` field to a nondefault value. Select a candidate to carry the target PDCCH.

```
for f = 1:length(formats)

    dciin = struct('DCIFormat',formats{f},'ModCoding',f);
    [dci,dcibits] = lteDCI(enb,chs,dciin);
    pdcch = lteDCIEncode(chs,dcibits);

    pdcchmux(candidates(f,1):candidates(f,2)) = pdcch;
end
```

Search PDCCH multiplex bits for any DCI messages directed at UE RNTI.

```
rxDCI = ltePDCCHSearch(enb,chs,pdcchmux)
rxDCI{:}
```

```
rxDCI =

  1×2 cell array

    [1×1 struct]    [1×1 struct]


ans =

  struct with fields:

           DCIFormat: 'Format1A'
                 CIF: 0
      AllocationType: 0
          Allocation: [1×1 struct]
           ModCoding: 2
              HARQNo: 0
             NewData: 0
                  RV: 0
            TPCPUCCH: 0
            TDDIndex: 0
          SRSRequest: 0
    HARQACKResOffset: 0


ans =

  struct with fields:

         DCIFormat: 'Format0'
               CIF: 0
       FreqHopping: 0
        Allocation: [1×1 struct]
         ModCoding: 1
           NewData: 0
               TPC: 0
        CShiftDMRS: 0
          TDDIndex: 0
        CSIRequest: 0
```

```
      SRSRequest: 0
AllocationType: 0
```

Input Arguments

enb — Cell-wide settings

structure

Cell-wide settings, specified as a structure with these fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL}) For information on link bandwidth assignment, see "Specifying Number of Resource Blocks" on page 1-553.
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL}) For information on link bandwidth assignment, see "Specifying Number of Resource Blocks" on page 1-553.
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as one of the following:

Parameter Field	Required or Optional	Values	Description
			• 'FDD' — Frequency division duplex (default) • 'TDD' — Time division duplex

Data Types: struct

chs — User-equipment-related channel configuration
structure

User-equipment-related (UE-related) channel configuration, specified as a structure containing the following UE-specific fields.

RNTI — Radio network temporary identifier
1 (default) | numeric scalar

Radio network temporary identifier value, specified as a numeric scalar.

Data Types: double

EnableCarrierIndication — Option to enable carrier indication
'Off' (default) | 'On' | optional

Option to enable carrier indication UE configuration, specified as 'Off' or 'On'. Default configuration is disabled. When enabled, 'On', the carrier indication field is present.

Data Types: char

EnableSRSRequest — Option to enable SRS request
'Off' (default) | 'On' | optional

Option to enable SRS request in the UE configuration, specified as 'Off' or 'On'. By default, EnableSRSRequest is disabled. When EnableSRSRequest is enabled ('On'), the SRS request field is present in UE-specific formats 0/1A for FDD or TDD and formats 2B/2C/2D for TDD.

Data Types: char

EnableMultipleCSIRequest — Option to enable multiple CSI requests
'Off' (default) | 'On' | optional

Option to enable multiple CSI requests in the UE configuration, specified as `'Off'` or `'On'`. By default, `EnableMultipleCSIRequest` is disabled. When `EnableMultipleCSIRequest` is enabled (`'On'`), the UE is configured to process multiple channel state information (CSI) requests from cells. Enabling multiple CSI requests affects the length of the CSI request field in UE-specific formats 0 and 4.

Data Types: `char`

`NTxAnts` — Number of UE transmission antennas

1 (default) | 2 | 4 | optional

Number of UE transmission antennas, specified as 1, 2, or 4. The number of UE transmission antennas affects the length of the precoding information field in DCI format 4.

Data Types: `double`

Data Types: `struct`

`softbits` — Input vector of soft bits

numeric column vector

Input vector of soft bits, specified as a column vector.

Data Types: `double`

Output Arguments

`dcistr` — Downlink control information (DCI) message structures

cell array of structures

Downlink control information (DCI) message structures, returned as a cell array of structures. Each structure represents a successfully decoded DCI whose fields match fields of the associated DCI format. Each structure contains the fields associated with one or more decoded DCI messages. Because multiple PDCCHs can be transmitted in a subframe, the UE must monitor all possible PDCCHs directed at it. If more than one PDCCH is directed to the UE or is successfully decoded, `dcistr` contains that number of decoded DCI messages.

Each cell contains a structure with the fields associated with the DCI format of the received PDCCHs.

`DCIFormat` — DCI format type

`'Format0' | 'Format1' | 'Format1A' | 'Format1B' | 'Format1C' | 'Format1D' | 'Format2' | 'Format2A' | 'Format2B' | 'Format2C' | 'Format3' | 'Format3A' | 'Format4' | 'Format5'`

DCI format type, specified as a character vector. This table presents the fields associated with each DCI format as defined in TS 36.212 [1], Section 5.3.3.

DCI Formats	dciout Fields	Size	Description
`'Format0'`	`DCIFormat`	-	`'Format0'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`FreqHopping`	1 bit	PUSCH frequency hopping flag
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation, coding scheme, and redundancy version
	`NewData`	1 bit	New data indicator
	`TPC`	2 bits	PUSCH TPC command
	`CShiftDMRS`	3 bits	Cyclic shift for DM RS
	`TDDIndex`	2 bits	For TDD config 0, this field is the Uplink Index. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`CSIRequest`	1, 2, or 3 bits	CSI request
	`SRSRequest`	0 or 1 bit	SRS request. This field can only be present in DCI formats scheduling PUSCH which are mapped onto the UE specific search space given by the C-RNTI
	`AllocationType`	1 bit	Resource allocation type, only present if $N_{\mathrm{RB}}^{\mathrm{UL}} \leq N_{\mathrm{RB}}^{\mathrm{DL}}$.
`'Format1'`	`DCIFormat`	-	`'Format1'`

DCI Formats	dciout Fields	Size	Description
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format1A'`	`DCIFormat`	-	`'Format1A'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	`Allocation`	Varies	Resource block assignment/ allocation
	`ModCoding`	5 bits	Modulation and coding scheme

DCI Formats	dciout Fields	Size	Description
	HARQNo	3 bits (FDD) 4 bits (TDD)	HARQ process number
	NewData	1 bit	New data indicator
	RV	2 bits	Redundancy version
	TPCPUCCH	2 bits	PUCCH TPC command
	TDDIndex	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	SRSRequest	0 or 1 bit	SRS request. This field can only be present in DCI formats scheduling PUSCH which are mapped onto the UE specific search space given by the C-RNTI
	HARQACKResOffset	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
'Format1B'	DCIFormat	-	'Format1B'
	CIF	0 or 3 bits	Carrier indicator field
	AllocationType	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	Allocation	Varies	Resource block assignment/ allocation
	ModCoding	5 bits	Modulation and coding scheme
	HARQNo	3 bits (FDD) 4 bits (TDD)	HARQ process number
	NewData	1 bit	New data indicator

DCI Formats	dciout Fields	Size	Description
	RV	2 bits	Redundancy version
	TPCPUCCH	2 bits	PUCCH TPC command
	TDDIndex	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	TPMI	2 bits for two antennas 4 bits for four antennas	PMI information
	PMI	1 bit	PMI confirmation
	HARQACKResOffset	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
'Format1C'	DCIFormat	-	'Format1C'
	Allocation	Varies	Resource block assignment/ allocation
	ModCoding	5 bits	Modulation and coding scheme
'Format1D'	DCIFormat	-	'Format1D'
	CIF	0 or 3 bits	Carrier indicator field
	AllocationType	1 bit	VRB assignment flag: 0 (localized), 1 (distributed)
	Allocation	Varies	Resource block assignment/ allocation
	ModCoding	5 bits	Modulation and coding scheme
	HARQNo	3 bits (FDD) 4 bits (TDD)	HARQ process number

DCI Formats	dciout Fields	Size	Description
	`NewData`	1 bit	New data indicator
	`RV`	2 bits	Redundancy version
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`TPMI`	2 bits for two antennas 4 bits for four antennas	Precoding TPMI information
	`DlPowerOffset`	1 bit	Downlink power offset
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2'`	`DCIFormat`	-	`'Format2'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command

DCI Formats	dciout Fields	Size	Description
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`SwapFlag`	1 bit	Transport block to codeword swap flag
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`PrecodingInfo`	3 bits for two antennas 6 bits for four antennas	Precoding information
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2A'`	`DCIFormat`	-	`'Format2A'`

DCI Formats	dciout Fields	Size	Description
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`SwapFlag`	1 bit	Transport block to codeword swap flag
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2

DCI Formats	dciout Fields	Size	Description
	`PrecodingInfo`	0 bits for two antennas 2 bits for four antennas	Precoding information
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2B'`	`DCIFormat`	-	`'Format2B'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`ScramblingId`	1 bit	Scrambling identity
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1

DCI Formats	dciout Fields	Size	Description
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2C'`	`DCIFormat`	-	`'Format2C'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`TxIndication`	3 bits	Antenna ports, scrambling identity, and number of layers indicator

DCI Formats	dciout Fields	Size	Description
	`SRSRequest`	Varies	SRS request. Only present for TDD.
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format2D'`	`DCIFormat`	-	`'Format2D'`
	`CIF`	0 or 3 bits	Carrier indicator field
	`AllocationType`	1 bit	Resource allocation header: type 0, type 1. If downlink bandwidth is ≤10 PRBs there is no resource allocation header and resource allocation type 0 is assumed.
	`Allocation`	Varies	Resource block assignment/ allocation
	`TPCPUCCH`	2 bits	PUCCH TPC command

DCI Formats	dciout Fields	Size	Description
	`TDDIndex`	2 bits	For TDD config 0, this field is not used. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	`HARQNo`	3 bits (FDD) 4 bits (TDD)	HARQ process number
	`TxIndication`	3 bits	Antenna ports, scrambling identity, and number of layers indicator
	`SRSRequest`	Varies	SRS request. Only present for TDD.
	`ModCoding1`	5 bits	Modulation and coding scheme for transport block 1
	`NewData1`	1 bit	New data indicator for transport block 1
	`RV1`	2 bits	Redundancy version for transport block 1
	`ModCoding2`	5 bits	Modulation and coding scheme for transport block 2
	`NewData2`	1 bit	New data indicator for transport block 2
	`RV2`	2 bits	Redundancy version for transport block 2
	`REMappingAndQCL`	2 bits	PDSCH RE Mapping and Quasi-Co-Location Indicator
	`HARQACKResOffset`	2 bits	HARQ-ACK resource offset. Present when this format is carried by EPDCCH. Not present when this format is carried by PDCCH
`'Format3'`	`DCIFormat`	-	`'Format3'`
	`TPCCommands`	Varies	TPC commands for PUCCH and PUSCH

DCI Formats	dciout Fields	Size	Description
'Format3A'	DCIFormat	-	'Format3A'
	TPCCommands	Varies	TPC commands for PUCCH and PUSCH
'Format4'	DCIFormat	-	'Format4'
	CIF	0 or 3 bits	Carrier indicator field
	Allocation	Varies	Resource block assignment/ allocation
	TPC	2 bits	PUSCH TPC command
	CShiftDMRS	3 bits	Cyclic shift for DM-RS
	TDDIndex	2 bits	For TDD config 0, this field is Uplink Index. For TDD config 1–6, this field is the Downlink Assignment Index. Not present for FDD.
	CSIReq	Varies	CSI request
	SRSRequest	2 bits	SRS request
	AllocationType	1 bit	Resource allocation header type 0 or type 1.
	ModCoding	5 bits	Modulation, coding scheme, and redundancy version
	NewData	1 bit	New data indicator
	ModCoding1	5 bits	Modulation and coding scheme for transport block 1
	NewData1	1 bit	New data indicator for transport block 1
	ModCoding2	5 bits	Modulation and coding scheme for transport block 2
	NewData2	1 bit	New data indicator for transport block 2

DCI Formats	dciout Fields	Size	Description
	PrecodingInfo	3 bits for two antennas 6 bits for four antennas	Precoding information
'Format5'	DCIFormat	-	'Format5'
	PSCCHResource	6 bits	Resource for PSCCH
	TPC	1 bit	TPC command for PSCCH and PSSCH
	FreqHopping	1 bit	Frequency hopping flag
	Allocation	Varies	Resource block assignment and hopping resource allocation
	TimeResourcePatte	7 bits	Time resource pattern

Data Types: char

Data Types: cell

dcibits — DCI message bits
cell array of numeric vectors

DCI message bits, returned as a cell array of one or more numeric vectors. Each vector contains the bit stream of a recovered DCI message, including any zero-padding. Each vector of bit values corresponds to successfully decoded DCI messages. For more information, see lteDCI.

Data Types: cell

Definitions

PDCCH Search Processing

PDCCH search processing blindly decodes DCI messages based on their lengths. The lengths and order in which DCI messages are searched for is provided by lteDCIInfo. If one or more messages have the same length, the first message format in the list is used to decode the message. The other potential message formats are ignored. The ltePDCCHSearch function does not consider transmission mode (TM) during blind

search, and no DCI message format is filtered based on transmission mode. It also does not search for format 3 and 3A (power adjustment commands for PUSCH and PUCCH). For more information on the association between transmission mode, transmission scheme, DCI format, and search space, see TS 36.213 [2], Section 7.1 and Table 7.1-5.

The UE is required to monitor multiple PDCCHs within the control region. The UE is informed only of the width, in OFDM symbols, of the control region within a subframe, and is not aware of the exact location of PDCCHs relevant to it. The UE finds the PDCCHs relevant to it by monitoring a set of PDCCH candidates, that is, a set of consecutive control candidate elements (CCEs) on which PDCCH can be mapped, in every subframe. For details, see `ltePDCCHSpace`. This process is referred to as *blind decoding*.

To simplify the decoding task at the UE, the whole control region is subdivided into common and UE-specific search spaces which the UE monitors (*monitor* implies attempting to decode each PDCCH). Each search space comprises 2, 4, or 6 PDCCH candidates whose data length depends on its corresponding PDCCH format. Each PDCCH must be transmitted on 1, 2, 4, or 8 CCE (1 CCE = 72 bits). The common search space is limited to only two aggregation levels, 4 and 8, while the UE-specific search space can have an aggregation level of 1, 2, 4, or 8.

All UEs within a cell monitor the common search space that carries control information common to all UEs. The common control information carries initial important information including paging information, system information, and random access procedures. The UE monitors the common search space by demasking each PDCCH candidate with different RNTIs, for example, P-RNTI, SI-RNTI, RA-RNTI and so on.

In the UE-specific search space, the UE finds the PDCCH relevant to it by monitoring a set of PDCCH candidates in every subframe. If no CRC error is detected when the UE demasks a PDCCH candidate with its RNTI (16-bit C-RNTI value), the UE determines that the PDCCH candidate carries its own control information.

The number and location of candidates within a search space is different for each PDCCH format. There are four PDCCH formats (0, 1, 2, or 3). If the UE fails to decode any PDCCH candidates for a given PDCCH format, it tries to decode candidates for another PDCCH format.

Specifying Number of Resource Blocks

The number of resource blocks specifies the uplink and downlink bandwidth. The LTE System Toolbox implementation assumes symmetric link bandwidth unless you

specifically assign different values to NULRB and NDLRB. If the number of resource blocks is initialized in only one link direction, then the initialized number of resource blocks (NULRB or NDLRB) is used for both uplink and downlink. When this mapping is used, no warning is displayed. An error occurs if NULRB and NDLRB are both undefined.

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHDeinterleave` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHInterleave` | `ltePDCCHPRBS` | `ltePDCCHSpace`

Introduced in R2014a

ltePDCCHSpace

PDCCH search space candidates

Syntax

```
ind = ltePDCCHSpace(enb,ue)
ind = ltePDCCHSpace(enb,ue,opts)
```

Description

`ind = ltePDCCHSpace(enb,ue)` returns the (0,2,4,6)-by-2 matrix `ind` of search space PDCCH candidate indices given the structures `enb` and `ue`. Depending on input parameters, each search space contains (0,2,4, or 6) PDCCH candidate locations defined by the rows of `ind`. Each two-element row contains the inclusive `[begin,end]` indices of a single PDCCH candidate location. By default, the one-based indices define the PDCCH locations in the block of all multiplexed PDCCH data bits to be transmitted in that subframe.

The control region of a downlink subframe comprises the multiplexing of all PDCCHs bits into a single block of data which is then processed and interleaved before PDCCH resource mapping. A UE has to blindly decode individual PDCCH directed at it. This task is simplified by subdividing the whole region into common and UE-specific search spaces which the UE should monitor. Each space comprises 2, 4, or 6 PDCCH candidates whose data length depends on its PDCCH format. Each PDCCH must be transmitted on 1, 2, 4, or 8 control channel elements (CCE) (1 CCE = 72 bits).

The returned search space is of the UE-specific type unless the `RNTI` field is missing from the structure `ue` when a common search space is returned. The search space always contains 2, 4, or 6 candidates; therefore, `ind` has 2, 4, or 6 rows, unless the parameter combinations are not valid, in which case the `ind` output returned is empty. For more information, see TS 36.213 [1], Section 9.1.1. The candidates in a space do not need to be unique, especially for smaller bandwidths.

`ind = ltePDCCHSpace(enb,ue,opts)` formats the returned indices using options defined in `opts`.

Examples

Get PDCCH Search Space Candidates

Find and use PDCCH search space candidates.

To illustrate the search space structuring of the PDCCH, set up a cell wide parameter structure, `enb`, with the following field values.

```
enb.NDLRB = 50;
enb.CFI = 2;
enb.CellRefP = 2;
enb.Ng = 'Sixth';
enb.NSubframe = 0;
```

This configuration defines a control region with the following information.

```
resInfo = ltePDCCHInfo(enb)
```

```
resInfo =

  struct with fields:

        NREG: 240
         NRE: 960
        NCCE: 26
    NREGUsed: 234
     NREUsed: 936
        MTot: 1920
    NSymbols: 2
```

The entire data block of padded, multiplexed PDCCHs needs to be 1920 bits, `resInfo.MTot`, in length. Using -1 to represent `NIL` padding "bits", create an "empty" multiplex.

```
pdcchs = -1*ones(1,resInfo.MTot);
```

Suppose you want to transmit all zeros in the first candidate of the UE-specific search space for PDCCH format 2 and the UE's `RNTI` = 1. For this format, a PDCCH spans 4 CCE or 288 bits, and the UE-specific search space contains two PDCCH candidates.

```
candidates = ltePDCCHSpace(enb,struct('PDCCHFormat',2,'RNTI',1))

candidates =

  2×2 uint32 matrix

   1441   1728
      1    288
```

These location values arise for `enb.NSubframe = 0`. They change in a pseudorandom fashion as the subframe number increases. Since the default candidate indices define inclusive, 1-based bounds, we can use them to index the PDCCH data multiplex directly by using the MATLAB® colon operator.

```
pdcchs(candidates(1,1):candidates(1,2)) = 0;
```

This command sets the 288 bits of the first PDCCH candidate to all zeros. The second candidate actually falls within the common search space also.

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure with these fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Numeric scalar value 6, 15, 25, 50, 75, and 100	Number of downlink resource blocks. (N_{RB}^{DL})
`CFI`	Required	1, 2, 3	Control format indicator value, specified as a double value.
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports

Parameter Field	Required or Optional	Values	Description
Ng	Required	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
NSubframe	Required	0 (default), nonnegative scalar integer 0 is default	Subframe number
NREG	Optional	Nonnegative scalar integer	Total number of resource element groups (REGs) associated with PDCCHs, specified as a nonnegative scalar integer. Optional. If the `NREG` field is absent, `enb` must contain the following fields. • `CyclicPrefix` • `CellRefP` • `CFI` • `Ng` • `DuplexMode` • `TDDConfig`, but only for `'TDD'` duplex mode
CyclicPre	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMod	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following field is required only when `DuplexMode` is set to `'TDD'`.			
TDDConf	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration

Data Types: `struct`

`ue` — UE-specific cell-wide settings

structure

UE-specific cell-wide settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`PDCCHForm`	Required	0, 1, 2, 3	PDCCH format
`RNTI`	Required	0 (default), scalar integer 1 is default	Radio network temporary identifier (RNTI) value (16 bits)

Data Types: `struct`

`opts` — Index generation options

character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing unit	`'bits'` (default), `'cce'`	Unit of the returned indices. Specify `'bits'` to indicate that the returned values correspond to bit indices. Specify `'cce'` to indicate that the returned values correspond tocontrol channel elements (CCEs) indices.

Data Types: `char | cell`

Output Arguments

`ind` — Search space PDCCH candidate indices

(0,2,4,6)-by-2 matrix

Search space PDCCH candidate indices, returned as a (0,2,4,6)-by-2 matrix given the structures `enb` and `ue`. It is a matrix of indices identifying a common or UE-specific PDCCH search space. Each two-element row contains the inclusive [*begin*,*end*] indices of a single PDCCH candidate location. By default, the one-based indices define the PDCCH locations in the block of all multiplexed PDCCH data bits to be transmitted in that subframe. `opts` defines alternative formats for returning the indices.

Data Types: `double`

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePDCCH` | `ltePDCCHDecode` | `ltePDCCHDeinterleave` | `ltePDCCHIndices` | `ltePDCCHInfo` | `ltePDCCHInterleave` | `ltePDCCHPRBS` | `ltePDCCHSearch`

Introduced in R2014a

ltePDSCH

Physical downlink shared channel

Syntax

```
sym = ltePDSCH(enb,chs,cws)
```

Description

`sym = ltePDSCH(enb,chs,cws)` returns a matrix containing the physical downlink shared channel (PDSCH) complex symbols for cell-wide settings, `enb`, channel transmission configuration, `chs`, and the codeword or codewords contained in `cws`. The channel processing includes the stages of scrambling, symbol modulation, layer mapping, and precoding.

Examples

Generate PDSCH symbols for Test Model E-TM1.1 10MHz

Generate the configuration structure for Test Model E-TM1.1 10 MHz, as specified in TS36.141

Initialize the test model using `lteTestModel`. Generate information related to PDSCH indices and use `info.Gd` output to determine the required transport block. Execute `lteDLSCH` to create the codeword, then generate the PDSCH symbols.

```
tm = lteTestModel('1.1','10MHz');
tm.PDSCH.RNTI = 0;
tm.PDSCH.RV = 0;

prbset = (0:tm.NDLRB-1)';
[ind,info] = ltePDSCHIndices(tm,tm.PDSCH,prbset);

trBlk  = randi([0,1],info.Gd,1);
cw = lteDLSCH(tm,tm.PDSCH,info.G,trBlk);
```

```
pdschSym = ltePDSCH(tm,tm.PDSCH,cw);
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter fields are dependent upon the condition that `chs.TxScheme` is set to `'SpatialMux'` or `'MultiUser'`.			
CFI	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)

Parameter Field	Required or Optional	Values	Description
		(corresponding to a frame).	
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

chs — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
Modulation	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
TxScheme	Required	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMu` `'MultiUser` `'Port5'`, `'Port7-8'`, `'Port8'`, `'Port7-14'`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td>NLayers</td><td>Required</td><td>Integer from 1 to 8</td><td>Number of transmission layers.

The number of layers is dependent on TxScheme.</td></tr>
<tr><td colspan="4">The following parameters are dependent upon the condition that TxScheme is set to 'SpatialMux' or 'MultiUser'.</td></tr>
<tr><td>PMISet</td><td>Required</td><td>Integer vector with element values from 0 to 15.</td><td>Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see ltePMIInfo.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.
The following parameters are dependent upon the condition that `TxScheme` is set to `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`.			
`W`	Optional	Numeric matrix, `[]` (default)	`NLayers`-by-*P* precoding matrix for the wideband UE-specific beamforming of the PDSCH symbols. *P* is the number of transmit antennas. An empty matrix, `[]`, signifies no precoding.

cws — Codeword or codewords

numeric vector | cell array

Codeword or codewords, specified as a vector of bit values for one codeword to be modulated, or a cell array containing one or two vectors of bit values corresponding to the one or two codewords to be modulated.

Output Arguments

`sym` — PDSCH symbols

complex numeric matrix

PDSCH symbols, returned as a complex numeric matrix. It has size *N*-by-*P*, where *N* is the number of modulation symbols for one antenna port and *P* is the number of transmission antennas. The complex symbols are generated using cell-wide settings, `enb`, channel transmission configuration, `chs`, and the codeword or codewords contained in `cws`.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.141. "Base Station (BS) conformance testing." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCH` | `ltePDSCHDecode` | `ltePDSCHIndices` | `ltePDSCHPRBS`

Introduced in R2014a

ltePDSCHDecode

Physical downlink shared channel decoding

Syntax

```
[cws,symbols] = ltePDSCHDecode(enb,chs,sym)
[cws,symbols] = ltePDSCHDecode(enb,chs,sym,hest,noiseest)
[cws,symbols] = ltePDSCHDecode(enb,chs,rxgrid,hest,noiseest)
```

Description

`[cws,symbols] = ltePDSCHDecode(enb,chs,sym)` performs the inverse of physical downlink shared channel (PDSCH) processing on the matrix of complex modulated PDSCH symbols, `sym`, using cell-wide settings structure, `enb`, and channel-specific configuration structure, `chs`. The channel inverse processing includes inverting the channel precoding, layer demapping and codeword separation, soft demodulation, and descrambling. Inverting the precoding is accomplished by matrix pseudoinversion of the precoding matrices. It returns a cell array, `cws`, of soft bit vectors, and a cell array, `symbols`, of received constellation symbol vectors resulting from performing the inverse of Physical Downlink Shared Channel (PDSCH) processing. For more information, see TS 36.211 [1], Section 6.4 and `ltePDSCH`. `cws` is optionally scaled by channel state information (CSI) calculated during the equalization process.

`[cws,symbols] = ltePDSCHDecode(enb,chs,sym,hest,noiseest)` performs the decoding of the complex modulated PDSCH symbols `sym` using cell-wide settings, `enb`, channel-specific configuration, `chs`, channel estimate, `hest`, and the noise estimate, `noiseest`.

The behavior varies based on the `chs.TxScheme` setting. For the `'TxDiversity'` transmission scheme, the precoding inversion is performed using an orthogonal space frequency block code (OSFBC) decoder. For the `'SpatialMux'`, `'CDD'`, and `'MultiUser'` transmission schemes, the precoding inversion is performed using a multiple-input, multiple-output (MIMO) minimum mean square error (MMSE) equalizer, equalizing between transmitted and received layers. For the `'Port0'`, `'Port5'`, `'Port7-8'`, `'Port8'`, and `'Port7-14'` transmission schemes, the reception is performed using MMSE equalization. The input channel estimate, `hest`, is assumed to

be with reference to the transmission layers, using the UE-specific reference signals, so the MMSE equalization will produce MMSE equalized layers.

`noiseest` is an estimate of the noise power spectral density per RE on the received subframe. This estimate is provided by the `lteDLChannelEstimate` function.

`[cws,symbols] = ltePDSCHDecode(enb,chs,rxgrid,hest,noiseest)` accepts the full received resource grid, `rxgrid`, for one subframe, in place of the `sym` input; the decoder will internally extract the PDSCH REs to obtain the complex modulated PDSCH symbols. `rxgrid` is a 3-D *M*-by-*N*-by-`NRxAnts` array of resource elements, where *M* and *N* are the number of subcarriers and symbols for one subframe for cell-wide settings `enb` and `NRxAnts` is the number of receive antennas. In this case, `hest` is a 4-D *M*-by-*N*-by-`NRxAnts`-by-`CellRefP` array where *M* and *N* are the number of subcarriers and symbols for one subframe for cell-wide settings `enb`, `NRxAnts` is the number of receive antennas, and `CellRefP` is the number of cell-specific reference signal antenna ports, given by `enb.CellRefP`. `hest` is processed to extract the channel estimates relevant to the PDSCH, those in the time and frequency locations corresponding to the PDSCH REs in `rxgrid`.

Examples

Decode PDSCH Symbols

Generate and decode PDSCH symbols.

Initialize cell parameter structure `enb` for RMC R.0.

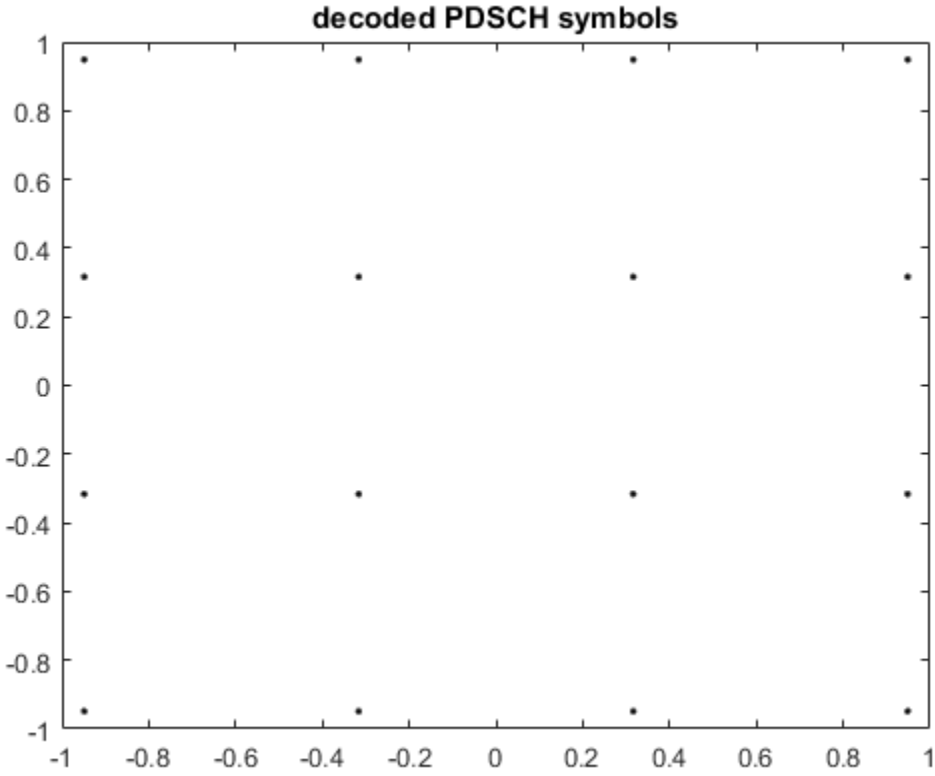
```
enb = lteRMCDL('R.0');
```

Populate a complex codeword matrix and generate modulated PDSCH symbols.

```
codewordBits = randi([0,1],enb.PDSCH.CodedTrBlkSizes(1),1);

pdschSym = ltePDSCH(enb,enb.PDSCH,codewordBits);
```

Decode and plot the PDSCH symbols.

```
[rxCodewords,rxSymbols] = ltePDSCHDecode(enb,enb.PDSCH,pdschSym);

plot (rxSymbols{:},'k.')
title('decoded PDSCH symbols')
```



Show size and first 5 elements of output codewords to be modulated, `rxCws`, and received symbols, `symbols`.

```
size_rxCodewords = size(rxCodewords{:})
rxCodewords{1}(1:1:5)

size_rxSymbols = size(rxSymbols{:})
rxSymbols{1}(1:5)
```

```
size_rxCodewords =

   504     1
```

```
ans =

    0.9487
    0.9487
   -0.3162
    0.3162
    0.3162


size_rxSymbols =

   126     1


ans =

  -0.9487 - 0.9487i
  -0.3162 + 0.9487i
  -0.3162 - 0.9487i
  -0.3162 - 0.3162i
   0.9487 - 0.9487i
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports

Parameter Field	Required or Optional	Values	Description
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter fields are dependent upon the condition that `chs.TxScheme` is set to `'SpatialMux'` or `'MultiUser'`.			
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CFI`	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

`chs` — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`	Modulation type, specified as a character vector or cell array of

Parameter Field	Required or Optional	Values	Description
			character vectors. If blocks, each cell is associated with a transport block.
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
TxScheme	Required	'Port0', 'TxDiversity', 'CDD', 'SpatialMu 'MultiUser 'Port5', 'Port7-8', 'Port8', 'Port7-14'	PDSCH transmission scheme, specified as one of the following options.
NLayers	Required	Integer from 1 to 8	Number of transmission layers.

Transmission scheme	Description
'Port0'	Single antenna port, port 0
'TxDiversity'	Transmit diversity
'CDD'	Large delay cyclic delay diversity scheme
'SpatialMux'	Closed loop spatial multiplexing
'MultiUser'	Multi-user MIMO
'Port5'	Single-antenna port, port 5
'Port7-8'	Single-antenna port, port 7, when **NLayers** = 1. Dual layer transmission, ports 7 and 8, when **NLayers** = 2.
'Port8'	Single-antenna port, port 8
'Port7-14'	Up to eight layer transmission, ports 7–14

Parameter Field	Required or Optional	Values	Description
`CSI`	Optional	`'Off'` (default), `'On'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.
The following parameters are dependent upon the condition that `TxScheme` is set to `'SpatialMux'` or `'MultiUser'`.			
`PMISet`	Required	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.

Parameter Field	Required or Optional	Values	Description
PRBSet	Required	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.
The following parameters are dependent upon the condition that `TxScheme` is set to `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`.			
W	Optional	Numeric matrix, `[]` (default)	`NLayers`-by-*P* precoding matrix for the wideband UE-specific beamforming of the PDSCH symbols. *P* is the number of transmit antennas. An empty matrix, `[]`, signifies no precoding.

sym — Complex modulated PDSCH symbols

numeric matrix

Complex modulated PDSCH symbols, specified as a numeric matrix of size `NRE`-by-`NRxAnts`. `NRE` is the number of QAM symbols per antenna assigned to the PDSCH and `NRxAnts` is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array | 4-D numeric array

Channel estimate, specified as a 3-D or 4-D numeric array. For the `'Port0'`, `'TxDiversity'`, `'SpatialMux'`, `'CDD'`, and `'MultiUser'` transmission schemes, the array size is `NRE`-by-`NRxAnts`-by-`CellRefP`, where `NRE` is the number of QAM symbols per antenna assigned to the PDSCH, `NRxAnts` is the number of receive antennas, and `CellRefP` is the number of cell-specific reference signal antennas, given by `enb.CellRefP`. For the `'Port5'`, `'Port7-8'`, `'Port8'`, and `'Port7-14'` transmission schemes, the array size is `NRE`-by-`NRxAnts`-by-`NLayers`, where `NLayers` is the number of transmission layers given by `chs.NLayers`.

When `rxgrid` is supplied, `hest` is a 4-D numeric array of size *M*-by-*N*-by-`NRxAnts`-by-`CellRefP`, where *M* and *N* are the number of subcarriers and symbols for one subframe for cell-wide settings, `enb`, `NRxAnts` is the number of receive antennas, and `CellRefP` is the number of cell-specific reference signal antenna ports, given by `enb.CellRefP`.

Data Types: `double`

`noiseest` — Noise estimate

numeric array

Noise estimate of the noise power spectral density per RE on the received subframe, specified as a numeric array.

Data Types: `double`

`rxgrid` — Full received resource grid

numeric array

Full received resource grid, specified as a 3-D *M*-by-*N*-by-`NRxAnts` array of resource elements, where *M* and *N* are the number of subcarriers and symbols for one subframe for cell-wide settings `enb` and `NRxAnts` is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`cws` — Codeword or codewords

cell array

Codeword or codewords, returned as a cell array containing one or two vectors of bit values corresponding to the one or two codewords to be modulated.

Data Types: `double`

`symbols` — Received constellation symbols
cell array of column vectors

Received constellation symbols, returned as a cell array of complex double column vectors, resulting from performing the inverse of PDSCH processing.

Data Types: `cell`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCHDecode` | `ltePDSCH` | `ltePDSCHIndices` | `ltePDSCHPRBS`

Introduced in R2014a

ltePDSCHIndices

Physical downlink shared channel (PDSCH) resource element indices

Syntax

```
[ind,info] = ltePDSCHIndices(enb,chs,prbset)
[ind,info] = ltePDSCHIndices(enb,chs,prbset,opts)
```

Description

`[ind,info] = ltePDSCHIndices(enb,chs,prbset)` returns a matrix, `ind`, containing physical downlink shared channel (PDSCH) resource element (RE) indices and a structure, `info`, containing information related to the PDSCH indices. By default, the output indices are a one-based linear indexed 3D array representing the subframe resource element grid for all antenna ports. You can use `ind` to index elements of the subframe resource grid directly for all antenna ports. This function is initialized with cell-wide settings, `enb`, channel transmission configuration, `chs`, and physical resource block indices, `prbset`.

`prbset` contains the physical resource block (PRB) indices corresponding to the resource allocation for this PDSCH transmission. You can specify `prbset` as either a column vector or a two-column matrix. If you specify a column vector, the resource allocation is the same in both slots of the subframe. If the PRBs in the first and second slots of the subframe differ, you can use the two-column matrix to specify PRBs. The PRB indices are zero-based.

Each column of the returned *N*-by-*P* matrix, `ind`, contains the per-antenna indices for the *N* resource elements in each of the *P* resource array planes. For the `'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, and `'MultiUser'` transmission schemes, *P* = `enb.CellRefP`. For the other transmission schemes, *P* = `chs.NTxAnts`. If `chs.NTxAnts = 0` or is absent, `ind` is an *N*-by-*NU* matrix containing the per-layer indices for the *N* resource elements in each of *NU* resource array planes. The planes are associated with the layers, where *NU* = `chs.NLayers`.

The `info` structure contains parameter fields `G` and `Gd`. `info.G` provides the appropriate size of the DL-SCH coder output, which is required as the parameter `outlen` provided

to the `lteDLSCH` function. `info.Gd` is the number of coded and rate-matched DL-SCH data symbols per layer, equal to the number of rows in the PDSCH indices. To provide accurate information in `info`, the `Modulation`, `TxScheme`, and `Nlayers` fields are required in `chs`.

Note: The `Modulation` and `Nlayers` fields are required only if the `info` output is assigned when you call the function.

`[ind,info] = ltePDSCHIndices(enb,chs,prbset,opts)` enables control over the format of the returned indices with options provided in cell array `opts`.

Examples

Generate PDSCH RE Indices

This example generates the 0-based PDSCH resource element (RE) indices mapping in linear index form for the 4-antenna case.

Create the cell-wide settings structure, `enb`.

```
enb = lteRMCDL('R.14');
enb.NDLRB = 6;
enb.CFI = 1;
enb.PDSCH.PRBSet = (1:enb.NDLRB-1).';
```

Generate PDSCH RE indices, specifying the 0-based and linear options.

```
ind = ltePDSCHIndices(enb,enb.PDSCH, ...
    enb.PDSCH.PRBSet,{'0based','ind'});
ind(1:10,:)
```

```
ans =

  10×4 uint32 matrix

    156   1164   2172   3180
    157   1165   2173   3181
    158   1166   2174   3182
    159   1167   2175   3183
```

```
160    1168    2176    3184
161    1169    2177    3185
162    1170    2178    3186
163    1171    2179    3187
164    1172    2180    3188
165    1173    2181    3189
```

The result, `ind`, is a matrix of 0-based mapping indices in linear index form. Since this is example is for the 4-antenna case, `ind`, has 4 columns.

Input Arguments

`enb` — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CFI`	Required	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)

Parameter Field	Required or Optional	Values	Description
DuplexMode	Optional	'FDD' (default), 'TDD'	Duplexing mode, specified as one of the following: • 'FDD' — Frequency division duplex (default) • 'TDD' — Time division duplex
The following apply when DuplexMode is set to 'TDD'.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)

The following table shows enb structure fields only required when the transmission scheme chs.TxScheme is set to 'Port7-14'.

Parameter Field	Required or Optional	Values	Description
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number
CSIRSPeriod	Optional	'Off' (default), 'On', Icsi-rs (0,...,154), [Tcsi-rs Dcsi-rs]. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following CSI-RS resource parameters apply only when CSIRSPeriod sets one or more CSI-RS subframe configurations to any value other than 'Off'. Each parameter length must be equal to the number of CSI-RS resources required.			
CSIRSConfig	Required	Nonnegative scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.

Parameter Field	Required or Optional	Values	Description
CSIRefP	Required	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
ZeroPowerCSIRSPer	Optional	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following zero power CSI-RS resource parameter is only required if one or more of the above zero power subframe configurations is set to any value other than `'Off'`.			
ZeroPowerCSIR	Required	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists. [1]

Data Types: `struct`

chs — PDSCH-specific channel transmission configuration

structure

PDSCH-specific channel transmission configuration, specified as a structure that can contain the following parameter fields.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td>TxScheme</td><td>Optional</td><td>'Port0', 'TxDiversity', 'CDD', 'SpatialMux', 'MultiUser', 'Port5', 'Port7-8', 'Port8', 'Port7-14'.</td><td>PDSCH transmission scheme, specified as one of the following options.
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td colspan="4">The following parameters apply when TxScheme is set to 'Port5', 'Port7-8', 'Port8', or 'Port7-14'.</td></tr>
<tr><td>NTxAnts</td><td>Optional</td><td>Nonnegative integer, 0 (default)</td><td>Number of transmission antenna ports. This argument is only present for UE-specific demodulation reference symbols.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
To provide accurate information in `info`, you are required to define `TxScheme` and the following additional parameters. These fields are only required when `info` is output.			
`Modulatio`	Optional	`'QPSK'` (default), `'16QAM'`, `'64QAM'`, or `'256QAM'`	Codeword modulation format, specified as a character vector or a cell array of one or two character vectors. To specify the modulation format for one codeword, use a character vector. To specify the modulation formats for two codewords, use a cell array of two character vectors.
`NLayers`	Optional	1 (default), 2, 3, 4, 5, 6, 7, 8	Number of transmission layers. The number of layers is dependent on `TxScheme`.

Data Types: `struct`

`prbset` — Physical resource block indices

column vector | 2-column numeric matrix

Physical resource block indices, specified as a column vector or a two-column numeric matrix. This argument contains the Physical Resource Block (PRB) indices corresponding to the resource allocation for this PDSCH transmission. If you specify a column vector, the resource allocation is the same in both slots of the subframe. If the PRBs in the first and second slots of the subframe differ, you can use the two-column matrix to specify PRBs. The PRB indices are zero-based.

Data Types: `double`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — Physical downlink shared channel (PDSCH) resource element (RE) indices

matrix

Physical downlink shared channel (PDSCH) resource element (RE) indices, specified as a matrix. Each column of the *N*-by-*P* matrix, `ind`, contains the per-antenna indices for the *N* resource elements in each of the *P* resource array planes. For the `'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, and `'MultiUser'` transmission schemes, *P* = `enb.CellRefP`. For the other transmissions schemes, *P* = `chs.NTxAnts`. If `chs.NTxAnts = 0` or is absent, the `ind` matrix is of size *N*-by-*NU*. In this case, `ind`contains the per-layer indices for the *N* resource elements in each of *NU* resource array planes associated with the layers, where *NU* = `chs.NLayers`. You can return the indices in alternative indexing formats using the argument `opts`.

Note: The active or zero-power CSI-RS resource elements are excluded from the output indices only for the Release 10/11, `'Port7-14'` transmission scheme. For all other schemes, the CSI-RS resource element indices are not avoided, which results in a Release 8/9 compatible PDSCH. Any active or zero-power CSI-RS would overwrite the associated PDSCH REs later in the subframe construction.

`info` — Information related to PDSCH indices

structure

Information related to PDSCH indices, returned as a structure. To provide accurate information in `info`, the channel transmission configuration structure, `chs`, must contain the fields `TxScheme`, `Modulation`, and `NLayers`. The structure `info` has the following fields.

Parameter Field	Description	Values	Data Type
`G`	Number of coded and rate-matched DL-SCH data bits for each codeword.	one or two element vector	`uint32`
`Gd`	Number of coded and rate-matched DL-SCH data symbols per layer.	Integer equal to the number of rows in the PDSCH indices	`uint32`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePDSCH` | `ltePDSCHDecode` | `ltePDSCHPRBS`

Introduced in R2014a

ltePDSCHPRBS

PDSCH pseudorandom scrambling sequence

Syntax

```
seq = ltePDSCHPRBS(enb,rnti,cwIndex,n)
seq = ltePDSCHPRBS(enb,rnti,cwIndex,n,mapping)
```

Description

`seq = ltePDSCHPRBS(enb,rnti,cwIndex,n)` returns a column vector containing the first `n` outputs of the Physical Downlink Shared Channel (PDSCH) scrambling sequence when initialized according to cell-wide settings, `enb`, 16-bit `rnti`, and `cwIndex`, which is either 0 or 1, indicating which codeword this sequence scrambles.

`seq = ltePDSCHPRBS(enb,rnti,cwIndex,n,mapping)` allows control over the format of the returned sequence `seq` with the input `mapping`.

Examples

Scramble Codeword Using PDSCH PRBS

Scramble the contents of a codeword using the PDSCH scrambling sequence.

Create cell-wide configuration structure for reference channel R.0, get PDSCH indices, and a create codeword.

```
enb = lteRMCDL('R.0');
pdsch = enb.PDSCH;
[~,pdschInfo] = ltePDSCHIndices(enb,pdsch,pdsch.PRBSet);
codedTrBlkSize = pdschInfo.G;
cw = randi([0 1],codedTrBlkSize,1);
```

Generate PDSCH scrambling sequence, and scramble the codeword using the PDSCH scrambling sequence.

```
RNTI = 11;
ncw = 0;
pdschPrbsSeq = ltePDSCHPRBS(enb,RNTI,ncw,length(cw));
scrambled = xor(pdschPrbsSeq, cw);
```

Scramble Two Codewords Using PDSCH PRBS

Scramble the contents of two codewords using the PDSCH scrambling sequence. When transmitting multiple codewords via spatial multiplexing, each codeword uses a different scrambling sequence.

Create cell-wide configuration structure for reference channel R.14, get PDSCH indices.

```
rmc.RC = 'R.14';
rmc = lteRMCDL(rmc,2);
pdsch = rmc.PDSCH;
[~,pdschInfo] = ltePDSCHIndices(rmc,pdsch,pdsch.PRBSet);
codedTrBlkSize1 = pdschInfo.G(1);
codedTrBlkSize2 = pdschInfo.G(2);
cws{1} = randi([0 1],codedTrBlkSize1,1);
cws{2} = randi([0 1],codedTrBlkSize2,1);
```

Generate PDSCH scrambling sequences for two codewords, and scramble the codewords using the PDSCH scrambling sequences.

```
RNTI = 11;
ncw = 0;
pdschPrbsSeq1 = ltePDSCHPRBS(rmc,RNTI,ncw,length(cws{1}));
ncw = 1;
pdschPrbsSeq2 = ltePDSCHPRBS(rmc,RNTI,ncw,length(cws{2}));
scrambled1 = xor(pdschPrbsSeq1, cws{1});
scrambled2 = xor(pdschPrbsSeq2, cws{2});
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

`NCellID` — Physical layer cell identity

nonnegative integer

Physical layer cell identity, specified as a nonnegative integer.

Data Types: `double`

`NSubframe` — Subframe number

nonnegative integer

Subframe number, specified as a nonnegative integer.

Data Types: `double`

Data Types: `struct`

`rnti` — Radio network temporary identifier

nonnegative integer

Radio network temporary identifier, specified as nonnegative integer.

Data Types: `double`

`cwIndex` — Codeword index

0 | 1

Codeword index, specified as a 0 or 1. This input indicates which codeword this sequence scrambles.

Data Types: `double`

`n` — Length of scrambling sequence

positive integer

Length of scrambling sequence, specified as a positive integer.

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — PDSCH scrambling sequence

logical column vector | numeric column vector

PDSCH scrambling sequence, returned as a numeric column vector. This output argument contains the first `n` outputs of the PDSCH pseudorandom scrambling sequence. If `mapping` is set to `'signed'`, `seq` is a vector of data type double. Otherwise, it is a vector of data type logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePDSCH` | `ltePDSCHDecode` | `ltePDSCHIndices`

Introduced in R2014a

ltePHICH

Physical hybrid ARQ indicator channel

Syntax

```
[sym] = ltePHICH(enb,hiset)
[sym,info] = ltePHICH(enb,hiset)
```

Description

`[sym] = ltePHICH(enb,hiset)` returns a matrix, `sym`, of symbols generated by the set of physical hybrid ARQ indicator channels (PHICH) in a subframe, given the cell-wide settings configuration structure, `enb`, and HARQ indicator set, `hiset`. For more information, see "PHICH Generation" on page 1-598.

`[sym,info] = ltePHICH(enb,hiset)` also returns an `info` structure, containing control resourcing information about the output symbols.

Examples

Generate PHICH Symbols

Generate physical HARQ indicator channel (PHICH) symbols for three different HARQ indicator (HI) sets. An HI set is comprised of the PHICH group index number, the sequence number within the group, and an ACK/NACK.

Create a cell-wide settings configuration structure with a single antenna (`enb.CellRefP=1`), normal CP, fifty downlink resource blocks (`enb.NDLRB=50`), and a one sixth HICH group multiplier (`enb.Ng='Sixth'`). For this system configuration, 16 PHICH are available. The available PHICH are split between two groups of eight sequences. The sequences are mapped to `info.NRE`=24 resource elements. Calling `lteRMCDL` with RMC R.7 provides the desired configuration structure.

Generate PHICH symbols with various HI set configurations.

PHICH Symbols for Empty HI Set

Generate `ltePHICH` output for an empty HI set.

```
enb = lteRMCDL('R.7');
[sym,info] = ltePHICH(enb,[])
sizeSym = size(sym)
```

```
sym =

   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i


info =

  struct with fields:

           NREG: 6
            NRE: 24
         NPHICH: 16
        NGroups: 2
```

```
    NMappingUnits: 2
       NSequences: 8
    PHICHDuration: 1
      ActiveHISet: []


sizeSym =

    24     1
```

`ltePHICH` returns an NRE-by-CellRefP matrix of zeros. The transmission configuration is one antenna, as shown by the second dimension of the `sym` matrix. The `info` output structure is populated based on inputs to `ltePHICH`.

PHICH Symbols for Single HI Set

Modulate a NACK (`hi=0`) onto the third orthogonal sequence (`nSeq=2`) of the second group (`nGroup=1`). Generate PHICH symbols specifying the HI set as [nGroup=1 nSeq=2 hi=0].

```
enb = lteRMCDL('R.7');
sym = ltePHICH(enb,[1 2 0])
sizeSym = size(sym)
```

```
sym =

   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
  -0.7071 - 0.7071i
  -0.7071 - 0.7071i
```

```
   0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 + 0.7071i


sizeSym =

    24     1
```

The result remains an NRE-by-CellRefP matrix.

PHICH Symbols for Multiple HI Sets

For the second PHICH, add an ACK (`hi=1`) on the last sequence (`nSeq=7`) of the first group (`nGroup=0`). Generate PHICH symbols specifying the HI sets as [[nGroup=1 nSeq=2 hi=0]; [nGroup=0 nSeq=7 hi=1]].

```
enb = lteRMCDL('R.7');
[sym,info] = ltePHICH(enb,[[1 2 0];[0 7 1]])
sizeSym = size(sym)
```

```
sym =

   0.7071 - 0.7071i
   0.7071 - 0.7071i
  -0.7071 + 0.7071i
   0.7071 - 0.7071i
   0.7071 - 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
  -0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
  -0.7071 - 0.7071i
```

```
  -0.7071 - 0.7071i
   0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
   0.7071 + 0.7071i


info =

  struct with fields:

            NREG: 6
             NRE: 24
          NPHICH: 16
         NGroups: 2
    NMappingUnits: 2
       NSequences: 8
    PHICHDuration: 1
      ActiveHISet: [2×3 double]


sizeSym =

    24     1
```

The result remains an NRE-by-CellRefP matrix.

Input Arguments

enb — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

NDLRB — Number of downlink resource blocks

positive integer

Number of downlink resource blocks, specified as a positive integer.

Data Types: `double`

`NCellID` — Physical layer cell identity
nonnegative integer

Physical layer cell identity, specified as a nonnegative integer.

Data Types: `double`

`CellRefP` — Number of cell-specific reference signal antenna ports
1 | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NSubframe` — Subframe number
nonnegative integer

Subframe number, specified as a nonnegative integer.

Data Types: `double`

`Ng` — HICH group multiplier
`'Sixth'` | `'Half'` | `'One'` | `'Two'`

HICH group multiplier, specified as `'Sixth'`, `'Half'`, `'One'`, or `'Two'`.

Data Types: `char`

`DuplexMode` — Duplex mode
`'FDD'` (default) | optional | `'TDD'`

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration
0 (default) | optional | 1 | 2 | 3 | 4 | 5 | 6

Uplink or downlink configuration, specified as a nonnegative scalar integer from 0 through 6. This argument is only required if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

Data Types: `struct`

`hiset` — HARQ indicator set

numeric matrix | [ ]

HARQ indicator set, specified as an R-by-3 numeric matrix. R is the number of rows. Each row of `hiset` defines a single PHICH in terms of `[nGroup,nSeq,hi]`.

- `nGroup` is the PHICH group index number.
- `nSeq` is the sequence index number within the group.
- `hi` is 1 or 0 representing hybrid ARQ indicator ACK or NACK, respectively.

The `nGroup` and `nSeq` indices are zero-based. For more information, see "PHICH Generation" on page 1-598.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`sym` — PHICH symbols

numeric matrix

PHICH symbols, returned as an `NRE`-by-`CellRefP` numeric matrix. `NRE` is the number of resource elements, and `CellRefP` is the number of cell-specific reference signal antenna ports. Each column of `sym` contains the per-antenna symbols for the combined set of PHICHs. The output matrix, `sym`, always contains `info.NRE` symbols to map into the total PHICH resource allocation, even if less than the full set of `NPHICH` channels are configured. For more information, see "PHICH Generation" on page 1-598.

Data Types: `double`
Complex Number Support: Yes

`info` — PHICH subframe resourcing information about output symbols

scalar structure

PHICH subframe resourcing information about the output symbols, returned as a scalar structure. `info` contains the following fields. For background on the `info` structure, see `ltePHICHInfo`.

`NREG` — Number of resource element groups assigned to all PHICH
positive integer

Number of resource element groups assigned to all PHICH, returned as a positive integer.

Data Types: `uint64`

`NRE` — Number of resource elements assigned to all PHICH
positive integer

Number of resource elements assigned to all PHICH, returned as a positive integer.

Data Types: `uint64`

`NPHICH` — Number of individual PHICH available
positive integer

Number of individual PHICH available, returned as a positive integer.

Data Types: `uint64`

`NGroups` — Number of PHICH groups
positive integer

Number of PHICH groups, returned as a positive integer.

Data Types: `int8`

`NMappingUnits` — Number of PHICH mapping units
positive integer

Number of PHICH mapping units, returned as a positive integer.

Data Types: `int8`

`NSequences` — Number of orthogonal sequences in each PHICH group
positive integer

Number of orthogonal sequences in each PHICH group, returned as a positive integer.

Data Types: `int8`

`PHICHDuration` — PHICH duration
integer

PHICH duration, returned as an integer.

Data Types: `int8`

`ActiveHISet` — Active HARQ indicator set
matrix | [ ]

Active HARQ indicator set, returned as an *N*-by-3 matrix. *N* is the number of rows with a valid `hiset` defined. `ActiveHISet` contains only rows that define a valid HARQ indicator set, even if the input `hiset` has rows in which `NGroup` ≥ `info.NGroups`. If `hiset` is empty, `ActiveHISet` is returned as an empty matrix, [ ].

Data Types: `int8`

Data Types: `struct`

Definitions

PHICH Generation

The physical hybrid ARQ indicator channel (PHICH) processing includes the stages of BPSK modulation, orthogonal sequence spreading, scrambling, resource element group (REG) alignment, layer mapping, precoding, PHICH group summation, and mapping unit creation. For details, see TS 36.211 [1], Section 6.9.

The control region of a subframe can contain up to `info.NPHICH` separate PHICH, each carrying a single hybrid ARQ (HARQ) acknowledgment (ACK), or negative acknowledgment (NACK). Settings in the `enb` structure define *NPHICH*.

The input `hiset` specifies an *R*-by-3 matrix, configuring individual PHICH that are combined in the output. *R* is the number of rows. Each row of `hiset` defines a single PHICH in terms of `[nGroup,nSeq,hi]`. In the `info` structure fields, the following conditions apply for the sets of hybrid indicators defined:

- `nGroup` < `info.NGroups`
- `nSeq` < `info.NSequences`

To generate PHICH symbol, `ltePHICH` uses the rows of `hiset` in which `nGroup` < `info.NGroups`. These rows are present in `info.ActiveHISet`. Any other rows present in `hiset` are ignored.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePHICHDecode` | `ltePHICHIndices` | `ltePHICHInfo` | `ltePHICHPRBS` | `ltePHICHPrecode`

Introduced in R2014a

ltePHICHDecode

Physical hybrid ARQ indicator channel decoding

Syntax

```
[hi,symbols] = ltePHICHDecode(enb,hires,sym)
[hi,symbols] = ltePHICHDecode(enb,hires,sym,hest,noiseest)
[hi,symbols] = ltePHICHDecode(enb,hires,sym,hest,noiseest,alg)
```

Description

`[hi,symbols] = ltePHICHDecode(enb,hires,sym)` performs the inverse of Physical Hybrid ARQ Indicator Channel (PHICH) processing given the cell-wide settings structure, `enb`, PHICH resources, `hires`, and the matrix of PHICH symbols, `sym`. It returns a column vector of hybrid ARQ indicator values, `hi`, and the received symbol constellation matrix, `symbols`. The channel inverse processing includes deprecoding, descrambling, despreading and symbol demodulation. For details, see TS 36.211 [1], Section 6.9 and `ltePHICH`.

`[hi,symbols] = ltePHICHDecode(enb,hires,sym,hest,noiseest)`, where `hest` contains the channel estimate, and `noiseest` contains the noise estimate.

- For the `TxDiversity` transmission scheme (`CellRefP`=2 or 4), the reception is performed using an Orthogonal Space Frequency Block Code (OSFBC) decoder.
- For the `'Port0'` transmission scheme (`CellRefP`=1), the reception is performed using MMSE equalization.

`[hi,symbols] = ltePHICHDecode(enb,hires,sym,hest,noiseest,alg)`, where specifying `alg` provides control over weighting the soft values that are used to determine `hi` with the channel state information (CSI) calculated during the equalization process.

Examples

Decode HARQ

Decode the HARQ bits given PHICH symbols. Two HARQ bits are encoded into PHICH symbols using an `hiset` matrix, where each row is used to define an individual PHICH.

The generated PHICH symbols are then decoded with the same parameters used to define the PHICHs in the encoder.

Using `lteRMCDL` to create a cell-wide settings configuration structure with RMC R.1, initializes relevant parameters for this example.

```
rc = 'R.1';
enb = lteRMCDL(rc);
```

Define the `hiset` input and generate PHICH symbols. First PHICH: [nGroup=1 nSeq=1 hi=1], second PHICH: [nGroup=1 nSeq=2 hi=0].

```
hiset = [ 1 1 1; 1 2 0 ];
phichSym = ltePHICH(enb,hiset);
```

Define the `hires` input. PHICH resources: same as the encoder, first PHICH: [nGroup=1 nSeq=1], second PHICH: [nGroup=1 nSeq=2].

```
hires = [ 1 1; 1 2];
```

Decode the PHICH.

```
hi = ltePHICHDecode(enb,hires,phichSym);
```

Check decoded hi bits are the same as encoded bits.

```
isequal(hi,hiset(:,3))
```

```
ans =

  logical

   1
```

Input Arguments

enb — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` is a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

`hires` — PHICH resources

numeric matrix

PHICH resources, specified as an *R*-by-2 numeric matrix. This matrix configures up to *NPHICH* individual PHICH for decoding by `ltePHICHDecode`. Each row of `hires` defines a single PHICH in terms of `[nGroup,nSeq]`, where `nGroup` is the PHICH group index number and `nSeq` is the sequence index number. These indices are zero-based.

Each row of output, `hi`, represents the received Hybrid ARQ indicator values for the PHICH defined in the corresponding row of `hires`. Similarly, each row of the output, `symbols`, contains the three received symbols (after despreading) for the corresponding row of `hires`.

In terms of `ltePHICHInfo` `info` structure fields, the following conditions apply:
`nGroup` < `info.NGroups`
`nSeq` < `info.NSequences`
Rows of `hires` with `nGroup` ≥ `info.NGroups` are ignored and output for these rows in `hi` and `symbols` is set to zero.

Data Types: `double`
Complex Number Support: Yes

`sym` — Complex modulated PHICH symbols

numeric matrix

Complex modulated PHICH symbols, specified as an `NRE`-by-`NRxAnts` numeric matrix of PHICH symbols. `NRE` is the number of BPSK symbols per antenna assigned to the

PHICH, and NRxAnts is the number of receive antennas. Even if less than the full set of *NPHICH* channels were configured, ensure the sym input matrix contains info.NRE symbols corresponding to the total PHICH resource allocation. Use ltePHICHInfo to view the info structure fields.

Data Types: double
Complex Number Support: Yes

hest — Channel estimate

3-D numeric array

Channel estimate, specified as an NRE-by-NRxAnts-by-enb.CellRefP numeric array, where:

- NRE are the frequency and time locations corresponding to the PCFICH RE positions (a total of NRE positions).
- NRxAnts is the number of receive antennas.
- enb.CellRefP is the number of cell-specific reference signal antennas.

Data Types: double
Complex Number Support: Yes

noiseest — Noise estimate

numeric scalar

Noise estimate, specified as a numeric scalar. This input argument is an estimate of the noise power spectral density per RE on received subframe. Such an estimate is provided by the lteDLChannelEstimate function.

Data Types: double

alg — Weighting algorithm

structure

Weighting algorithm, specified as a structure. This input argument controls weighting output soft bits, bits, with CSI. alg contains the following fields.

Parameter Field	Required or Optional	Values	Description
CSI	Optional	'On' (default), 'Off'	Flag provides control over weighting the soft values

Parameter Field	Required or Optional	Values	Description
			that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.

Data Types: `struct`

Output Arguments

`hi` — Hybrid ARQ indicator values

numeric column vector

Hybrid ARQ indicator values, returned as a numeric column vector. Each row represents the received Hybrid ARQ indicator values for the PHICH defined in the corresponding row of `hires`.

Data Types: `double`

`symbols` — Received symbols

numeric matrix

Received symbols, returned as a numeric matrix. Each row contains the received constellation symbols (after despreading) for the corresponding row of `hires`.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePHICH` | `ltePHICHDeprecode` | `ltePHICHIndices` | `ltePHICHInfo` | `ltePHICHPRBS` | `ltePHICHTransmitDiversityDecode`

Introduced in R2014a

ltePHICHDeprecode

PHICH deprecoding

Syntax

```
out = ltePHICHDeprecode(in,cp,ngroup)
out = ltePHICHDeprecode(enb,ngroup,in)
```

Description

`out = ltePHICHDeprecode(in,cp,ngroup)` performs deprecoding of the *N*-by-*P* matrix of antennas, `in`, onto *NU*=*P* layers, given cyclic prefix length, `cp`, and PHICH group, `ngroup`. *N* is the number of symbols per antenna. It performs PHICH deprecoding using matrix pseudoinversion to undo the processing described in TS 36.211, Section 6.9.2 [1]. This function returns `out`, an *M*-by-*NU* matrix, where *NU* is the number of transmission layers and *M* is the number of symbols per layer.

`out = ltePHICHDeprecode(enb,ngroup,in)` performs deprecoding of the *N*-by-*P* matrix of antennas, `in`, onto *NU*=*P* layers, for PHICH group, `ngroup`, using the cell-wide settings structure, `enb`.

Examples

Deprecode PHICH symbols2

This example shows the deprecoding of a set of physical HARQ indicator channel (PHICH) symbols for reference measurement channel (RMC) R.11.

Initialize a cell-wide parameter configuration structure, `enb`, for RMC R.11.

```
rc = 'R.11';
enb = lteRMCDL(rc);
nLayers = enb.PDSCH.NLayers;
```

Generate an arbitrary set of input symbols as the PHICH symbols.

```
phichSym = reshape(lteSymbolModulate(randi([0,1],40*nLayers*2,1), ...
    'QPSK'),40,nLayers);
```

Precode the PHICH symbols using normal cyclic prefix (setting for `enb.CyclicPrefix` as per R.11) and PHICH group 1.

```
nGroup = 1;
precodedSym = ltePHICHPrecode(phichSym,enb.CyclicPrefix,nGroup);
```

Deprecode the precoded PHICH symbols using normal cyclic prefix and PHICH group 1.

```
out = ltePHICHDeprecode(precodedSym,enb.CyclicPrefix,nGroup);
```

Check PHICH symbols vs. deprecoded PHICH symbols.

```
isequal(phichSym,out)
```

```
ans =

  logical

   1
```

Input Arguments

`in` — Precoded input symbols

complex-valued numeric matrix

Precoded input symbols, specified as a complex-valued numeric matrix of antennas. It has size N-by-P, where N is the number of symbols per antenna and P is the number of antennas. The number of input symbols, N, must be a multiple of the number of antennas, P.

Data Types: `double`
Complex Number Support: Yes

`cp` — Cyclic prefix length

`'Normal' | 'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`ngroup` — PHICH group number

positive scalar integer (≥1)

PHICH group number, specified as a positive scalar integer of 1 or more.

Data Types: `double`

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

Output Arguments

`out` — Deprecoded output symbols

numeric matrix

Deprecoded output symbols, returned as a numeric matrix. It has size *M*-by-*NU*, where *M* is the number of symbols per layer and *NU* is the number of transmission layers.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteLayerDemap` | `ltePHICHDecode` | `ltePHICHIndices` | `ltePHICHInfo` | `ltePHICHPRBS` | `ltePHICHPrecode` | `ltePHICHTransmitDiversityDecode`

Introduced in R2014a

ltePHICHIndices

PHICH resource element indices

Syntax

```
ind = ltePHICHIndices(enb)
ind = ltePHICHIndices(enb,opts)
```

Description

`ind = ltePHICHIndices(enb)` returns the subframe resource element (RE) indices, `ind`, for the Physical Hybrid-ARQ Indicator Channels (PHICH), given the parameter fields of cell-wide settings structure, `enb`. By default, the number of rows of `ind` is the number of resource elements (N_{RE}), and `ind` is an N_{RE}-by-`CellRefP` matrix of indices in a one-based linear indexing style. These indices can directly index elements of an *N*-by-*M*-by-`CellRefP` array that represents the subframe resource grid across `CellRefP` antenna ports. Each column of `ind` identifies the same set of N_{RE} resource elements, but with indices offset to select them in a different antenna "page" of the 3-D resource array.

The indices returned are for all PHICH groups in a subframe, where the number of groups depends on the bandwidth and PHICH `Ng` parameter. See `ltePHICHInfo` for details. The indices are ordered as the modulation symbols should be mapped for the set of consecutive PHICH groups. The PHICH resources are normally all assigned in the first OFDM symbol of a subframe, unless the PHICH duration is of the extended type.

`ind = ltePHICHIndices(enb,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PHICH Indices

Generate PHICH resource element (RE) indices in linear form and resource element group (REG) indices in subscript form.

Get one-based PHICH resource element (RE) indices in linear form.

```
enb = lteRMCDL('R.14');
enb.NDLRB = 6;
indOneBased = ltePHICHIndices(enb,{'ind','re'})
```

```
indOneBased =

  12×4 uint32 matrix

     8   1016   2024   3032
     9   1017   2025   3033
    11   1019   2027   3035
    12   1020   2028   3036
    26   1034   2042   3050
    27   1035   2043   3051
    29   1037   2045   3053
    30   1038   2046   3054
    50   1058   2066   3074
    51   1059   2067   3075
    53   1061   2069   3077
    54   1062   2070   3078
```

Get zero-based PHICH resource element group (REG) indices in subscript form, where each column of `ind` corresponds to a dimension of the 3-D resource grid array: subcarrier, OFDM symbol, and antenna port.

```
indZeroBased = ltePHICHIndices(enb,{'Obased','sub','reg'})
```

```
indZeroBased =

  12×3 uint32 matrix

    6    0    0
   24    0    0
   48    0    0
    6    0    1
   24    0    1
   48    0    1
    6    0    2
   24    0    2
   48    0    2
    6    0    3
   24    0    3
```

```
    48     0     3
```

Input Arguments

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` can contain the following fields. The `TDDConfig` and `NSubframe` parameter fields are only required if `DuplexMode` is set to `'TDD'`.

`NDLRB` — Number of downlink resource blocks

positive integer

Number of downlink resource blocks, specified as a positive integer.

Data Types: `double`

`NCellID` — Physical layer cell identity

nonnegative integer

Physical layer cell identity, specified as a nonnegative integer.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`CellRefP` — Number of cell-specific reference signal antenna ports

1 | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

Data Types: `double`

`Ng` — HICH group multiplier

`'Sixth'` | `'Half'` | `'One'` | `'Two'`

HICH group multiplier, specified as `'Sixth'`, `'Half'`, `'One'`, or `'Two'`.

Data Types: `char`

`PHICHDuration` — PHICH duration
`'Normal'` (default) | optional | `'Extended'`

PHICH duration, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`DuplexMode` — Duplex mode
`'FDD'` (default) | optional | `'TDD'`

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration
0 (default) | optional | 1 | 2 | 3 | 4 | 5 | 6

Uplink or downlink configuration, specified as a nonnegative scalar integer from 0 through 6. Only required if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

`NSubframe` — Subframe number
nonnegative integer

Subframe number, specified as a nonnegative integer. Only required if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

Data Types: `struct`

`opts` — Index generation options
character vector | cell array of character vectors

Index generation options, specified as a character vector or a cell array of character vectors that can contain the following values.

Option	Values	Description
Indexing style	`'ind'` (default), `'sub'`	Style for the returned indices, specified as one of the following options. • `'ind'` — returns the indices in linear index form as a column vector (default)

Option	Values	Description
		• `'sub'` — returns the indices in `[subcarrier, symbol, antenna]` subscript row style. The number of rows in the output, `ind`, is the number of resource elements (N_{RE}). Thus, `ind` is an N_{RE}-by-3 matrix.
Index base	`'1based'` (default), `'0based'`	Base value of the returned indices. Specify `'1based'` to generate indices where the first value is one. Specify `'0based'` to generate indices where the first value is zero.
Indexing unit	`'re'` (default), `'reg'`	Unit of the returned indices. Specify `'re'` to indicate that the returned values correspond to individual resource elements (REs). Specify `'reg'` to indicate that the returned values correspond to resource element groups (REGs).

Data Types: `char` | `cell`

Output Arguments

`ind` — PHICH resource element indices

numeric matrix

PHICH resource element indices, returned as a numeric matrix. The size of the matrix is N_{RE}-by-`CellRefP`. By default, it contains one-based linear indexing RE indices.

Data Types: `uint32`

See Also

See Also

`ltePHICH` | `ltePHICHDecode` | `ltePHICHDeprecode` | `ltePHICHInfo` | `ltePHICHPRBS` | `ltePHICHPrecode`

Introduced in R2014a

ltePHICHInfo

PHICH resource information

Syntax

```
info = ltePHICHInfo(enb)
```

Description

`info = ltePHICHInfo(enb)` returns a structure, `info`, containing information about the physical hybrid ARQ indicator channel (PHICH) subframe resources.

Examples

Get PHICH Resource Information

Get PHIH resouce information for normal cyclic prefix system subframe with 50 DL resource blocks and HICH group multiplier set to 'Sixth'. See that there are 16 PHICH available, split between two PHICH groups of 8 sequences.

Initialize the cell-wide configuration structure, `enb`

```
enb.NDLRB = 50;
enb.Ng = 'Sixth';
```

Display the PHICH information

```
info = ltePHICHInfo(enb)
```

```
Warning: Using default value for parameter field CyclicPrefix (Normal)
Warning: Using default value for parameter field DuplexMode (FDD)
Warning: Using default value for parameter field PHICHDuration (Normal)

info =

  struct with fields:

            NREG: 6
```

```
            NRE: 24
          NPHICH: 16
         NGroups: 2
    NMappingUnits: 2
       NSequences: 8
    PHICHDuration: 1
```

Get PHICH Resource Information from RMC

This example shows that for RMC R.14, there are 16 PHICH available, split between two PHICH groups of 8 sequences.

Initialize the cell-wide configuration structure, `enb`, using RMC R.14

```
rc = 'R.14';
enb = lteRMCDL(rc);
```

Display the PHICH information

```
info = ltePHICHInfo(enb)
```

```
info =

  struct with fields:

            NREG: 6
             NRE: 24
          NPHICH: 16
         NGroups: 2
    NMappingUnits: 2
       NSequences: 8
    PHICHDuration: 1
```

Input Arguments

`enb` — eNodeB cell-wide settings

scalar structure

eNodeB cell-wide settings, specified as a structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
Ng	Required	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
PHICHDuration	Optional	Nonnegative scalar integer	PHICH duration
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number

Output Arguments

`info` — PHICH subframe resource information

scalar structure

PHICH subframe resource information, returned as a scalar structure. `info` contains the following fields.

Parameter Field	Description	Values	Data Type
NRE	Number of resource elements (REs) assigned to all PHICH	Nonnegative scalar integer	`uint64`

Parameter Field	Description	Values	Data Type
NREG	Number of resource element groups assigned to all PHICH	Nonnegative scalar integer	uint64
NPHICH	Number of individual PHICH available	Nonnegative scalar integer	uint64
NGroups	Number of PHICH groups	Nonnegative scalar integer	int8
NMappingUnits	Number of PHICH mapping units	Nonnegative scalar integer	int8
NSequences	Number of orthogonal sequences in each PHICH group	Nonnegative scalar integer	int8
PHICHDuration	PHICH duration	Nonnegative scalar integer	int8

The control region of a subframe can contain up to `NPHICH` separate PHICHs with each carrying a single hybrid ARQ ACK or NACK. Multiple PHICHs can be mapped to the same set of resource elements through PHICH groups. Each PHICH in a group is carried on one of `NSequences` orthogonal sequences. For mapping to resources, the groups are combined into mapping units where each unit spans three resource element groups. Thus, `NREG` is 3×`NMappingUnits` and `NRE` is 4×3×`NMappingUnits`. The `Ng` parameter controls the number of groups available for a given bandwidth.

See Also

See Also

`ltePHICH` | `ltePHICHDecode` | `ltePHICHDeprecode` | `ltePHICHIndices` | `ltePHICHPRBS` | `ltePHICHPrecode` | `ltePHICHTransmitDiversityDecode`

Introduced in R2014a

ltePHICHPRBS

PHICH pseudorandom scrambling sequence

Syntax

```
seq = ltePHICHPRBS(enb,n)
seq = ltePHICHPRBS(enb,n,mapping)
```

Description

`seq = ltePHICHPRBS(enb,n)` returns a column vector containing the first `n` outputs of the Physical Hybrid ARQ Indicator Channel (PHICH) scrambling sequence when initialized according to cell-wide settings structure, `enb`.

`seq = ltePHICHPRBS(enb,n,mapping)` allows control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Generate PHICH Pseudorandom Scrambling Sequence

Create a cell-wide configuration structure initialing for RMC R.0. Generate the pseudorandom scrambling sequence for the PHICH.

```
enb = lteRMCDL('R.0');
phichInfo = ltePHICHInfo(enb);
phichPrbsSeq = ltePHICHPRBS(enb,phichInfo.NRE);
numRE = phichInfo.NRE
size(phichPrbsSeq)
```

```
numRE =

  uint64

   12
```

```
ans =

    12     1
```

Using RMC R.0 results in 12 BPSK modulated symbols, where one bit per symbol is mapped onto a single resource element (RE).

Input Arguments

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` contains the following fields.

`NCellID` — Physical layer cell identity

nonnegative integer

Physical layer cell identity, specified as a nonnegative integer.

Data Types: `double`

`NSubframe` — Subframe number

nonnegative integer

Subframe number, specified as a nonnegative integer.

Data Types: `double`

Data Types: `struct`

`n` — Length of PHICH scrambling sequence

positive scalar integer

Length of PHICH scrambling sequence, specified as a positive scalar integer of 1 or more.

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — PHICH pseudorandom scrambling sequence

logical column vector | numeric column vector

PHICH pseudorandom scrambling sequence, returned as a logical column vector or a numeric column vector. This argument contains the first `n` outputs of the PHICH scrambling sequence. If `mapping` is set to `'signed'`, `seq` is a vector of data type double. Otherwise, it is a vector of data type logical.

Data Types: `logical | double`

See Also

See Also

`ltePHICH | ltePHICHDecode | ltePHICHDeprecode | ltePHICHIndices | ltePHICHInfo | ltePHICHPrecode | ltePHICHTransmitDiversityDecode`

Introduced in R2014a

ltePHICHPrecode

PHICH precoding

Syntax

```
out = ltePHICHPrecode(in,cp,ngroup)
out = ltePHICHPrecode(enb,ngroup,in)
```

Description

`out = ltePHICHPrecode(in,cp,ngroup)` precodes the *N*-by-*NU* matrix of layers, `in`, onto *P*=*NU* antennas, given cyclic prefix length, `cp`, and PHICH group, `ngroup`. It performs PHICH precoding according to TS 36.211, Section 6.9.2 [1]. This function returns an *M*-by-*P* matrix, where *P* is the number of transmission antennas and *M* is the number of symbols per antenna.

`out = ltePHICHPrecode(enb,ngroup,in)` precodes the *N*-by-*NU* matrix of layers, `in`, onto *P*=*NU* antennas for PHICH group, `ngroup`, using the cell-wide settings structure, `enb`.

Examples

Precode PHICH symbols

This example shows precoding of an arbitrary set of PHICH symbols for reference measurement channel (RMC) R.11, PHICH group 1.

Initialize a cell-wide parameter configuration structure, `enb`, for RMC R.11.

```
rc = 'R.11';
enb = lteRMCDL(rc);
nLayers = enb.PDSCH.NLayers;
```

Generate an arbitrary set of input symbols as the PHICH symbols.

```
phichSym = reshape(lteSymbolModulate(randi([0,1],40*nLayers*2,1), ...
    'QPSK'),40,nLayers);
```

Precode the PHICH symbols using normal cyclic prefix (set in `enb.CyclicPrefix` as per R.11), and PHICH group 1.

```
nGroup = 1;
precodedSym = ltePHICHPrecode(phichSym ,enb.CyclicPrefix, nGroup);
```

Have a peek at the first 5 precoded symbols of the output, columns represent the number of transmit antennas, for this example there are two transmit antennas.

```
precodedSym(1:5, :)
```

```
ans =

  -0.5000 - 0.5000i  -0.5000 - 0.5000i
   0.5000 - 0.5000i  -0.5000 + 0.5000i
   0.5000 - 0.5000i   0.5000 - 0.5000i
  -0.5000 - 0.5000i   0.5000 + 0.5000i
  -0.5000 + 0.5000i   0.5000 + 0.5000i
```

Input Arguments

`in` — PHICH input symbols

complex-valued numeric matrix

PHICH input symbols, specified as a complex-valued numeric matrix. `in` is a matrix of *N*-by-*NU* layers.

Data Types: `double`
Complex Number Support: Yes

`cp` — Cyclic prefix length

`'Normal' | 'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`ngroup` — PHICH group

positive scalar integer

PHICH group number, specified as a positive scalar integer of 1 or more.

Data Types: `double`

`enb` — Cell-wide settings

scalar structure

Cell-wide settings, specified as a scalar structure. `enb` can contain the following field.

Parameter Field	Required or Optional	Values	Description
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

Output Arguments

`out` — Precoded output

numeric matrix

Precoded output, returned as a numeric matrix of size *M*-by-*P*. *M* is the number of symbols per antenna and *P* is the number of transmission antennas.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteLayerMap` | `ltePHICH` | `ltePHICHDeprecode` | `ltePHICHIndices` | `ltePHICHInfo` | `ltePHICHPRBS`

Introduced in R2014a

ltePHICHTransmitDiversityDecode

PHICH OSFBC decoding

Syntax

```
[out,CSI]=ltePHICHTransmitDiversityDecode(in,cp,ngroup,hest)
```

Description

`[out,CSI]=ltePHICHTransmitDiversityDecode(in,cp,ngroup,hest)` returns Orthogonal Space Frequency Block Code (OSFBC) decoded symbols, `out`, and channel state information, `CSI`, given received PHICH symbols, `in`, along with cyclic prefix length, `cp`, PHICH resource group number, `ngroup`, and, channel estimate, `hest`.

Examples

Deprecode PHICH Symbols

Generate the PHICH symbols for multiple antennas using RMC R.11.

Initialize cell-wide settings for RMC R.11.

```
enb = lteRMCDL('R.11');
phichInfo = ltePHICHInfo(enb);
hiset = [1,1,1;1,2,0];
phichSym = ltePHICH(enb,hiset);
```

Create an ideal, or identity, channel estimate.

```
hest = permute(repmat(eye(enb.CellRefP),[1,1,phichInfo.NRE]),[3,1,2]);
```

Deprecode the received symbols, using the channel estimates.

```
ng = phichInfo.NGroups;
out = ltePHICHTransmitDiversityDecode(phichSym,enb.CyclicPrefix,ng,hest)
```

```
out =

   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
  -1.4142 - 1.4142i
  -1.4142 - 1.4142i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   1.4142 + 1.4142i
  -1.4142 - 1.4142i
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   1.4142 + 1.4142i
  -1.4142 - 1.4142i
   0.0000 + 0.0000i
```

Input Arguments

`in` — Received PHICH symbols

numeric matrix

Received PHICH symbols, specified as a numeric matrix of size *M*-by-`NRxAnts`, where *M* is the number of received symbols for each of `NRxAnts` receive antennas.

Data Types: `double`
Complex Number Support: Yes

`cp` — Cyclic prefix length

`'Normal' | 'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`ngroup` — PHICH group number

positive scalar integer (≥1)

PHICH group number, specified as a positive scalar integer of 1 or more.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array

Channel estimate, specified as an *M*-by-`NRxAnts`-by-`NTxAnts` numeric array. *M* is the number of received symbols in `in`, `NRxAnts` is the number of receive antennas, and `NTxAnts` is the number of transmit antennas.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`out` — OSFBC decoded symbols

numeric matrix

OSFBC decoded symbols, returned as a numeric matrix of size *M*-by-1, where *M* is the number of received symbols for each receive antenna.

Data Types: `double`
Complex Number Support: Yes

`CSI` — Soft channel state information

numeric matrix

Soft channel state information, returned as a numeric matrix of size *M*-by-1. It provides an estimate of the received RE gain for each received RE.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`ltePHICH` | `ltePHICHDecode` | `ltePHICHDeprecode` | `ltePHICHIndices` | `ltePHICHInfo` | `ltePHICHPRBS`

Introduced in R2014a

ltePMIInfo

Precoder matrix indication reporting information

Syntax

```
info = ltePMIInfo(enb,chs)
```

Description

`info = ltePMIInfo(enb,chs)` returns a precoder matrix indication (PMI) reporting information structure, given structures containing cell-wide settings, and the channel transmission configuration settings. For more information, see TS 35.213 [1].

Examples

PMI Reporting Information

Get the PMI reporting information for RMC R.13.

```
enb = lteRMCDL('R.13');
pmiInfo = ltePMIInfo(enb, enb.PDSCH)
```

```
pmiInfo =

  struct with fields:

                    k: 50
            NSubbands: 1
               MaxPMI: 15
    CodebookSubsetSize: 16
```

Input Arguments

enb — Cell-wide settings

structure

Cell-wide settings, specified as a scalar structure. The structure contains the following fields:

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CellRefP	Optional	1 (default), 2, 4	Number of cell-specific reference signal (CRS) antenna ports
The following parameter applies when `chs.TxScheme` is set to `Port7–14`.			
CSIRefP	Optional	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports

Data Types: `struct`

chs — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing the following fields.

Parameter Field	Required or Optional	Values	Description
PMIMode	Optional	`'Wideband'` (default), `'Subband'`	PMI reporting mode. `PMIMode='Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and `PMIMode='Subband'` corresponds to PUSCH reporting Mode 3-1.
NLayers	Optional	Integer from 1 to 8 Default number of layers is 1.	Number of transmission layers.
TxScheme	Optional	`'Port0'`, `'TxDiversity'`, `'CDD'`,	PDSCH transmission scheme, specified as one of the following options.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>'SpatialMu
'MultiUser
'Port5',
'Port7-8',
'Port8',
'Port7-14'</td><td><table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td colspan="4">The following parameter applies when 'Port7–14' transmission scheme with CSIRefP equal to 4, or for 'Port7-8' or 'Port8' transmission scheme with CellRefP equal to 4.</td></tr>
<tr><td>AltCodeI</td><td>Optiona</td><td>'Off' (default), 'On'</td><td>If set to 'On', enables the alternative codebook for CSI reporting with four antennas defined in TS 36.213, Tables 7.2.4-0A to 7.2.4-0D. The default is 'Off'. (alternativeCodebookEnabledFor4TX-r12)</td></tr>
</table>

Data Types: `struct`

Output Arguments

`info` — Information related to PMI reporting

structure

Information related to PMI reporting, returned as a structure containing these fields:

Parameter Field	Description	Values
`k`	Subband size, in resource blocks (equal to `NRB` for wideband PMI reporting or transmission schemes without PMI reporting).	numeric scalar
`NSubbands`	Number of subbands for PMI reporting (equal to 1 for wideband PMI reporting) or transmission schemes without PMI reporting.	numeric scalar
`MaxPMI`	Maximum permitted PMI value for the given configuration. Valid PMI values range from 0 to `MaxPMI`. For CSI reporting, when `CSIRefP = 8`, or for CSI reporting with the alternative codebook for four antennas,`MaxPMI` is a 2–element vector, indicating the maximum permissible values of *i1* and *i2*, the first and second codebook indices. For transmission schemes without PMI reporting, `MaxPMI = 0`.	nonnegative numeric scalar
`CodeBookSub`	Size of the codebook subset restriction bitmap. For transmission schemes without PMI reporting, `CodebookSubsetSize=0`.	scalar

`info.NSubbands` can be used to determine the correct size of the vector `PMISet` required for closed-loop spatial multiplexing operation; `PMISet` should be a column vector with `info.NSubbands` rows. For CSI reporting with `CSIRefP = 8`, or for CSI reporting with the alternative codebook for four antennas, `info.NSubbands` indicates the number of second codebook indices, *i2*, in the report. The first codebook index, *i1*, is always chosen in a wideband fashion, and is therefore a scalar. The PMI reporting mode is set with `chs.PMIMode`.

References

[1] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteCSICodebook` | `lteDLPrecode` | `ltePDSCH` | `ltePDSCHDecode` | `ltePMISelect`

Introduced in R2014a

ltePMISelect

PDSCH precoder matrix indicator calculation

Syntax

```
[pmiset,info,sinrs,subbandsinrs] = ltePMISelect(enb,chs,hest,
noiseest)
```

Description

`[pmiset,info,sinrs,subbandsinrs] = ltePMISelect(enb,chs,hest, noiseest)` performs PDSCH precoder matrix indication (PMI) set calculation for the given cell-wide settings, `enb`, channel configuration structure, `chs`, channel estimate resource array, `hest`, and receiver noise variance, `noiseest`. For more information, see "PMI Selection" on page 1-644.

Examples

PMI Selection

This example shows PMI selection and configuration of a downlink transmission with the selected PMI set.

Populate an empty resource grid for RMC R.13 with cell specific reference signal symbols. OFDM modulate the grid to create `txWaveform`. Initialize channel configuration structure. Pass `txWaveform` through channel and demodulate `rxWaveform` to recover `rxSubframe`

```
enb = lteRMCDL('R.13');
enb.PDSCH.PMIMode = 'Subband';
reGrid = lteResourceGrid(enb);
reGrid(lteCellRSIndices(enb)) = lteCellRS(enb);

[txWaveform,info] = lteOFDMModulate(enb,reGrid);

chcfg.SamplingRate = info.SamplingRate;
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 4;
```

```
chcfg.DopplerFreq = 5;
chcfg.MIMOCorrelation = 'Low';
chcfg.InitTime = 0;
chcfg.Seed = 1;

rxWaveform = lteFadingChannel(chcfg,txWaveform);
rxSubframe = lteOFDMDemodulate(enb,rxWaveform);
```

Initialize channel estimation structure. Perform channel estimation. Use estimates of the channel and noise power spectral density for PMI selction. This PMI set is then used to configure a downlink transmission.

```
cec.FreqWindow = 1;
cec.TimeWindow = 31;
cec.InterpType = 'cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 1;
cec.InterpWindow = 'Centered';

[hest, noiseEst] = lteDLChannelEstimate(enb,cec,rxSubframe);

pmi = ltePMISelect(enb,enb.PDSCH,hest,noiseEst)
enb.PDSCH.PMISet = pmi;
txWaveform = lteRMCDLTool(enb,[1;0;0;1]);
```

```
pmi =

     1
     1
     6
     2
    12
    12
    12
    12
    12
```

Input Arguments

enb — Cell-wide settings

structure

Cell-wide settings, specified as a structure containing the following fields:

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
CellRefP	Required	1 (default), 2, 4, 8	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters apply when `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
The following parameters apply when `chs.TxScheme` is set to `'Port7–14'` transmission scheme.			
CSIRefP	Required	1, 2, 4	Array of number of CSI-RS antenna ports
CSIRSConf	Required	Scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRSPeri	Optional	`'On'` (default), `'Off'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.

Parameter Field	Required or Optional	Values	Description
`Nframe`	Optional	0 (default), nonnegative scalar integer	Frame number

Data Types: `struct`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing the following fields:

Parameter Field	Required or Optional	Values	Description
`NLayers`	Required	Integer from 1 to 8	Number of transmission layers.
`PMIMode`	Optional	`'Wideband'` (default), `'Subband'`	PMI reporting mode. `PMIMode='Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and `PMIMode='Subband'` corresponds to PUSCH reporting Mode 3-1.
`TxScheme`	Optional	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, `'MultiUser'`, `'Port5'`, `'Por` `'Port8'`, `'Por`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td></td><td>layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td>CodebookSubs</td><td>Optional</td><td>Character vector or integer vector, all ones (default)</td><td>Codebook subset restriction, specified as a character vector bitmap. The default values are all ones, permitting all PMI values. This parameter is configured by higher layers and indicates the values of PMI that can be reported. The bitmap, defined in TS 36.213, Section 7.2, is arranged a_A-1,a_A-2,...a_0. For example, the element CodebookSubset(1) corresponds to a_A-1 and the element CodebookSubset(end) corresponds to a_0. The length of the bitmap is given by the info.CodebookSubsetSize field returned by <code>ltePMIInfo</code>. You can also specify the bitmap in a hexadecimal form by prefixing the character vector with <code>'0x'</code>. Alternatively, you can specify a numeric array identical to the <code>pmiset</code> output, indicating to restrict the selection to only those <code>pmiset</code> values. Specifying the parameter in this way enables you to obtain SINR estimates against an existing reported PMI for RI and CQI selection. If this parameter field is defined but is empty, no codebook subset restriction is applied. <code>(codebookSubsetRestriction)</code></td></tr>
<tr><td colspan="4">The following parameter applies for <code>'Port7–14'</code> transmission scheme with <code>CSIRefP</code> equal to 4, or for <code>'Port7-8'</code> or <code>'Port8'</code> transmission scheme with <code>CellRefP</code> equal to 4.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
`AltCodebo`	Optional	`'Off'` (default), `'On'`	If set to `'On'`, enables the alternative codebook for CSI reporting with four antennas defined in TS 36.213, Tables 7.2.4-0A to 7.2.4-0D. The default is `'Off'`. (*alternativeCodebookEnabledFor4TX-r12*)

Data Types: `struct`

`hest` — Channel estimate

multidimensional array

Channel estimate, specified as a multidimensional array of size *K*-by-*L*-by-*NRxAnts*-by-*P* where:

- *K* is the number of subcarriers.
- *L* is the number of OFDM symbols.
- *NRxAnts* is the number of received antennas.
- *P* is the number of planes.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Receiver noise variance

numeric scalar

Receiver noise variance, specified as a numeric scalar. This input argument specifies an estimate of the received noise power spectral density.

Data Types: `double`

Output Arguments

`pmiset` — PMI set selected

column vector | integer

Precoder matrix indications (PMI) set selected, returned as a column vector or an integer.

- For the `'Port7-14'` transmission scheme with eight CSI-RS ports, or for CSI reporting with the alternative codebook for four antennas, `pmiset` has `info.NSubbands + 1` rows. The first row indicates wideband codebook index *i1*. The subsequent `info.NSubbands` rows indicate the subband codebook indices *i2* or if `info.NSubbands = 1`, the wideband codebook index *i2*.
- For other numbers of CSI-RS ports in the `'Port7-14'` transmission scheme, and for other transmission schemes, `pmiset` has `info.NSubbands` rows. Each row gives the subband codebook index for that subband.
- For wideband reporting (`info.NSubbands = 1`), `pmiset` is a scalar specifying the selected wideband codebook index.

Note: `pmiset` is empty if the noise estimate, `noiseest`, is zero or NaN, or if the channel estimate, `hest`, contains any NaNs in the locations of the reference signal REs used for PMI estimation.

`info` — Information related to PMI reporting

structure

Information related to PMI reporting, returned as a scalar structure. `info` contains the following fields:

Parameter Field	Description	Values
`k`	Subband size, in resource blocks (equal to `NRB` for wideband PMI reporting or transmission schemes without PMI reporting).	numeric scalar
`NSubbands`	Number of subbands for PMI reporting (equal to 1 for wideband PMI reporting) or transmission schemes without PMI reporting.	numeric scalar
`MaxPMI`	Maximum permitted PMI value for the given configuration. Valid PMI values range from 0 to `MaxPMI`. For CSI reporting, when `CSIRefP = 8`, or for CSI reporting with the alternative codebook for four antennas,`MaxPMI` is a 2–element vector, indicating the maximum permissible values of *i1* and *i2*, the first and second codebook indices. For transmission schemes without PMI reporting, `MaxPMI = 0`.	nonnegative numeric scalar

Parameter Field	Description	Values
`CodeBookSubs`	Size of the codebook subset restriction bitmap. For transmission schemes without PMI reporting, `CodebookSubsetSize=0`.	scalar

`sinrs` — Signal-to-interference plus noise ratios

multidimensional array

Signal to interference plus noise ratios, returned as a multidimensional array of size *K*-by-*L*-by-*N1*-by-*N2*, where:

- *K* is the number of subcarriers
- *L* is the number of OFDM symbols
- Definition of *N1* and *N2* depends on the CSI-RS ports:
  - For the `'Port7-14'` transmission scheme with eight CSI-RS ports, or for CSI reporting with the alternative codebook for four antennas, *N1* and *N2* are the number of possible first and second codebook indices:
    - *N1* is `info.MaxPMI(1) + 1`
    - *N2* is `info.MaxPMI(2) + 1`
  - For other numbers of CSI-RS ports in the `'Port7-14'` transmission scheme, and for other transmission schemes:
    - *N1* is 1
    - *N2* is `info.MaxPMI + 1`

The array contains non-`NaN` values in the time and frequency locations (first two dimensions) of the reference signal REs. This array is used for PMI estimation for all possible codebook indices (last two dimensions). These values are the calculated sinrs in the reference signal RE locations for each codebook index combination. You can obtain the values using a linear MMSE SINR metric. All locations not corresponding to a reference signal RE are set to `NaN`.

`subbandsinrs` — Subband signal-to-interference plus noise ratios

multidimensional array

Subband signal-to-interference plus noise ratios (`sinrs`), returned as an `info.NSubbands`-by-*N1*-by-*N2*-by-`chs.NLayers` array. This array indicates the

average linear SINR in the subband specified for each possible PMI value (*N1* and *N2* dimensions) and each layer. The `sinrs` output is formed by summing a 5–dimensional *K*-by-*L*-by-*N1*-by-*N2*-by-`chs.NLayers` estimate of the `sinrs` across all the layers. `subbandsinrs` is formed by averaging that same five-dimensional estimate across each subband that is in the appropriate region of the K dimension and across the L dimension. Dimensionality described in `sinrs` applies here.

Definitions

PMI Selection

PDSCH precoder matrix indication (PMI) selection calculates a PMI set, `pmiset`. Functions, such as `lteRMCDLTool` or `ltePDSCH`, can use the returned `pmiset` to configure the PMI for downlink transmissions they generate. PMI selection is performed using the PMI definitions specified in TS 36.213, Section 7.2.4.

- The CSI reporting codebook is used for:
  - `'Port7-14'` transmission scheme with eight CSI-RS ports
  - CSI reporting with the alternative codebook for four antennas (*alternativeCodeBookEnabledFor4TX -r12* = true).
- The codebook for closed-loop spatial multiplexing, defined in TS 36.211 Tables 6.3.4.2.3-1 and 6.3.4.2.3-2, is used for other cases.

ThePMI feedback type associated with the PMI selection process can be wideband or subband:

- `PMIMode = 'Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2).
- `PMIMode = 'Subband'` corresponds to PUSCH reporting Mode 3-1.

PMI selection is based on the rank indicated by `chs.NLayers`, except for `'TxDiversity'` transmission scheme, where the rank is 1. In PUCCH reporting Mode 1-1, you can achieve codebook subsampling for submode 2, as specified in TS 36.213, Table 7.2.2-1D, with an appropriate `chs.CodebookSubset`.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteCQISelect` | `lteCSICodebook` | `lteDLPrecode` | `ltePDSCH` | `ltePDSCHDecode` | `ltePMIInfo` | `lteRISelect`

Introduced in R2014a

ltePRACH

Physical random access channel

Syntax

```
[waveform,info]=ltePRACH(ue,chs)
```

Description

`[waveform,info]=ltePRACH(ue,chs)` returns a column vector, `waveform`, containing complex symbols of the Physical Random Access Channel given UE-specific settings structure, `ue`, and channel transmission configuration structure, `chs`. PRACH information is returned in a structure, `info`, as described in `ltePRACHInfo`. `waveform` is *N*-by-1, where *N*=`info.SamplingRate`×`info.TotSubframes`×0.001, and contains the time-domain PRACH signal spanning `info.TotSubframes`, as described in TS 211, Section 5.7 [2]. The waveform consists of a period of zeros (for the case of a time offset or Preamble Format 4), a cyclic prefix, the "useful" part of the PRACH signal, and a period of zeros to extend the waveform to span `info.TotSubframes`. The duration of the PRACH is a function of the Preamble Format as described in TS 36.211, Table 5.7.1-1 [2]. Depending on the configuration given in `ue` and `chs`, it is possible that no PRACH are generated; in this case `info.PRBSet` is empty to signal this condition, and `waveform` consists of all zeros. The conditions under which no PRACH are generated are described in the help for `ltePRACHInfo`.

`chs.PreambleIdx` can be a vector in the functions `ltePRACHInfo` and `ltePRACHDetect`. This assists with modelling of an eNodeB receiver searching for multiple preambles. However, this function, `ltePRACH` only generates a single PRACH and therefore `chs.PreambleIdx` should be a scalar. If `chs.PreambleIdx` is a vector, the first element is used.

By default, for the given `ue.NULRB`, the `waveform` output, is sampled at the same sampling rate as other uplink channels (PUCCH, PUSCH, and SRS) using the `lteSCFDMAModulate` modulator.

If the value of `chs.PreambleIdx` is such that an insufficient quantity of cyclic shifts are available at the configured logical root index, `chs.SeqIdx`, the logical root index number needs to be incremented. As such, the physical root used, `info.RootSeq`, differs

from the physical root configured by `chs.SeqIdx`. The cyclic shift corresponding to `chs.PreambleIdx` can be found in `info.CyclicShift`. For High Speed mode, when `info.CyclicShift` = –1, the PRACH waveform is generated with no cyclic shift.

Examples

Generate PRACH Symbols

This example generates PRACH symbols of format 0 in an ue.NULRB=9 bandwidth, leaving all other parameters at their default values.

Initialize ue-specific settings and channel transmission configuration.

```
ue.DuplexMode = 'FDD';
ue.NULRB = 6;
chs.Format = 0;
chs.HighSpeed = 0;
chs.CyclicShiftIdx = 0;
chs.FreqOffset = 0;
chs.SeqIdx = 0;
chs.PreambleIdx = [ 0 ];
```

Generate PRACH symbols and PRACH info.

```
[prachSym,prachInfo] = ltePRACH(ue,chs);
prachInfo
```

```
prachInfo =

  struct with fields:

                 NZC: 839
    SubcarrierSpacing: 1250
                 Phi: 7
                   K: 12
         TotSubframes: 1
               Fields: [0 3168 24576 2976]
               PRBSet: [6×1 double]
                  NCS: 0
          CyclicShift: 0
              RootSeq: 129
         SamplingRate: 1920000
           BaseOffset: 0
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure. `ue` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are applicable when `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter fields is applicable when `DuplexMode` is set to `'TDD'` or when `chs.ConfigIdx` is present.			
`NSubframe`	Optional	0 (default), Nonnegative scalar integer	Subframe number
`NFrame`	Optional	0 (default), nonnegative scalar integer	Frame number
The following parameter fields are dependent upon the condition that the Preamble Format (`chs.Format`) is set to `'4'`.			
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

`chs` — Channel transmission configuration

scalar structure

Channel transmission configuration, specified as a scalar structure. `chs` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`Format`	Optional	0, 1, 2, 3, 4 (default is determined by `ConfigIdx` field if present). However, the `Format` field must be specified if the `ConfigIdx` field is not specified.	Preamble format See Note: 1.
`SeqIdx`	Optional	Scalar integer from 0 to 837. The default value is 0.	Logical root sequence index (*RACH_ROOT_SEQUENCE*)
`ConfigIdx`	Optional	Scalar integer from 0 to 63. The default value default value is determined by `Format` field, if present. However, the `ConfigIdx` field must be specified if the `Format` field is not specified.	PRACH Configuration Index (*prach-ConfigurationIndex*) See Note: 1.
`PreambleIdx`	Optional	Scalar integer or vector of integers from 0 to 63. The default value is 0.	Preamble index within cell (*ra-PreambleIndex*)
`CyclicShiftIdx`	Optional	Scalar integer from 0 to 15. The default value is 0.	Cyclic shift configuration index (*zeroCorrelationZoneConfig*, yields N_{CS})

Parameter Field	Required or Optional	Values	Description
`HighSpeed`	Optional	0 (default) or 1	High Speed flag (*highSpeedFlag*). A value of 1 signifies a restricted set. A value of 0 signifies an unrestricted set.
`TimingOffset`	Optional	0.0 (default), Numeric scalar	PRACH timing offset, in microseconds See Note: 2.
The following parameters are applicable when `ue.DuplexMode` is set to `'TDD'`.			
`FreqIdx`	Optional	0 (default), 0, 1, 2, 3, 4, 5	Frequency resource index (f_{RA}). Only required for `'TDD'` duplexing mode.
The following parameter fields are dependent upon the condition that the Preamble Format (`chs.Format`) is set to `0, 1, 2, or 3`.			
`FreqOffset`	Optional	Scalar integer from 0 to 94. The default value is 0.	PRACH frequency offset ($n_{PRBoffset}$). Only required for Preamble format 0–3.

Note:

1. Although the parameters `chs.Format` and `chs.ConfigIdx` are both described as 'Optional', at least one of these parameters must be specified. If both parameters are present then `chs.Format` is used and `chs.ConfigIdx` is ignored.

2. The parameter `chs.TimingOffset` is not a genuine parameter of the PRACH generation as defined in the standard. It is provided to allow easy generation of a delayed PRACH output for use in testing, to simulate the effect of the distance between UE and eNodeB. The maximum value of `chs.TimingOffset` that yields a complete PRACH transmission in the output `waveform` is a timing offset equal to the duration of the last field of `info.Fields`; this timing offset corresponds to the maximum cell size and hence maximum distance between UE and eNodeB. If this maximum timing offset is exceeded, part of the PRACH signal is lost. The end of the useful part of the PRACH signal is out with the span of `waveform`.

Data Types: `struct`

Output Arguments

`waveform` — PRACH waveform symbols

complex-valued numeric column vector

PRACH waveform symbols, returned as a complex-valued numeric column vector. It has size *N*-by-1, where *N* = (`info.SamplingRate` × `info.TotSubframes` × 0.001). It contains the time-domain PRACH signal spanning `info.TotSubframes`.

Data Types: `double`
Complex Number Support: Yes

`info` — PRACH information
scalar structure

PRACH information, returned as a scalar structure. It contains the following fields.

`NZC` — Zadoff-Chu sequence length
positive integer

Zadoff-Chu sequence length, returned as a positive integer. (N_{ZC})

Data Types: `double`

`SubcarrierSpacing` — Subcarrier spacing of PRACH preamble
positive integer

Subcarrier spacing of PRACH preamble, in Hz, returned as a positive integer. (*deltaf_RA*)

Data Types: `double`

`Phi` — Frequency-domain location offset
positive integer

Frequency-domain location offset, returned as a positive integer. (*phi*)

Data Types: `double`

`K` — Ratio of uplink data to PRACH subcarrier spacing
numeric scalar

Ratio of uplink data to PRACH subcarrier spacing, returned as a numeric scalar. (*K*)

Data Types: `double`

`TotSubframes` — Number of subframes duration of PRACH
numeric scalar

Number of subframes duration of the PRACH, returned as a numeric scalar. Each subframe lasts 30720 fundamental periods, therefore `TotSubframes` is `ceil(sum(Fields)/30720)`, the number of subframes required to hold the entire PRACH waveform. The duration of the PRACH is a function of the Preamble Format as described in TS 36.211, Table 5.7.1-1 [2].

Data Types: `double`

`Fields` — PRACH field lengths

1-by-4 numeric vector

PRACH field lengths, returned as a 1-by-4 numeric vector. The elements are [*OFFSET T_CP T_SEQ GUARD*]. *T_CP* and *T_SEQ* are the lengths in fundamental time periods (*T_s*), of cyclic prefix and PRACH sequence, respectively. *OFFSET* is the number of fundamental time periods from the start of configured subframe to the start of the cyclic prefix, and is nonzero only for TDD special subframes. *GUARD* is the number of fundamental time periods from the end of the PRACH sequence to the end of the number of subframes spanned by the PRACH.

Data Types: `double`

`PRBSet` — PRBs occupied by PRACH preamble

nonnegative integer column vector

PRBs occupied by PRACH preamble, returned as a nonnegative integer column vector. (starts at N_{PRB}, 0-based).

- An empty `info.PRBSet` indicates that the PRACH is not present and the waveform generated by ltePRACH consists of all zeros.
- An `info.PRBSet` that contains six consecutive Physical Resource Block numbers indicates the frequency domain location of the PRACH.

Note: The PRACH uses a different SC-FDMA symbol construction from the other channels (PUCCH, PUSCH and SRS) and therefore the PRBSet indicates the frequency range (180kHz per RB) that the PRACH occupies, it does not occupy the set of 12 subcarriers in each RB in the same fashion as other channels. The PRACH occupies a bandwidth approximately equal to 1.08MHz = 6RBs.

Data Types: `uint32`

`NCS` — Length of zero correlation zone plus 1

positive integer

Length of zero correlation zone plus 1, specified as a positive integer (N_CS). `NCS` corresponds to the complete extent of autocorrelation lags (0 and N_CS–1 nonzero) that exhibit perfect correlation properties (1 at 0 lag, 0 at nonzero lags). `NCS` is expressed directly, as in the standard, related to the fundamental Zadoff-Chu sequence construction. The actual sample span of the zero correlation zone in the waveform generated by `ltePRACH` is a function of the sampling rate.

Data Types: `double`

`CyclicShift` — Cyclic shift or shifts of Zadoff-Chu sequence

numeric row vector

Cyclic shift or shifts of Zadoff-Chu sequence, returned as a numeric row vector. (C_v). For High Speed mode, any element of `CyclicShift` equal to –1 indicates that there are no cyclic shifts in the restricted set for the corresponding preamble index.

Data Types: `double`

`RootSeq` — Physical root Zadoff-Chu sequence index or indices

numeric row vector

Physical root Zadoff-Chu sequence index or indices, returned as a numeric row vector. (u)

Data Types: `double`

`CyclicOffset` — Cyclic shift or shifts corresponding to Doppler Shift

vector

Cyclic shift or shifts corresponding to Doppler Shift of ($1/T\_SEQ$), returned as a vector. This parameter is present for High Speed mode. (d_u)

Data Types: `double`

`SamplingRate` — Sampling rate of PRACH modulator

numeric scalar

Sampling rate of the PRACH modulator, returned as a numeric scalar.

Data Types: `double`

`BaseOffset` — Base timing offset

numeric scalar

Base timing offset, in microseconds, returned as a numeric scalar. This parameter field is used for the detection test in TS 36.104 [1]. (duration of *N_CS*/2)

Data Types: `double`

Data Types: `struct`

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePRACHDetect` | `ltePRACHInfo`

Introduced in R2014a

ltePRACHDetect

Physical random access channel detection

Syntax

```
[indout,offset] = ltePRACHDetect(ue,chs,waveform,indin)
```

Description

`[indout,offset] = ltePRACHDetect(ue,chs,waveform,indin)` performs PRACH detection given UE-specific settings structure, `ue`, channel configuration structure, `chs`, received signal potentially containing a PRACH transmission, `waveform`, and range of preamble indices for which to search, specified in `indin`. The detector performs each distinct correlation required to cover all preamble indices, specified in `indin`, and searches the output of the correlations for peaks which exceed a detection threshold. The position of the peak in the correlator output is used to determine the preamble index detected and its associated timing offset. The preamble index and timing offset are returned in `indout` and `offset` respectively. For more information, see "PRACH Detector" on page 1-660.

Examples

Detect PRACH Preamble

Detect a PRACH preamble which has been delayed by 7 samples.

Initialize configuration structures for ue-specific (`ue`) and channel (`chs`) parameters.

```
ue.NULRB = 9;
ue.DuplexMode = 'FDD';
chs.Format = 0;
chs.CyclicShiftIdx = 1;
chs.PreambleIdx = 44;
chs.HighSpeed = 0;
chs.FreqOffset = 0;
```

```
chs.SeqIdx = 0;
```

Generate transmit waveform containing PRACH. Insert a seven sample delay. Detect the PRACH.

```
tx = ltePRACH(ue,chs);
rx = [zeros(7,1); tx];
[index,offset] = ltePRACHDetect(ue,chs,rx,(0:63).')
```

```
index =

    44


offset =

    7.1895
```

The timing offset fractional part is an estimate of the fractional delay present in the correlation peak. This is due to the cyclic shift present in the PRACH preamble. A cyclic shift in the frequency domain is a delay in the time domain.

Input Arguments

ue — UE-specific settings

structure array

UE-specific settings, specified as a structure array. `ue` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`DuplexMode`	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

Parameter Field	Required or Optional	Values	Description
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
`TDDConfig`	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`SSC`	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter fields are dependent upon the condition that `DuplexMode` is set to `'TDD'` or when `chs.ConfigIdx` is present.			
`NSubframe`	Optional	0 (default), Nonnegative scalar integer	Subframe number
`NFrame`	Optional	0 (default), nonnegative scalar integer	Frame number
The following parameter fields are dependent upon the condition that the Preamble Format (`chs.Format`) is set to `'4'`.			
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

`chs` — Channel transmission configuration

structure array

Channel transmission configuration, specified as a structure array. `chs` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Format`	Optional	0, 1, 2, 3, 4 (default is determined by `ConfigIdx` field if present). However, the `Format` field must be specified if	Preamble format See Note:.

Parameter Field	Required or Optional	Values	Description
		the `ConfigIdx` field is not specified.	
`SeqIdx`	Optional	Scalar integer from 0 to 837. The default value is 0.	Logical root sequence index (*RACH_ROOT_SEQUENCE*)
`ConfigIdx`	Optional	Scalar integer from 0 to 63. The default value default value is determined by `Format` field, if present. However, the `ConfigIdx` field must be specified if the `Format` field is not specified.	PRACH Configuration Index (*prach-ConfigurationIndex*) See Note:.
`CyclicShiftIdx`	Optional	Scalar integer from 0 to 15. The default value is 0.	Cyclic shift configuration index (*zeroCorrelationZoneConfig*, yields N_{CS})
`HighSpeed`	Optional	0 (default) or 1	High Speed flag (*highSpeedFlag*). A value of 1 signifies a restricted set. A value of 0 signifies an unrestricted set.
The following parameters are dependent upon the condition that `ue.DuplexMode` is set to `'TDD'`.			
`FreqIdx`	Optional	0 (default), 0, 1, 2, 3, 4, 5	Frequency resource index (f_{RA}). Only required for `'TDD'` duplexing mode.
The following parameter fields are dependent upon the condition that the Preamble Format (`chs.Format`) is set to `0, 1, 2, or 3`.			
`FreqOffset`	Optional	Scalar integer from 0 to 94. The default value is 0.	PRACH frequency offset ($n_{PRBoffset}$). Only required for Preamble format 0–3.

Note: Although the parameters `chs.Format` and `chs.ConfigIdx` are both described as 'Optional', at least one of these parameters must be specified. If both parameters are present, then `chs.Format` is used and `chs.ConfigIdx` is ignored.

Data Types: `struct`

`waveform` — Received signal potentially containing PRACH transmission

numeric matrix

Received signal potentially containing PRACH transmission, specified as an *N*-by-*P* numeric matrix. This matrix contains the received time-domain signal in which to search for PRACH transmissions. *N* is the number of time-domain samples. *P* is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

`indin` — Range of preamble indices within the cell for which to search

column vector

Range of preamble indices within the cell for which to search, specified as a column vector. It can be from 1 through 64 in length, containing values from 0 through 63.

Data Types: `double`

Output Arguments

`indout` — Preamble index

scalar | [ ], empty

Preamble index, returned as:

- a scalar, if an index from `indin` results in the maximum correlation above detection threshold.
- an empty,[ ], if no index from `indin` results in the maximum correlation above the detection threshold or the maximum correlation was obtained for an index not included in `indin`.

Data Types: `double`

`offset` — Timing offset

scalar | [ ], empty

Timing offset expressed in samples at the input sampling rate, returned as:

- a scalar, if an index from `indin` results in the maximum correlation above detection threshold.

- an empty,[ ], if no index from `indin` results in the maximum correlation above the detection threshold or the maximum correlation was obtained for an index not included in `indin`.

The timing offset estimate has an integer part corresponding to the correlation peak sample position and a fractional part estimating the fractional delay present in the correlation peak. The cyclic shift in the frequency domain present in the PRACH preamble can contribute to this fractional delay.

Data Types: `double`

Definitions

PRACH Detector

The detector performs each distinct correlation required to cover all preamble indices, specified in `indin`, and searches the output of the correlations for peaks which exceed a detection threshold. The position of the peak in the correlator output is used to determine the preamble index detected and its associated timing offset. The preamble index and timing offset are returned in `indout` and `offset` respectively. Generate the input `waveform` for one transmit antenna with the `ltePRACH` function. Generate input `waveform` with multiple transmit antenna (for example 2 or 4) using one of the channel model functions, `lteFadingChannel`, `lteHSTChannel`, or `lteMovingChannel`. Any other waveform provided must be sampled at the same sampling rate that `ltePRACH` would produce for the same configuration, specifically the same value of `ue.NULRB` as configured for the PRACH detector (`lrePRACHDetect`). The appropriate sampling rate can be found in the `SamplingRate` field of the output of `ltePRACHInfo`. Except for the case of the appropriate delay to position the transmission of Preamble Format 4 in the UpPTS for TDD special subframes, it is assumed that any PRACH signal in `waveform` is synchronized such that the first sample of `waveform` corresponds to the start of an uplink subframe. Therefore, the detector interprets any delay from the start of `waveform` to the first sample of the PRACH therein as a timing offset.

The detector first calls `info=ltePRACHInfo` to establish the set of root sequences `info.RootSeq` required to cover all preamble indices in `indin`. A correlation is then performed for each distinct value in `info.RootSeq`, with the inputs to the correlation being the input `waveform` and a locally generated PRACH waveform. The correlation is performed in the frequency domain. Multiplication of the FFT of the useful part of the locally generated PRACH waveform by a portion of the input `waveform` extracted with

the same timing as the useful part of the locally generated PRACH waveform, followed by an IFFT to give the correlation. Further fields from `info` are then used to establish the length of the window of the correlator output that corresponds to each preamble index, the zero correlation zone. The detector establishes the preamble index by testing of the position of the peak in the correlator output to determine if it lies in the window of the correlator output given by the cyclic shift for each preamble index in turn. The offset within the current window is used to compute the timing offset.

See Also

See Also

`ltePRACH` | `ltePRACHInfo`

Introduced in R2014a

ltePRACHInfo

PRACH resource information

Syntax

```
info = ltePRACHInfo(ue,chs)
```

Description

`info = ltePRACHInfo(ue,chs)` returns a structure, `info`, containing PRACH resource information given UE-specific settings structure, `ue`, and channel transmission configuration structure, `chs`. For more information, see "PRACH Information" on page 1-669.

Examples

Find Root Zadoff-Chu Sequences from PRACH Information

Find the set of root Zadoff-Chu sequences required for all preamble indices (0,...,63) in a cell.

```
ue.NULRB = 6;
config.Format = 0;
config.CyclicShiftIdx = 8;
config.PreambleIdx = (0:63);
prachInfo = ltePRACHInfo(ue,config);
unique(prachInfo.RootSeq)
```

```
ans =

   129   140   699   710
```

Input Arguments

ue — UE-specific settings

structure array

UE-specific settings, specified as a structure array that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
DuplexMode	Optional	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters are dependent upon the condition that `DuplexMode` is set to `'TDD'`.			
TDDConfig	Optional	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optional	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
The following parameter fields are dependent upon the condition that `DuplexMode` is set to `'TDD'` or when `chs.ConfigIdx` is present.			
NSubframe	Optional	0 (default), Nonnegative scalar integer	Subframe number
NFrame	Optional	0 (default), nonnegative scalar integer	Frame number
The following parameter fields are dependent upon the condition that the Preamble Format, `chs.Format`, is set to `'4'`.			

Parameter Field	Required or Optional	Values	Description
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

`chs` — Channel transmission configuration

scalar structure

Channel transmission configuration, specified as a scalar structure that can contain these parameter fields.

Parameter Field	Required or Optional	Values	Description
`Format`	Optional	0, 1, 2, 3, 4 (default is determined by `ConfigIdx` field if present). However, the `Format` field must be specified if the `ConfigIdx` field is not specified.	Preamble format See Note:.
`SeqIdx`	Optional	Scalar integer from 0 to 837. The default value is 0.	Logical root sequence index (*RACH_ROOT_SEQUENCE*)
`ConfigIdx`	Optional	Scalar integer from 0 to 63. The default value default value is determined by `Format` field, if present. However, the `ConfigIdx` field must be specified if the `Format` field is not specified.	PRACH Configuration Index (*prach-ConfigurationIndex*) See Note:.
`PreambleIdx`	Optional	Scalar integer or vector of integers	Preamble index within cell (*ra-PreambleIndex*)

Parameter Field	Required or Optional	Values	Description
		from 0 to 63. The default value is 0.	
`CyclicShiftIdx`	Optional	Scalar integer from 0 to 15. The default value is 0.	Cyclic shift configuration index (*zeroCorrelationZoneConfig*, yields N_{CS})
`HighSpeed`	Optional	0 (default) or 1	High Speed flag (*highSpeedFlag*). A value of 1 signifies a restricted set. A value of 0 signifies an unrestricted set.
The following parameters are dependent upon the condition that `ue.DuplexMode` is set to `'TDD'`.			
`FreqIdx`	Optional	0 (default), 0, 1, 2, 3, 4, 5	Frequency resource index (f_{RA}). Only required for `'TDD'` duplexing mode.
The following parameter fields are dependent upon the condition that the Preamble Format, `chs.Format`, is set to `0, 1, 2, or 3`.			
`FreqOffset`	Optional	Scalar integer from 0 to 94. The default value is 0.	PRACH frequency offset ($n_{PRBoffset}$). Only required for Preamble format 0–3.
Note: Although the parameters `chs.Format` and `chs.ConfigIdx` are both described as `'Optional'`, at least one of these parameters must be specified. If both parameters are present, then `chs.Format` is used and `chs.ConfigIdx` is ignored.			

Data Types: `struct`

Output Arguments

`info` — PRACH resource information

scalar structure

PRACH resource information, returned as a scalar structure. `info` contains the following fields.

`NZC` — Zadoff-Chu sequence length

positive integer

Zadoff-Chu sequence length, returned as a positive integer. (*N_ZC*)

Data Types: `double`

`SubcarrierSpacing` — Subcarrier spacing of PRACH preamble

positive integer

Subcarrier spacing of PRACH preamble, in Hz, returned as a positive integer. (*deltaf_RA*)

Data Types: `double`

`Phi` — Frequency-domain location offset

positive integer

Frequency-domain location offset, returned as a positive integer. (*phi*)

Data Types: `double`

`K` — Ratio of uplink data to PRACH subcarrier spacing

numeric scalar

Ratio of uplink data to PRACH subcarrier spacing, returned as a numeric scalar. (*K*)

Data Types: `double`

`TotSubframes` — Number of subframes duration of PRACH

numeric scalar

Number of subframes duration of the PRACH, returned as a numeric scalar. Each subframe lasts 30720 fundamental periods, therefore `TotSubframes` is `ceil(sum(Fields)/30720)`, the number of subframes required to hold the entire PRACH waveform. The duration of the PRACH is a function of the Preamble Format as described in TS 36.211, Table 5.7.1-1 [2].

Data Types: `double`

`Fields` — PRACH field lengths

1-by-4 numeric vector

PRACH field lengths, returned as a 1-by-4 numeric vector. The elements are [*OFFSET T_CP T_SEQ GUARD*]. *T_CP* and *T_SEQ* are the lengths in fundamental time periods (*T_s*), of cyclic prefix and PRACH sequence, respectively. *OFFSET* is the number of fundamental time periods from the start of configured subframe to the start of the cyclic prefix, and is non-zero only for TDD special subframes. *GUARD* is the number of

fundamental time periods from the end of the PRACH sequence to the end of the number of subframes spanned by the PRACH.

Data Types: `double`

`PRBSet` — PRBs occupied by PRACH preamble

nonnegative integer column vector

PRBs occupied by PRACH preamble, returned as a nonnegative integer column vector. (starts at *n_PRB*, zero-based).

- If no PRACH is present, the `info.PRBSet` field is empty.
- If PRACH is present, the `info.PRBSet` field contains six consecutive Physical Resource Block (PRB) indices, indicating the frequency-domain location of the PRACH.

Note: The PRACH uses a different SC-FDMA symbol construction from the other channels, PUCCH, PUSCH, and SRS. Specifically, the PRACH does not occupy the set of 12 subcarriers in each RB in the same fashion as other channels. Therefore, the `PRBSet` indicates the frequency range, 180 kHz per RB, occupied by the PRACH. The PRACH occupies a bandwidth approximately equal to 1.08 MHz, or 6RBs.

Data Types: `uint32`

`NCS` — Length of zero correlation zone plus 1

positive integer

Length of zero correlation zone plus 1, specified as a positive integer (N_{CS}). `NCS` corresponds to the complete extent of autocorrelation lags (0 and N_{CS}–1 non-zero) that exhibit perfect correlation properties (1 at 0 lag, 0 at non-zero lags). `NCS` is expressed directly, as in the standard, related to the fundamental Zadoff-Chu sequence construction. The actual sample span of the zero correlation zone in the waveform generated by `ltePRACH` is a function of the sampling rate.

Data Types: `double`

`CyclicShift` — Cyclic shift or shifts of Zadoff-Chu sequence

numeric row vector

Cyclic shift or shifts of Zadoff-Chu sequence, returned as a numeric row vector. (*C_v*).

For High Speed mode, any element of `CyclicShift` equal to –1 indicates that there are no cyclic shifts in the restricted set for the corresponding preamble index.

Data Types: `double`

`RootSeq` — Physical root Zadoff-Chu sequence index or indices

numeric row vector

Physical root Zadoff-Chu sequence index or indices, required to generate the PRACH for each of the configured set of preamble indices returned as a numeric row vector. (*u*) `RootSeq` is either a vector or a scalar aligned with the configuration of `chs.PreambleIdx`

Data Types: `double`

`CyclicOffset` — Cyclic shift or shifts corresponding to Doppler Shift

vector

`CyclicOffset` values are cyclic shifts corresponding to a Doppler Shift of 1/*T_SEQ* (*d_u*).

For High Speed mode, the field `CyclicOffset` is present. It contains cyclic offset values for each of the configured set of preamble indices. `CyclicOffset` is either a vector or a scalar aligned with the configuration of `chs.PreambleIdx`.

Data Types: `double`

`SamplingRate` — Sampling rate of PRACH modulator

numeric scalar

Sampling rate of the PRACH modulator, returned as a numeric scalar.

Data Types: `double`

`BaseOffset` — Base timing offset

numeric scalar

Base timing offset, in microseconds. This field is used for the detection test in TS 36.104 [1]. (duration of $N_{CS}/2$)

Data Types: `double`

Data Types: `struct`

Definitions

PRACH Information

The parameters “PRACH Mask Index” and “PRACH Resource Index,” described in TS 36.321 [3], are not explicit in the configuration, but are implicit in the choice of `ue.NSubframe` and `ue.NFrame`.

The PRACH is always be generated provided it fits with the overall duplexing arrangement. For FDD, the PRACH is generated in any subframe. For TDD, the PRACH is generated only in special subframes for Preamble Format 4, and in uplink subframes for Preamble Format 0-3, provided there are `info.TotSubframes` consecutive uplink subframes for the chosen TDD configuration starting from the current subframe.

If `chs.ConfigIdx` is present, further validation is used to comply with TS 36.211 [2], Table 5.7.1-2 for FDD and Table 5.7.1-4 for TDD. Specifically, `chs.Format`, if present, is validated against `chs.ConfigIdx` and a preamble is only generated in appropriate frames and subframes. If `chs.Format` is absent, the format is inferred, if possible, from `chs.ConfigIdx`. If the entry in TS 36.211 [2], Table 5.7.1-2 for FDD or Table 5.7.1-4 for TDD indicates “N/A” for the preamble format, an error is issued.

For TDD, `chs.FreqIdx` corresponds to the first entry in the quadruples in TS 36.211 [2], Table 5.7.1-4. The other three entries ($t_{RA}^{(0)}$, $t_{RA}^{(1)}$, $t_{RA}^{(2)}$) in the quadruple are specified by `ue.NSubframe` and `ue.NFrame`.

The PRACH is generated if a combination of `chs.ConfigIdx`, `ue.TDDConfig`, $t_{RA}^{(0)}$, $t_{RA}^{(1)}$, and $t_{RA}^{(2)}$ given by `ue.NSubframe`, `ue.NFrame`, and `chs.FreqIdx` appears in TS 36.211 [2], Table 5.7.1-4.

Note: In accordance with this logic,

- if `chs.ConfigIdx` is absent, `ue.NSubframe` and `ue.NFrame` are not required at all for FDD.
- In the case that a preamble is not generated under these rules, `info.PRBSet` is empty and the waveform generated by `ltePRACH` consists of all zeros.

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.321. "Medium Access Control (MAC) protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePRACH` | `ltePRACHDetect`

Introduced in R2014a

ltePRBS

Pseudorandom binary sequence

Syntax

```
seq = ltePRBS(cinit,n)
seq = ltePRBS(cinit,n,mapping)
```

Description

`seq = ltePRBS(cinit,n)` returns an `n`-element column vector containing the first `n` elements of the pseudorandom binary sequence (PRBS) generator when initialized with 32-bit integer, `cinit`. PRBS sequences are used for scrambling of physical channels for interference mitigation.

`seq = ltePRBS(cinit,n,mapping)` allows control over the format of the returned sequence `seq` with the input `mapping`.

Examples

Generate PRBS from Physical Layer Cell Identity

Generate a pseudorandom binary sequence based on physical layer cell identity for RMC R.0.

Create cell-wide configuration structure for RMC R.0. Use the physical layer cell identity, `NCellID`, as an initial value to generate the pseudorandom binary sequence.

```
enb = lteRMCDL('R.0');
prbsSeq = ltePRBS(enb.NCellID,5)
```

```
prbsSeq =

  5×1 logical array

   0
```

```
   0
   0
   0
   0
```

Generate Pseudorandom Binary Sequence

Generate an unsigned pseudorandom binary sequence.

```
seq = ltePRBS(162,4);
seq(1:4)
```

```
ans =

  4×1 logical array

   1
   0
   1
   1
```

Generate Signed Pseudorandom Binary Sequence

Generate a signed pseudorandom binary sequence.

```
seq = ltePRBS(162,4,'signed');
seq(1:4)
```

```
ans =

    -1
     1
    -1
    -1
```

Input Arguments

`cinit` — Initialization value

32-bit integer

32-bit integer initialization value

Data Types: `int32` | `uint32` | `double`

n — Number of outputs

positive scalar integer

Number of outputs, specified as a positive scalar integer

Data Types: `double`

mapping — Format of returned sequence

`'binary'` (default) | `'signed'`

Format of returned sequence, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`. `'binary'` maps true to 1 and false to 0 and `'signed'` maps true to –1 and false to 1.

Data Types: `char`

Output Arguments

seq — Pseudorandom binary sequence

logical column vector | numeric column vector

Pseudorandom binary sequence, returned as a logical column vector, or a numeric column vector. The vector contains the first `n` elements of the PRBS generator, when initialized with 32-bit integer `cinit`. If `mapping` is set to `'signed'`, `seq` is a vector of data type double. Otherwise, it is a vector of data type logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePBCHPRBS` | `ltePCFICHPRBS` | `ltePDCCHPRBS` | `ltePDSCHPRBS` | `ltePHICHPRBS` | `ltePSBCHPRBS` | `ltePSCCHPRBS` | `ltePSSCHPRBS` | `ltePUCCH2PRBS` | `ltePUCCH3PRBS`

Introduced in R2014a

ltePRS

Positioning reference signal

Syntax

```
sym = ltePRS(enb)
```

Description

`sym = ltePRS(enb)` returns a column vector containing the positioning reference signal (PRS) symbols for transmission in a single subframe on antenna port 6. These symbols are ordered as they should be mapped into the resource elements along with `ltePRSIndices`. As determined by the PRS subframe configuration and duplex mode, the output vector is empty if no PRS is scheduled in the subframe.

The optional `PRSPeriod` parameter controls the downlink subframes in which PRS is present. See the `ltePRSIndices` function reference page for details.

Examples

Generate Positioning Reference Signal Symbols

Generate the PRS symbols for subframe 0 of a 10MHz downlink.

Create a cell-wide configuration structure initialized for RMC R.2. Configure for full band PRS (`NPRSRB = NDLRB`). Configure Iprs = 0, which sets [Tprs Dprs] = [160 0].

```
rmc = lteRMCDL('R.2');
rmc.NPRSRB = rmc.NDLRB;
rmc.PRSPeriod = 0;
prsSymbols = ltePRS(rmc);
```

Generate PRS symbols.

```
prsSymbols(1:4)
```

```
ans =
```

```
0.7071 + 0.7071i
0.7071 + 0.7071i
0.7071 + 0.7071i
0.7071 + 0.7071i
```

Input Arguments

`enb` — Cell-wide settings
structure

Cell-wide settings, specified as a structure. `enb` contains the following parameter fields.

The parameters `TDDConfig` and `SSC` are only required if `DuplexMode` is set to `'TDD'`.

`NDLRB` — Number of downlink resource blocks
positive scalar integer (6,...,110)

Number of downlink resource blocks, specified as a positive scalar integer from 6 through 110.

Example: 45

Data Types: `double`

`CellRefP` — Number of cell-specific reference signal antenna ports
1 | 2 | 4

Number of cell-specific reference signal antenna ports, specified as a 1, 2, or 4.

Example: 1

Data Types: `double`

`NCellID` — Physical layer cell identity number
nonnegative scalar integer

Physical layer cell identity number, specified as a nonnegative scalar integer.

Example: 4

Data Types: `double`

`NSubframe` — Subframe number
nonnegative scalar integer

Subframe number, specified as nonnegative scalar integer.

Example: 5

Data Types: `double`

`NFrame` — Frame number

0 (default) | optional | nonnegative scalar integer

Frame number, specified as nonnegative scalar integer.

Example: 6

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as a `'Normal'` or `'Extended'`.

Data Types: `char`

`DuplexMode` — Duplex mode type

`'FDD'` (default) | optional | `'TDD'`

Duplex mode type, specified as `'FDD'` or `'TDD'`. Used for separating the transmission signals.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration for TDD

0 (default) | optional | nonnegative scalar integer (0,...,6)

Uplink or downlink configuration for TDD, specified as a nonnegative scalar integer from 0 through 6. Required only for `'TDD'` duplex mode.

Example: 4

Data Types: `double`

`SSC` — Special subframe configuration

0 (default) | optional | nonnegative scalar integer (0,...,9)

Special subframe configuration, specified as nonnegative scalar integer from 0 through 9. Required only for `'TDD'` duplex mode.

Example: 6

Data Types: `double`

`NPRSRB` — Number of PRS physical resource blocks

0,...,NDLRB

Number of PRS physical resource blocks, specified as nonnegative scalar integer from 0 through NDLRB.

Example: 8

Data Types: `double`

`PRSPeriod` — Positioning reference signal (PRS) period

`'On'` (default) | optional | `'Off'` | `[Iprs]` | `[Tprs Dprs]`

Positioning reference signal (PRS) period, specified as `'On'`, `'Off'`, a numeric scalar, or a 1-by-2 vector. This parameter controls the downlink subframes in which PRS will be present. For details, see `ltePRSIndices`.

Example: 0

Example: [160 0]

Data Types: `char` | `double`

Output Arguments

`sym` — Positioning Reference Signal (PRS) symbols

complex numeric column vector

Positioning Reference Signal (PRS) symbols, returned as complex numeric column vector, for transmission in a single subframe on antenna port 6.

Example: 0.7071 + 0.7071i

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`lteCellRS` | `lteCSIRS` | `lteDMRS` | `lteEPDCCHDMRS` | `ltePRBS` | `ltePRSIndices`

Introduced in R2014a

ltePRSIndices

PRS resource element indices

Syntax

```
ind = ltePRSIndices(enb)
ind = ltePRSIndices(enb,opts)
```

Description

`ind = ltePRSIndices(enb)` returns a column vector of one-based linear indices for the PRS elements in the subframe, given the cell-wide settings parameter structure, `enb`. The length of `ind` is the number of resource elements (NRE). It returns the indices for the Positioning Reference Signal (PRS) resource element (RE) locations transmitted on antenna port 6. By default, these indices are in one-based linear indexing form that can directly index elements in a matrix representing a single subframe of the port 6 resource grid. Other index representations can also be created. These indices are ordered as the complex PRS symbols should be mapped and will not include any elements allocated to PBCH, PSS, and SSS. A PRS subframe configuration schedule can be defined as required. If the subframe contains no PRS, `ind` is an empty vector.

The optional `enb.PRSPeriod` parameter controls the downlink subframes in which PRS will be present, either always `'On'` or `'Off'`, or defined by the scalar subframe configuration index, *Iprs* (0,...,2399), or the explicit subframe periodicity and offset pair, `[Tprs Dprs]`, as listed in TS 36.211 [1], Section 6.10.4.3. The PRS containing subframes are located in conjunction with the parameters `enb.NSubframe` and optional `enb.NFrame`. `NSubframe` can be greater than 10; thus, setting `NSubframe` to 11 is equivalent to setting `NSubframe` to 1 and `NFrame` to 1.

`ind = ltePRSIndices(enb,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PRS Resource Element Indices

Generate the PRS resource element (RE) indices for subframe 0 of a 10 MHz downlink.

Create a cell-wide configuration structure initialized for RMC R.2. Configure for full band PRS (NPRSRB = NDLRB). Configure Iprs = 0, which sets [Tprs Dprs] = [160 0].

```
rmc = lteRMCDL('R.2');
rmc.NPRSRB = rmc.NDLRB;
rmc.PRSPeriod = 0;
```

Generate PRS indices.

```
prsIndices = ltePRSIndices(rmc,'ind');
prsIndices(1:4)
```

```
ans =

  4×1 uint32 column vector

   1804
   1810
   1816
   1822
```

Input Arguments

enb — Cell-wide settings

structure

Cell-wide settings, specified as a structure. enb contains the following fields.

The parameters TDDConfig and SSC are only required if DuplexMode is set to 'TDD'.

NDLRB — Number of downlink resource blocks

6,...,110

Number of downlink resource blocks, specified as a nonnegative scalar integer from 6 through 110.

Example: 50

Data Types: `double`

`CellRefP` — Number of cell-specific reference signal antenna ports

1 (default) | 2 | 4

Number of cell-specific reference signal antenna ports, specified as 1, 2, or 4.

Example: 1

Data Types: `double`

`NCellID` — Physical layer cell identity

nonnegative scalar integer

Physical layer cell identity, specified as a nonnegative scalar integer.

Example: 3

Data Types: `double`

`NSubframe` — Subframe number

nonnegative scalar integer

Subframe number, specified as a nonnegative scalar integer.

Example: 3

Data Types: `double`

`NFrame` — Frame number

0 (default) | optional | nonnegative scalar integer

Frame number, specified as a nonnegative scalar integer.

Example: 3

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`DuplexMode` — Duplex mode type

`'FDD'` (default) | optional | `'TDD'`

Duplex mode type, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration for TDD

0 (default) | optional | 0,...,6

Uplink or downlink configuration for TDD, specified as a nonnegative scalar integer from 0 through 6. Optional. Required only for `'TDD'` duplex mode.

Example: 4

Data Types: `double`

`SSC` — Special subframe configuration for TDD

0 (default) | optional | 0,...,9

Example: 5

Special subframe configuration for TDD, specified as a nonnegative scalar integer from 0 through 9. Required only for `'TDD'` duplex mode.

Data Types: `double`

`NPRSRB` — Number of PRS physical resource blocks

0,...,`NDLRB`

Number of PRS physical resource blocks, specified as a nonnegative scalar integer from 0 through `NDLRB`.

Example: 32

Data Types: `double`

`PRSPeriod` — Positioning reference signal (PRS) period

`'On'` (default) | optional | `'Off'` | `[Iprs]` | `[Tprs Dprs]`

Positioning reference signal (PRS) period, specified as `'On'`, `'Off'`, a numeric scalar, or a 1-by-2 vector. This parameter controls the downlink subframes in which PRS will be present. For details, see `ltePRSIndices`.

Example: 0

Example: [160 0]

Data Types: `char` | `double`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PRS resource element indices

integer column vector | integer matrix

PRS resource element indices, returned as an integer column vector of length *NRE* or an integer matrix of size *NRE*-by-3. These indices are for the PRS resource element (RE) locations transmitted on antenna port 6.

Example: 1804

Data Types: `uint32`

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteCellRSIndices` | `lteCSIRSIndices` | `lteDMRSIndices` | `ltePRS`

Introduced in R2014a

ltePSBCH

Physical sidelink broadcast channel

Syntax

```
sym = ltePSBCH(ue,cw)
```

Description

`sym = ltePSBCH(ue,cw)` returns a column vector containing the physical sidelink broadcast channel (PSBCH) symbols for the specified UE settings structure and PSBCH codeword bits. The function performs PSBCH-specific scrambling, QPSK modulation, and SC-FDMA transform precoding, as defined in TS 36.211 [1], Section 9.6. For more information, see “Physical Sidelink Broadcast Channel Processing” on page 1-688.

Examples

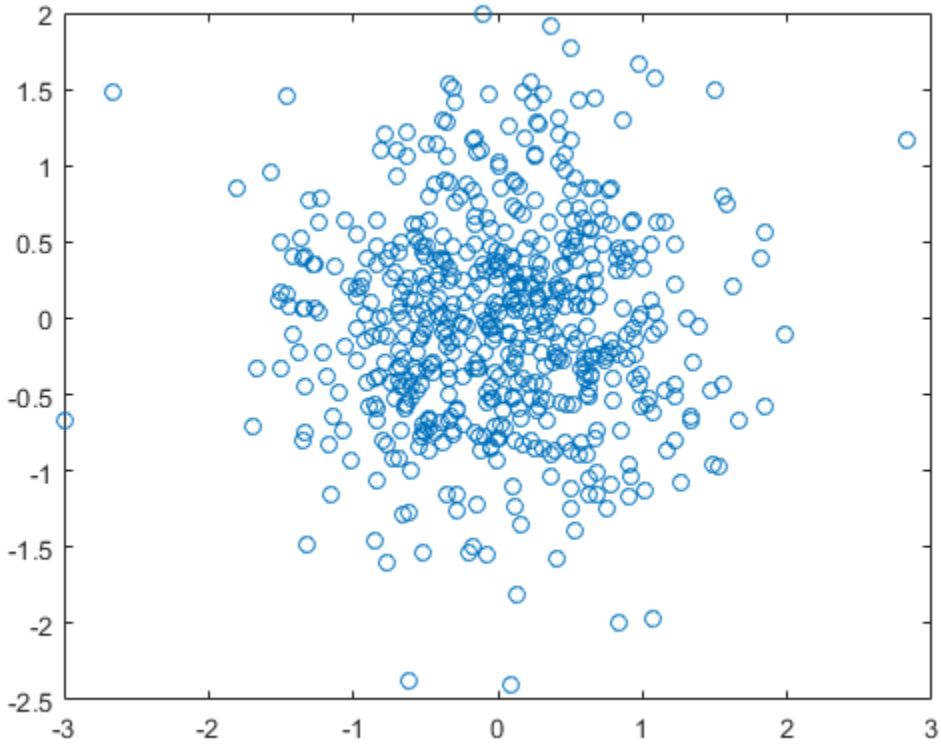
Encode PSBCH Codeword

Create a codeword using the SL-BCH transport channel and encode the bits on the PSBCH.

```
ue.NSLID = 1;
ue.CyclicPrefixSL = 'Normal';
codeword = lteSLBCH(ue,zeros(40,1));
symbols = ltePSBCH(ue,codeword);
```

The plot shows the effects of the SC-FDMA precoding on the QPSK modulation symbols.

```
plot(symbols,'o')
```



Input Arguments

ue — User equipment settings
structure

User equipment settings, specified as a parameter structure containing this field:

`NSLID` — Physical layer sidelink synchronization identity
integer from 0 to 355

Physical layer sidelink synchronization identity, specified as an integer from 0 to 355. (N_{ID}^{SL})

Data Types: `double`

Data Types: `struct`

cw — PSBCH codeword

vector

PSBCH codeword, specified as a vector that must be a multiple of 144 bits in length. Since the PSBCH is QPSK modulated, there are 2 bits per symbol. Nominally, the length of `cw` is $2*N_{RE}$ bits, specifically 1152 bits for normal cyclic prefix or 864 for extended cyclic prefix.

N_{RE} is the number of resource elements in a subframe, including the SC-FDMA guard symbol, and is a multiple of 72. Nominally, N_{RE} is 576 for normal cyclic prefix or 432 for extended cyclic prefix.

Data Types: `double`

Output Arguments

sym — Modulated PSBCH symbols

column vector

Modulated PSBCH symbols, returned as an N_{RE}-by-1 column vector.

N_{RE} is the number of resource elements in a subframe, including the SC-FDMA guard symbol, and is a multiple of 72. Nominally, N_{RE} is 576 for normal cyclic prefix or 432 for extended cyclic prefix.

Data Types: `double`
Complex Number Support: Yes

Definitions

Physical Sidelink Broadcast Channel Processing

The physical sidelink broadcast channel (PSBCH) is transmitted in the central 72 resource elements in the available SC-FDMA symbols of synchronization subframes. The available symbols exclude the three symbols per slot assigned to the PSBCH DRS and sidelink synchronization signals. The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process. Before transmission, the PSBCH resource elements are removed from the last SC-FDMA symbol by `lteSCFDMAModulate` during the sidelink-specific SC-FDMA modulation and guard symbol creation.

If a terminal is transmitting a synchronization subframe, then it should be sent every 40 ms, with the exact subframe dependent on the RRC-signaled subframe number offset (*syncOffsetIndicator-r12*). The subframe also contains values for the `ltePSBCHDRSIndices` on port 1010 and `ltePSSSIndices` and `lteSSSSIndices` on port 1020. No PSCCH or PSSCH transmission will occur in a sidelink subframe configured for synchronization purposes.

Physical Sidelink Broadcast Channel Indexing

Use the `ltePSBCHIndices` indexing function and the corresponding `ltePSBCH` sequence function to populate the resource grid for the desired synchronization subframe number. The indices are ordered as the PSBCH QPSK modulation symbols should be mapped, applying frequency-first mapping, and include indices for the last SC-FDMA guard symbol. The PSBCH values returned by `ltePSBCH` are ordered as they should be mapped into the resource elements of the adjacent symbols using `ltePSBCHIndices`. For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSBCHDecode` | `ltePSBCHDRS` | `ltePSBCHIndices`

Introduced in R2016b

ltePSBCHDecode

PSBCH decoding

Syntax

```
[softbits,symbols] = ltePSBCHDecode(ue,sym)
```

Description

`[softbits,symbols] = ltePSBCHDecode(ue,sym)` returns a vector of log-likelihood ratio (LLR) soft bits and the intermediate QPSK modulation symbols for the specified UE settings structure (`ue`) and modulated PSBCH symbols (`sym`).

The PSBCH decoder performs the inverse of the `ltePSBCH` function processing, as defined in TS 36.211 [1], Section 9.6, which includes SC-FDMA transform deprecoding, QPSK demodulation, and PSBCH-specific descrambling.

Examples

Decode PSBCH

Demodulate PSBCH symbols for a SL-BCH codeword containing a modulated MIB-SL message with noise added. Plot the noisy RE symbols, the symbols prior to QPSK demodulation. and the resulting LLR soft bits.

Create a UE settings structure.

```
ue.NSLRB = 25;
ue.InCoverage = 1;
ue.DuplexMode = 'FDD';
ue.NFrame = 0;
ue.NSubframe = 0;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 0;
```

Encode the MIB-SL message and add noise.

```
cw = lteSLBCH(ue,lteSLMIB(ue));
sym = ltePSBCH(ue,cw);
rxsym = awgn(sym,13,'measured');
```

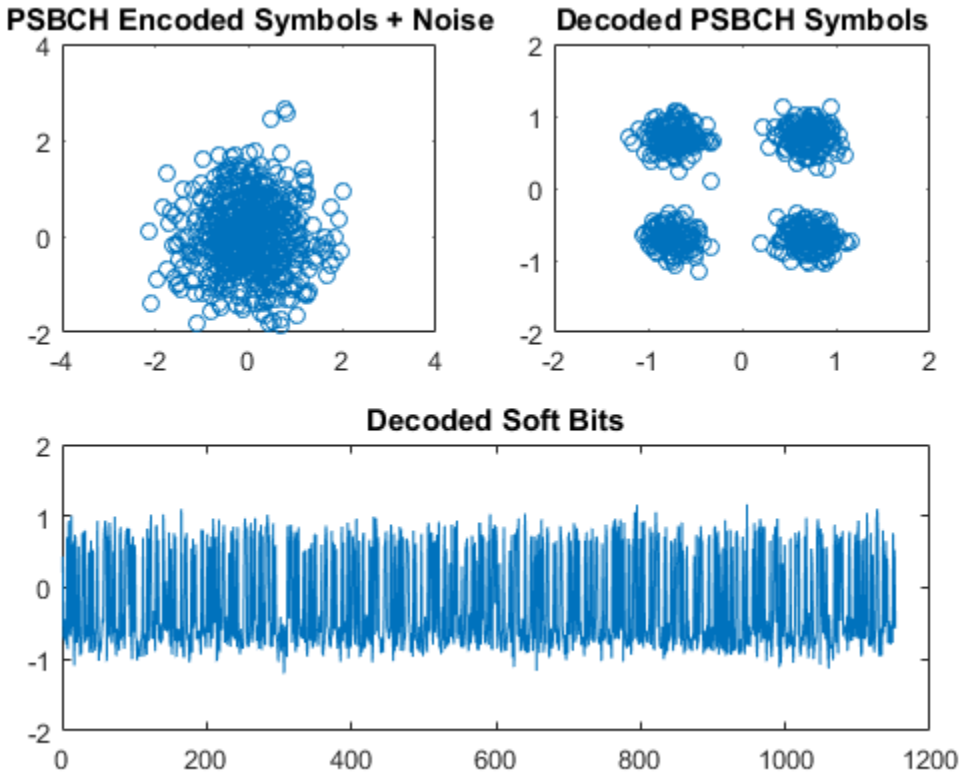
Decode the received symbols. The recovered codeword contains LLR soft bits. Hard decisions map positive soft bits to 1 and negative soft bits to 0. Compare the hard decisions on the recovered soft bits ot verify that the recovered message matches the transmitted message.

```
[rxcw,rxmodsym] = ltePSBCHDecode(ue,rxsym);
isequal(cw,rxcw>0)
```

```
ans =

  logical

   1
```

Plot the noisy RE symbols, the symbols prior to QPSK demodulation, and the resulting LLR soft bits.

```
subplot(2,2,[1,1])
plot(rxsym,'o')
title('PSBCH Encoded Symbols + Noise')

subplot(2,2,[2,2])
plot(rxmodsym,'o')
title('Decoded PSBCH Symbols')

subplot(2,2,[3,4])
plot(rxcw)
title('Decoded Soft Bits')
```



Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing this field:

NSLID — Physical layer sidelink synchronization identity

integer from 0 to 355

Physical layer sidelink synchronization identity, specified as an integer from 0 to 355.

Data Types: `double`

Data Types: `struct`

`sym` — Modulated PSBCH symbols

column vector

Modulated PSBCH symbols, specified as a N_{RE}-by-1 column vector.

N_{RE} is the number of resource elements in a subframe, including the SC-FDMA guard symbol, and is a multiple of 72. Nominally, N_{RE} is 576 for normal cyclic prefix or 432 for extended cyclic prefix.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`softbits` — Log-likelihood ratio soft bits

vector

Log-likelihood ratio (LLR) soft bits, returned as a vector with $2*N_{RE}$ elements.

N_{RE} is the number of resource elements in a subframe, including the SC-FDMA guard symbol, and is a multiple of 72. Nominally, N_{RE} is 576 for normal cyclic prefix or 432 for extended cyclic prefix.

Data Types: `double` | `logical` | `int8`

`symbols` — Modulated PSBCH symbols

column vector

Modulated PSBCH symbols, returned as a column vector with N_{RE} elements.

N_{RE} is the number of resource elements in a subframe, including the SC-FDMA guard symbol, and is a multiple of 72. Nominally, N_{RE} is 576 for normal cyclic prefix or 432 for extended cyclic prefix.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePSBCH` | `ltePSBCHDRS` | `ltePSBCHDRSIndices` | `ltePSBCHIndices`

Introduced in R2016b

ltePSBCHDRS

PSBCH demodulation reference signal

Syntax

```
[seq,info] = ltePSBCHDRS(ue)
```

Description

`[seq,info] = ltePSBCHDRS(ue)` returns a 144-by-1 complex column vector sequence containing PSBCH demodulation reference signal (DM-RS) values and an associated information structure for the specified UE settings structure. For more information, see “PSBCH Demodulation Reference Signal” on page 1-698.

Examples

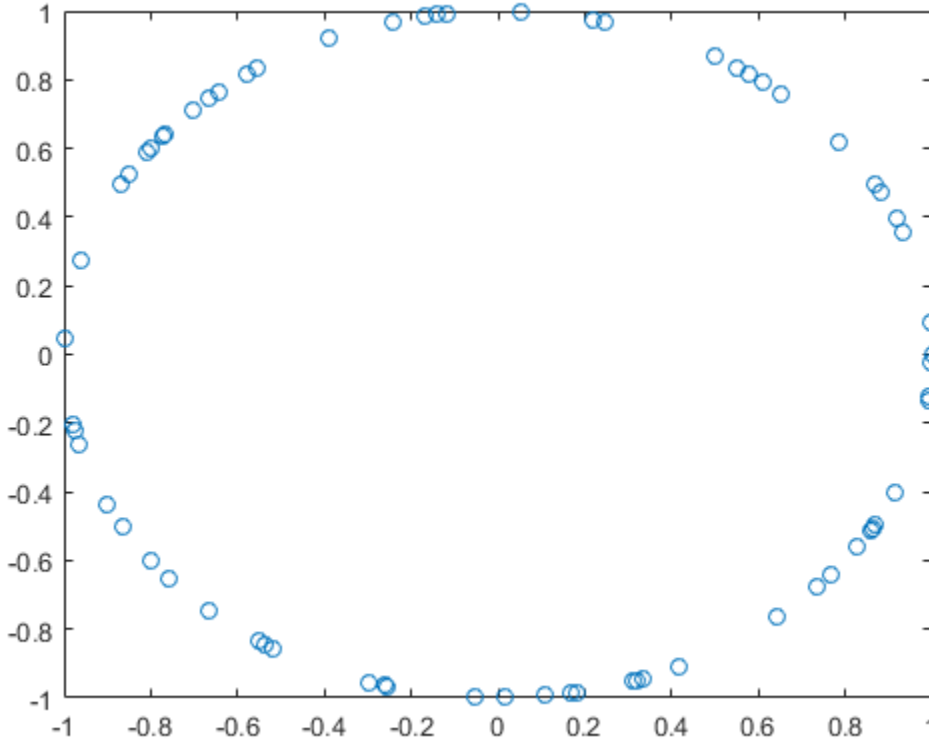
Generate PSBCH DM-RS Sequence

Generate a PSBCH DM-RS sequence associated with both DM-RS SC-FDMA symbols in a subframe.

```
ue.NSLID = 170;
[psbchdrs_seq,info] = ltePSBCHDRS(ue);
```

Plot the DM-RS sequence (real vs. imaginary).

```
plot(psbchdrs_seq,'o')
```



Input Arguments

ue — User equipment settings
structure

User equipment settings, specified as a parameter structure containing this field:

`NSLID` — Physical layer sidelink synchronization identity
integer from 0 to 355

Physical layer sidelink synchronization identity, specified as an integer from 0 to 355. ($N_{\mathrm{ID}}^{\mathrm{SL}}$)

Data Types: `double`

Data Types: `struct`

Output Arguments

`seq` — PSBCH DM-RS values

column vector

PSBCH DM-RS values, returned as a 144-by-1 column vector.

Data Types: `double`
Complex Number Support: Yes

`info` — PSBCH DM-RS information

structure

PSBCH DM-RS information about the intermediate variables used to create the DM-RS, returned as a parameter structure containing these fields:

`Alpha` — Reference signal cyclic shift for each slot

two-column vector

Reference signal cyclic shift for each slot, returned as a two-column vector. (a)

`Alpha` is proportional to `NCS`, where $\alpha = \frac{2\pi n_{cs,\lambda}}{12}$.

`SeqGroup` — Base sequence group number for each slot

two-column vector

Base sequence group number for each slot, returned as a two-column vector. (u)

`SeqIdx` — Base sequence number for each slot

two-column vector

Base sequence number for each slot, returned as a two-column vector. (v)

`RootSeq` — Root Zadoff-Chu sequence index for each slot
two-column vector

Root Zadoff-Chu sequence index for each slot, returned as a two-column vector. (q)

`NCS` — Cyclic shift values for each slot
two-column vector

Cyclic shift values for each slot, returned as a two-column vector. ($n_{\mathrm{cs},\lambda}$)

`NZC` — Zadoff-Chu sequence length
integer

Zadoff-Chu sequence length, returned as an integer. ($N_{\mathrm{ZC}}^{\mathrm{RS}}$)

`OrthSeq` — Orthogonal cover value for each slot
matrix

Orthogonal cover value for each slot, returned as a matrix. ($\overline{w}$)

Data Types: `struct`

Definitions

PSBCH Demodulation Reference Signal

The PSBCH demodulation reference signal (DM-RS) is transmitted alongside the `ltePSBCH` values in the central 72 resource elements and in two SC-FDMA symbols in a synchronization subframe. For zero-based indexing, the SC-FDMA symbol indices are {3,10} for normal cyclic prefix and {2,8} for extended cyclic prefix. These are the same symbols used by the PUSCH DM-RS, see `ltePUSCHDRSIndices`.

Note: The indicated symbol indices are based on TS 36.211, Section 9.8, but expanded from symbol index per slot to symbol index per subframe to align with the LTE System Toolbox subframe orientation. For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

PSBCH Demodulation Reference Signal Indexing

Use the indexing function, `ltePSBCHDRSIndices`, and the corresponding sequence function, `ltePSBCHDRS`, to index the resource grid for any synchronization subframe number. The indices are ordered as the PSBCH DM-RS symbols should be, applying frequency-first mapping, into the two DM-RS SC-FDMA symbols. For more information on mapping symbols to the resource element grid, see "Resource Grid Indexing".

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSBCH` | `ltePSBCHDecode` | `ltePSBCHDRSIndices` | `ltePSBCHIndices`

Introduced in R2016b

ltePSBCHDRSIndices

PSBCH DM-RS resource element indices

Syntax

```
ind = ltePSBCHDRSIndices(ue)
ind = ltePSBCHDRSIndices(ue,opts)
```

Description

`ind = ltePSBCHDRSIndices(ue)` returns the subframe resource element (RE) indices for the demodulation reference signal (DM-RS) associated with a PSBCH transmission for the specified UE settings structure. By default, the indices are returned in one-based linear indexing form. You can use this form to directly index elements of a matrix representing the subframe resource grid for antenna port 1010. For more information, see “PSBCH Demodulation Reference Signal Indexing” on page 1-703.

`ind = ltePSBCHDRSIndices(ue,opts)` formats the returned indices using options specified in cell array `opts`.

Examples

Create PSBCH DM-RS Values

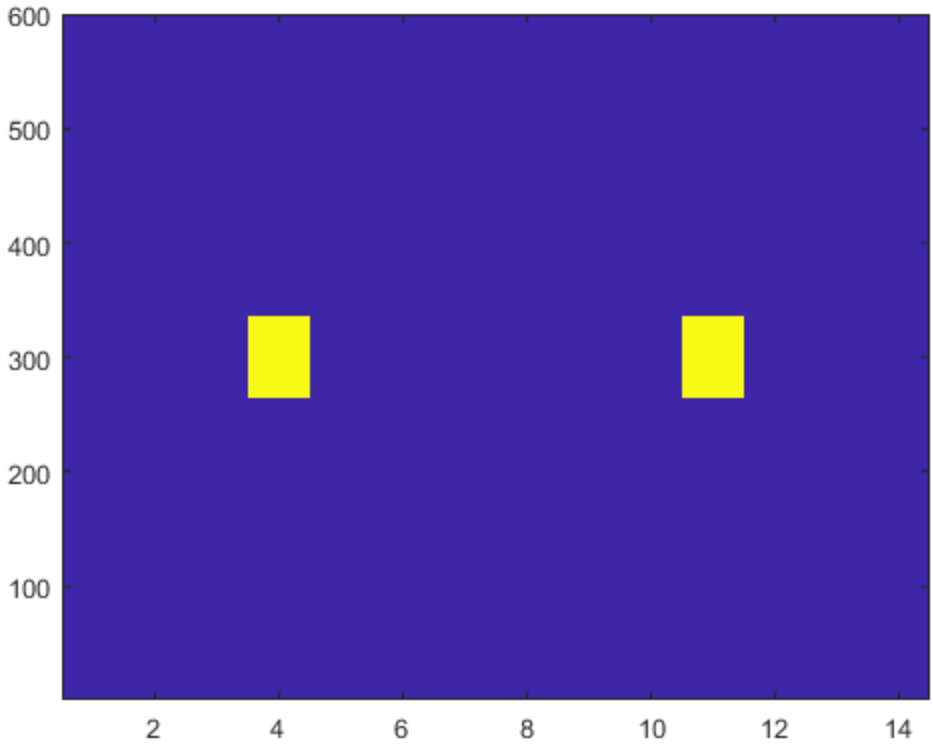
Write the complex PSBCH DM-RS values into the PSBCH DM-RS resource elements in a synchronization subframe with normal cyclic prefix and display an image of their locations.

Create a user equipment settings structure and an empty resource grid subframe for 10 MHz bandwidth and normal cyclic prefix.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 1;
subframe = lteSLResourceGrid(ue);
```

Generate PSBCH DM-RS indices and load PSBCH DM-RS values into `subframe`. Display the PSBCH DM-RS locations.

```
psbchdrs_indices = ltePSBCHDRSIndices(ue);
subframe(psbchdrs_indices) = ltePSBCHDRS(ue);
image(100*abs(subframe))
axis xy
```



Input Arguments

ue — User equipment settings

structure

UE equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — Resource element indices
integer column vector | three-column integer matrix

Resource element indices, returned as an integer column vector or a three-column integer matrix. By default, the indices are returned in a 144-by-1 column vector in one-based linear indexing form. You can use this form to directly access elements of a matrix representing the subframe resource grid for antenna port 1010. To specify alternative indexing formats, use the `opts` input argument.

Definitions

PSBCH Demodulation Reference Signal Indexing

Use the indexing function, `ltePSBCHDRSIndices`, and the corresponding sequence function, `ltePSBCHDRS`, to index the resource grid for any synchronization subframe number. The indices are ordered as the PSBCH DM-RS symbols should be, applying frequency-first mapping, into the two DM-RS SC-FDMA symbols. For more information on mapping symbols to the resource element grid, see "Resource Grid Indexing".

PSBCH Demodulation Reference Signal

The PSBCH demodulation reference signal (DM-RS) is transmitted alongside the `ltePSBCH` values in the central 72 resource elements and in two SC-FDMA symbols in a synchronization subframe. For zero-based indexing, the SC-FDMA symbol indices are {3,10} for normal cyclic prefix and {2,8} for extended cyclic prefix. These are the same symbols used by the PUSCH DM-RS, see `ltePUSCHDRSIndices`.

Note: The indicated symbol indices are based on TS 36.211, Section 9.8, but expanded from symbol index per slot to symbol index per subframe to align with the LTE System Toolbox subframe orientation. For more information on mapping symbols to the resource element grid, see "Resource Grid Indexing".

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePSBCH` | `ltePSBCHDecode` | `ltePSBCHDRS` | `ltePUSCHDRSIndices`

Introduced in R2016b

ltePSBCHIndices

PSBCH resource element indices

Syntax

```
ind = ltePSBCHIndices(ue)
ind = ltePSBCHIndices(ue,opts)
```

Description

`ind = ltePSBCHIndices(ue)` returns a column vector of physical sidelink broadcast channel (PSBCH) resource element (RE) indices for the specified UE settings structure. By default, the indices are returned in one-based linear indexing form. You can use this form to directly index elements of a matrix representing the subframe resource grid for antenna port 1010. For more information, see “Physical Sidelink Broadcast Channel Indexing” on page 1-710.

`ind = ltePSBCHIndices(ue,opts)` formats the returned indices using options specified in cell array `opts`.

Examples

Generate PSBCH Indices

Generate PSBCH values and indices. Write the values into the PSBCH resource elements in a synchronization subframe with a normal cyclic prefix, and display an image of their locations. This mapping also writes the PSBCH values into the last SC-FDMA guard symbol within a subframe. The sidelink SC-FDMA modulator removes PSBCH values from the last SC-FDMA guard symbol in a separate processing step.

Create a user equipment settings structure and a resource grid that has 10 MHz bandwidth and normal cyclic prefix.

```
ue.NSLRB = 50;
```

```
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 1;
```

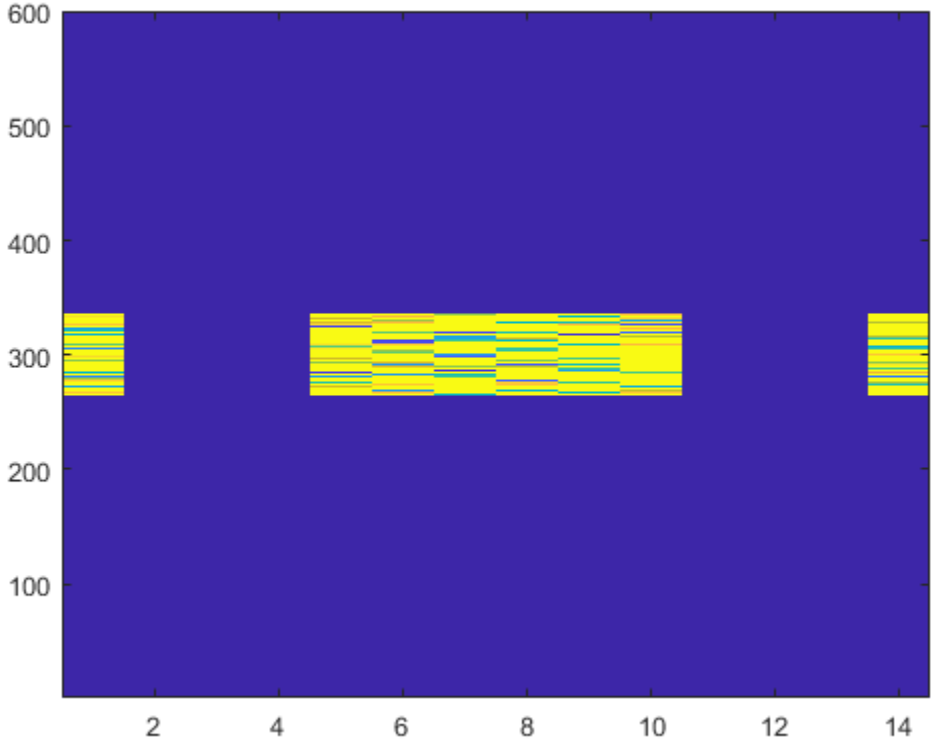
Generate an empty resource grid, PSBCH codeword values, and PSBCH indices. Display the first five indices.

```
grid = lteSLResourceGrid(ue);
codeword = lteSLBCH(ue,zeros(40,1));
psbch_indices = ltePSBCHIndices(ue);
psbch_indices(1:5)
```

```
ans =

  5×1 uint32 column vector

   265
   266
   267
   268
   269
```

Load the PSBCH codeword values into the resource grid and display their locations.

```
grid(psbch_indices) = ltePSBCH(ue,codeword);
image(100*abs(grid))
axis xy
```



Generate Zero-Based PSBCH Indices

Generate PSBCH indices using zero-based indexing style. Compare these indices to one-based indices.

Create a user equipment settings structure with 10 MHz bandwidth and normal cyclic prefix.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 1;
```

Generate PSBCH zero-based indices. View the first five indices.

```
psbch_indices = ltePSBCHIndices(ue,'0based');
psbch_indices_size = size(psbch_indices)
psbch_indices(1:5)
```

```
psbch_indices_size =

   576     1


ans =

  5×1 uint32 column vector

   264
   265
   266
   267
   268
```

Generate PSBCH one-based indices and view the first five indices.

```
psbch_indices = ltePSBCHIndices(ue,'1based');
psbch_indices_size = size(psbch_indices)
psbch_indices(1:5)
```

```
psbch_indices_size =

   576     1


ans =

  5×1 uint32 column vector

   265
   266
   267
   268
   269
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing style.

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.

Category	Options	Description
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PSBCH resource element indices

integer column vector | three-column integer matrix

PSBCH resource element indices, returned as an integer column vector or a three-column integer matrix. The returned vector or matrix has 576 PSBCH resource element indices for normal cyclic prefix or 432 PSBCH resource element indices for extended cyclic prefix. For more information, see “Physical Sidelink Broadcast Channel Indexing” on page 1-710.

Data Types: `uint32`

Definitions

Physical Sidelink Broadcast Channel Indexing

Use the `ltePSBCHIndices` indexing function and the corresponding `ltePSBCH` sequence function to populate the resource grid for the desired synchronization subframe number. The indices are ordered as the PSBCH QPSK modulation symbols should be mapped, applying frequency-first mapping, and include indices for the last SC-FDMA guard symbol. The PSBCH values returned by `ltePSBCH` are ordered as they should be mapped into the resource elements of the adjacent symbols using `ltePSBCHIndices`. For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

Physical Sidelink Broadcast Channel

The physical sidelink broadcast channel (PSBCH) is transmitted in the central 72 resource elements in the available SC-FDMA symbols of synchronization subframes. The available symbols exclude the three symbols per slot assigned to the PSBCH DRS and sidelink synchronization signals. The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process. Before transmission, the PSBCH resource elements are removed from the last SC-FDMA symbol by `lteSCFDMAModulate` during the sidelink-specific SC-FDMA modulation and guard symbol creation.

If a terminal is transmitting a synchronization subframe, then it should be sent every 40 ms, with the exact subframe dependent on the RRC-signaled subframe number offset (*syncOffsetIndicator-r12*). The subframe also contains values for the `ltePSBCHDRSIndices` on port 1010 and `ltePSSSIndices` and `lteSSSSIndices` on port 1020. No PSCCH or PSSCH transmission will occur in a sidelink subframe configured for synchronization purposes.

See Also

See Also

`ltePSBCH` | `ltePSBCHDecode` | `ltePSBCHDRSIndices` | `lteSLBCHDecode`

Introduced in R2016b

ltePSBCHPRBS

PSBCH pseudorandom binary scrambling sequence

Syntax

```
seq = ltePSBCHPRBS(ue,n)
seq = ltePSBCHPRBS(ue,n,mapping)
```

Description

`seq = ltePSBCHPRBS(ue,n)` returns a column vector containing the first `n` outputs of the PSBCH pseudorandom binary scrambling sequence (PRBS) for the specified UE settings structure.

The scrambling sequence generated should be applied to the coded PSBCH data carried by the associated subframe. The PRBS sequence generator used is initialized with c_{init} = `ue.NSLID`.

`seq = ltePSBCHPRBS(ue,n,mapping)` specifies the format of the returned sequence through the `mapping` input.

Examples

Scramble PSBCH Codeword

Scramble a PSBCH codeword by generating the PSBCH pseudorandom binary sequence (PRBS) and applying an exclusive OR operation on the two sequences.

Create a UE configuration structure and SL-BCH codeword. Generate the required length of the PRBS and scramble the PSBCH codeword with the PRBS sequence using `xor`.

```
ue = struct('NSLID',2);
codeword = lteSLBCH(ue,ones(40,1));
psbchPrbs = ltePSBCHPRBS(ue,length(codeword));
```

```
scrambled = xor(psbchPrbs,codeword);
```

Descramble PSBCH Codeword

Descramble a received PSBCH codeword.

Scramble PSBCH Codeword

- Create a UE configuration structure and SL-BCH codeword.
- Generate the required length of the PRBS and scramble the PSBCH codeword with the PRBS sequence using `xor`.
- Modulate the logical scrambled data.

```
ue = struct('NSLID',2);
codeword = lteSLBCH(ue,ones(40,1));

psbchPrbs = ltePSBCHPRBS(ue,length(codeword));
scrambled = xor(psbchPrbs,codeword);

txsym = lteSymbolModulate(scrambled,'QPSK');
```

Descramble Recovered Codeword

- Add noise to transmitted symbols and demodulate received soft data.
- Generate the PSBCH PRBS in signed form.
- Descramble a vector of noisy demodulated symbols representing a sequence of soft bits. To do so, perform a pointwise multiplication between the PRBS sequence and the recovered data.
- Compare the transmitted codeword to the recovered codeword.

```
rxsym = awgn(double(txsym),30,'measured');
softdata = lteSymbolDemodulate(rxsym,'QPSK');

scramblingSeq = ltePSBCHPRBS(ue,length(softdata),'signed');

descrambled = softdata.*scramblingSeq;

isequal(codeword,descrambled > 0)


ans =
```

```
logical

 1
```

The transmitted codeword matches the hard decision on the descrambled data.

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a parameter structure containing this field:

`NSLID` — Physical layer sidelink synchronization identity

integer from 0 to 355

Physical layer sidelink synchronization identity, specified as an integer from 0 to 355. ($N_{\mathrm{ID}}^{\mathrm{SL}}$)

Data Types: `double`

Data Types: `struct`

`n` — Number of outputs

nonnegative integer

Number of outputs, specified as a nonnegative integer.

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — PSBCH pseudorandom scrambling sequence

logical column vector | numeric column vector

PSBCH pseudorandom scrambling sequence, returned as a column vector. `seq` contains the first `n` outputs of the physical sidelink broadcast channel (PSBCH) scrambling sequence.

- When `mapping` is set to `'signed'`, then `seq` is a `double` column vector.
- When `mapping` is set to `'binary'`, then `seq` is a `logical` column vector.

Data Types: `logical` | `double`

See Also

See Also

`ltePBCHPRBS` | `ltePRBS` | `ltePSBCH` | `ltePSBCHDecode` | `ltePSBCHIndices`

Introduced in R2016b

ltePSCCH

Physical sidelink control channel

Syntax

```
sym = ltePSCCH(cw)
```

Description

`sym = ltePSCCH(cw)` returns a column vector containing the physical sidelink control channel (PSCCH) complex symbols for the input codeword bits. Channel processing performed by the function includes PSCCH-specific scrambling, QPSK modulation, and SC-FDMA transform precoding, as defined in TS 36.211 [1], Section 9.4.

For more information, see “Physical Sidelink Control Channel Processing” on page 1-718.

Examples

Generate SCI Message on PSCCH

Create a codeword using an encoded SCI message payload and process the bits on the PSCCH.

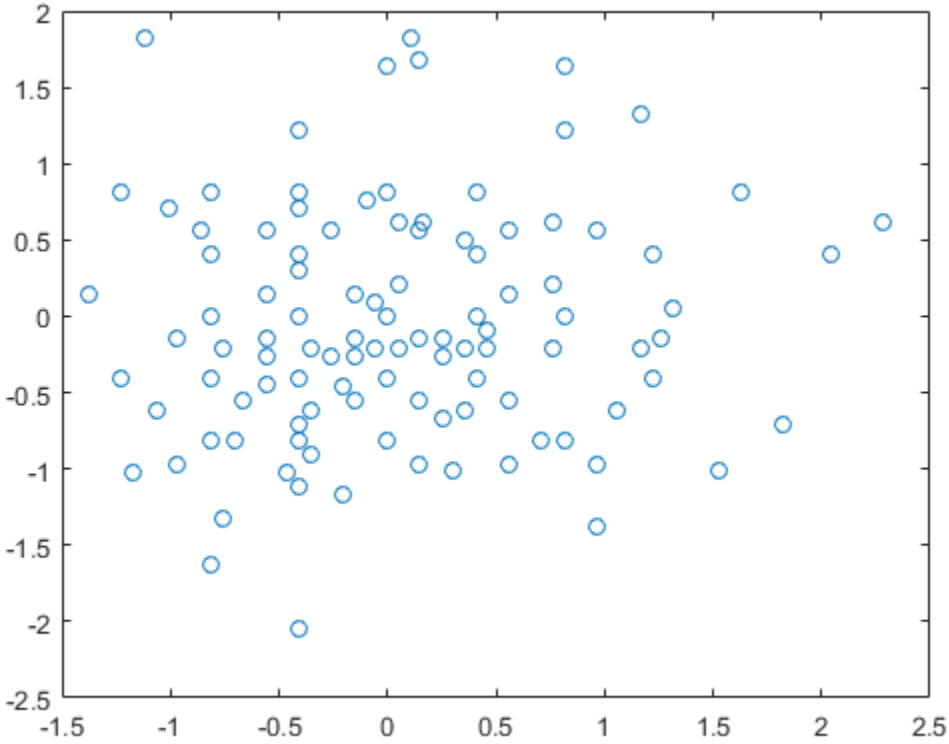
Create a UE setttings structure and use it to generate SCI message bits. Produce an encoded SCI message codeword.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
[~,scibits] = lteSCI(ue);

cw = lteSCIEncode(ue,scibits);
```

Generate PSCCH symbols. View the length of the symbol column vector. Plot the constellation to show the effect of the SC-FDMA precoding on the modulation symbols.

```
symbols = ltePSCCH(cw);
numSymbols = size(symbols)
```

```
plot(symbols,'o')

numSymbols =

   144     1
```



Input Arguments

cw — PSCCH codeword

vector

PSCCH codeword, specified as an M_{bit}-by-1 integer vector. M_{bit} is the number of bits transmitted on the physical sidelink control channel in one subframe and must be a multiple of 12. For more information, see "Physical Sidelink Control Channel Processing" on page 1-718.

Data Types: `double | int8`

Output Arguments

`sym` — Modulated PSCCH symbols

column vector

Modulated PSCCH symbols, returned as an N_{RE}-by-1 column vector. N_{RE} is number of PSCCH resource elements in a subframe. For more information, see "Physical Sidelink Control Channel Processing" on page 1-718.

Definitions

Physical Sidelink Control Channel Processing

Physical sidelink control channel (PSCCH) processing includes PSCCH-specific scrambling, QPSK modulation, and SC-FDMA transform precoding. PSCCH processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.4.

For PSCCH, the input codeword length is $M_{bits} = N_{RE} \times N_{bps}$, where N_{RE} is the number of PSCCH resource elements in a subframe and N_{bps} is the number of bits per symbol. Because the PSCCH is QPSK modulated, there are 2 bits per symbol. Nominally, the codeword length for PSCCH is 288 bits for normal cyclic prefix or 240 bits for extended cyclic prefix. Nominally, N_{RE} is 144 for normal cyclic prefix or 120 for extended cyclic prefix. Specifically, $N_{RE} = N_{PRB} \times N_{REperPRB} \times N_{SYM}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission. PSCCH is transmitted on a single PRB.
- $N_{REperPRB}$ is the number of resource elements in a PRB. Each PRB has 12 resource elements.

- N_{SYM} is the number of SC-FDMA symbols in a PSCCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols is a PSCCH subframe is 12 for normal cyclic prefix or 10 for extended cyclic prefix.

When an SCI message is sent as a sidelink shared grant, it is transmitted twice on two separate PSCCH instances within the associated PSCCH resource pool.

Physical Sidelink Control Channel Indexing

Use the `ltePSCCHIndices` indexing function and the corresponding `ltePSCCH` sequence function to populate the PSCCH subframe resource grid. The PSCCH is transmitted in the available SC-FDMA symbols in a PSCCH subframe, using a single layer representing antenna port 1000. It excludes each symbol per slot assigned to PSCCH DM-RS. For more information on PSCCH DM-RS, see the `ltePSCCHDRSIndices` function.

The indices are ordered as the PSCCH QPSK modulation symbols should be mapped, applying frequency-first mapping. The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates this guard symbol.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSCCHDecode` | `ltePSCCHDRS` | `ltePSCCHDRSIndices` | `ltePSCCHIndices` | `ltePSCCHPRBS` | `lteSCI` | `lteULPrecode`

Introduced in R2016b

ltePSCCHDecode

PSCCH decoding

Syntax

```
softbits = ltePSCCHDecode(sym)
[softbits,symbols] = ltePSCCHDecode(sym)
```

Description

`softbits = ltePSCCHDecode(sym)` returns a vector of log-likelihood ratio (LLR) soft bits for the input modulated PSCCH symbols.

The PSCCH decoder performs SC-FDMA transform deprecoding, QPSK demodulation, and PSCCH-specific descrambling. These operations are the inverse of the `ltePSCCH` function processing, as defined in TS 36.211 [1], Section 9.4. For more information, see “Physical Sidelink Control Channel Processing” on page 1-724.

`[softbits,symbols] = ltePSCCHDecode(sym)` also returns the intermediate QPSK modulation symbols.

Examples

Decode PSCCH Symbols

Decode PSCCH symbols that contain a fully encoded SCI format 0 message with noise added. After PSCCH demodulation, decode and recover the SCI message structure.

Create UE settings and SCI message configuration structures. Generate a PSCCH transmission. Add noise to the symbols.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
sci0 = struct('FreqHopping',1,'ModCoding',3);

[sci0,scibits] = lteSCI(ue,sci0);
```

```
cw = lteSCIEncode(ue,scibits);
sym = ltePSCCH(cw);

rxsym = sym + 0.1*randn(size(sym));
```

Decode the PSCCH symbols and SCI message. View the SCI message structure settings. Confirm that the transmitted and recovered SCI messages match.

```
[rxsoftbits,sym] = ltePSCCHDecode(rxsym);
[rxinfo,rxerr] = lteSCIDecode(ue,rxsoftbits);

[recsci0,recscibits] = lteSCI(ue,rxinfo);
recsci0

isequal(scibits,recscibits)


recsci0 =

  struct with fields:

             SCIFormat: 'Format0'
           FreqHopping: 1
            Allocation: [1×1 struct]
    TimeResourcePattern: 0
              ModCoding: 3
           TimeAdvance: 0
                 NSAID: 0


ans =

  logical

   1
```

Plot Decoded PSCCH Symbols

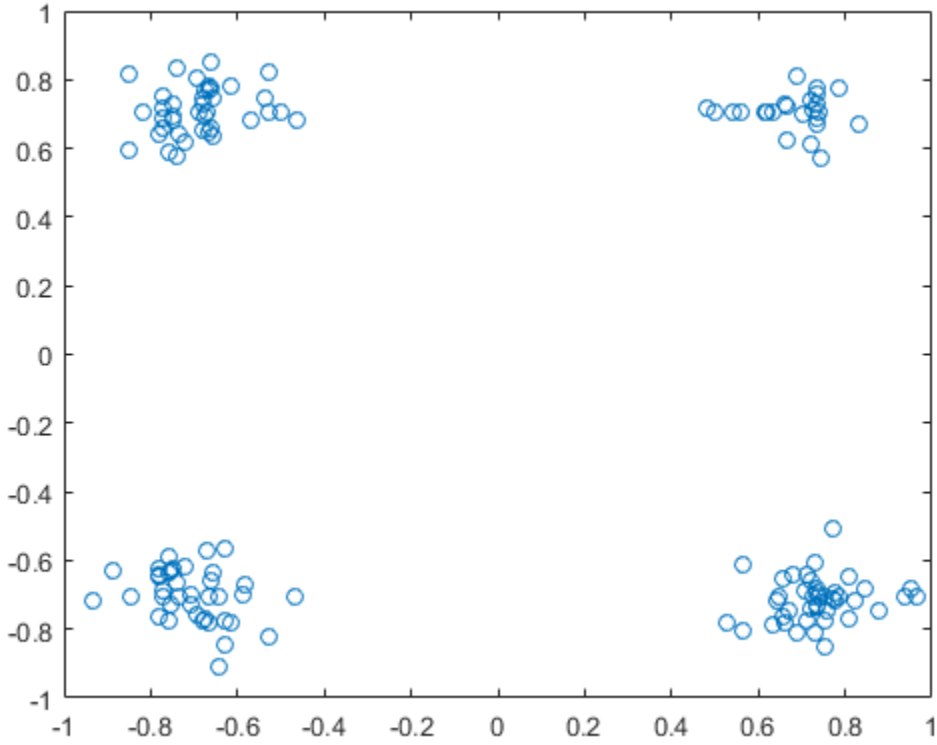
Decode PSCCH symbols that contain a fully encoded SCI format 0 message with noise added. After PSCCH demodulation, plot the intermediadte QPSK modulated symbols.

Create UE settings and SCI message configuration structures. Generate a PSCCH transmission. Add noise to the symbols.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
sci0 = struct('FreqHopping',1,'ModCoding',3);

[sci0,scibits] = lteSCI(ue,sci0);
cw = lteSCIEncode(ue,scibits);
sym = ltePSCCH(cw);

rxsym = sym + 0.1*randn(size(sym));
```

Decode the PSCCH symbols and plot the output intermediate QPSK modulated symbols.

```
[rxsoftbits,symbols] = ltePSCCHDecode(rxsym);
plot(symbols,'o')
```



Input Arguments

`sym` — Modulated PSCCH symbols

column vector

Modulated PSCCH symbols, specified as an N_{RE}-by-1 column vector. N_{RE} is the number of resource elements in a PSCCH subframe, including the SC-FDMA guard symbol. For more information, see “Physical Sidelink Control Channel Processing” on page 1-724.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`softbits` — Log-likelihood ratio soft bits

vector

Log-likelihood ratio (LLR) soft bits, returned as a $(2 \times N_{RE})$-by-1 vector. N_{RE} is the number of resource elements in a PSCCH subframe, including the SC-FDMA guard symbol. For more information, see "Physical Sidelink Control Channel Processing" on page 1-724.

`symbols` — Modulated PSCCH symbols

column vector of complex numbers

Modulated PSCCH symbols, returned as an N_{RE}-by-1 column vector. N_{RE} is the number of resource elements in a PSCCH subframe, including the SC-FDMA guard symbol. For more information, see "Physical Sidelink Control Channel Processing" on page 1-724.

Definitions

Physical Sidelink Control Channel Processing

Physical sidelink control channel (PSCCH) processing includes PSCCH-specific scrambling, QPSK modulation, and SC-FDMA transform precoding. PSCCH processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.4.

For PSCCH, the input codeword length is $M_{bits} = N_{RE} \times N_{bps}$, where N_{RE} is the number of PSCCH resource elements in a subframe and N_{bps} is the number of bits per symbol. Because the PSCCH is QPSK modulated, there are 2 bits per symbol. Nominally, the codeword length for PSCCH is 288 bits for normal cyclic prefix or 240 bits for extended cyclic prefix. Nominally, N_{RE} is 144 for normal cyclic prefix or 120 for extended cyclic prefix. Specifically, $N_{RE} = N_{PRB} \times N_{REperPRB} \times N_{SYM}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission. PSCCH is transmitted on a single PRB.
- $N_{REperPRB}$ is the number of resource elements in a PRB. Each PRB has 12 resource elements.

- N_{SYM} is the number of SC-FDMA symbols in a PSCCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols is a PSCCH subframe is 12 for normal cyclic prefix or 10 for extended cyclic prefix.

When an SCI message is sent as a sidelink shared grant, it is transmitted twice on two separate PSCCH instances within the associated PSCCH resource pool.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSCCH` | `ltePSCCHDRS` | `ltePSCCHDRSIndices` | `ltePSCCHIndices` | `ltePSCCHPRBS`

Introduced in R2016b

ltePSCCHDRS

PSCCH demodulation reference signal

Syntax

```
[seq,info] = ltePSCCHDRS
```

Description

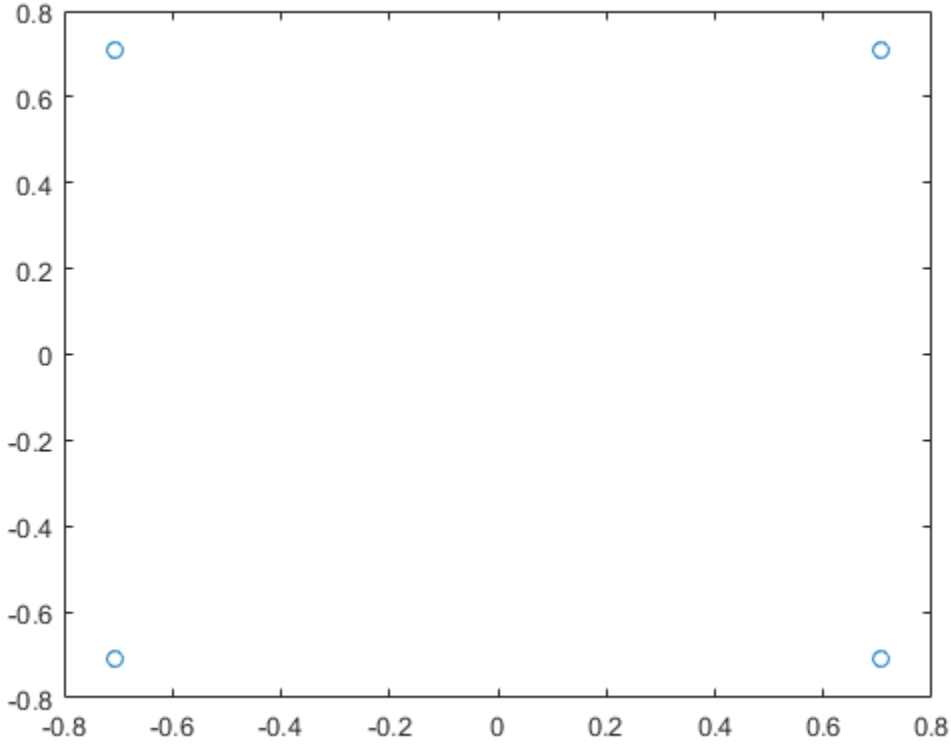
`[seq,info] = ltePSCCHDRS` returns a 24-by-1 complex column vector sequence containing PSCCH demodulation reference signal (DM-RS) values and an associated information structure. For more information, see “PSCCH Demodulation Reference Signal Processing” on page 1-729.

Examples

Generate PSCCH DM-RS Sequence

Generate a PSCCH DM-RS sequence associated with both DM-RS SC-FDMA symbols in a subframe. Plot the constellation of the sequence, which is QPSK modulated.

```
[pscchDrsSeq,info] = ltePSCCHDRS;
plot(pscchDrsSeq,'o')
```



Output Arguments

seq — PSCCH DM-RS values

column vector

PSCCH DM-RS values, returned as a 24-by-1 column vector. For more information, see “PSCCH Demodulation Reference Signal Processing” on page 1-729.

Data Types: `double`
Complex Number Support: Yes

`info` — PSCCH DM-RS information
structure

PSCCH DM-RS information about the intermediate variables used to create the DM-RS, returned as a parameter structure containing these fields:

`Alpha` — Reference signal cyclic shift for each slot
two-column vector

Reference signal cyclic shift for each slot, returned as a two-column vector. (α)

`Alpha` is proportional to `NCS`, where $\alpha = \frac{2\pi n_{cs,\lambda}}{12}$.

`SeqGroup` — Base sequence group number for each slot
two-column vector

Base sequence group number for each slot, returned as a two-column vector. (u)

`SeqIdx` — Base sequence number for each slot
two-column vector

Base sequence number for each slot, returned as a two-column vector. (v)

`RootSeq` — Root Zadoff-Chu sequence index for each slot
two-column vector

Root Zadoff-Chu sequence index for each slot, returned as a two-column vector. (q)

`NCS` — Cyclic shift values for each slot
two-column vector

Cyclic shift values for each slot, returned as a two-column vector. ($n_{\mathrm{cs},\lambda}$)

`NZC` — Zadoff-Chu sequence length
integer

Zadoff-Chu sequence length, returned as an integer. ($N_{\mathrm{ZC}}^{\mathrm{RS}}$)

`OrthSeq` — Orthogonal cover value for each slot
matrix

Orthogonal cover value for each slot, returned as a matrix. ($\bar{w}$)

Data Types: `struct`

Definitions

PSCCH Demodulation Reference Signal Processing

The PSCCH demodulation reference signal (DM-RS) sequence is transmitted alongside the `ltePSCCH` values using the two SC-FDMA symbols allocated to DM-RS in a PSCCH subframe. The output vector is the repetition of a 12-element sequence and specified in TS 36.211, Section 9.8. The output vector is mapped onto the 12 subcarriers of the DM-RS SC-FDMA symbol in each slot of the single PSCCH physical resource block (PRB) transmission on antenna port 1000.

The single-PRB PSCCH DM-RS is transmitted using a short base QPSK reference sequence instead of the Zadoff-Chu sequence that is normally used for reference signals. Because the Zadoff-Chu sequence is not used, the `RootSeq` and `NZC` fields are set to –1 in the `info` structure returned by `ltePSCCHDRS`.

PSCCH Demodulation Reference Signal Indexing

Use the indexing function, `ltePSCCHDRSIndices`, and the corresponding sequence function, `ltePSCCHDRS`, to populate the resource grid for any PSCCH subframe. The PSCCH DM-RS is transmitted in the available SC-FDMA symbols in a PSCCH subframe, using a single layer on antenna port 1000.

The indices are ordered as the PSCCH DM-RS QPSK modulation symbols should be, applying frequency-first mapping. One-based linear indexing is the default return format but you can also generate alternative indexing formats by using the `opts` input.

The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates the last symbol, which serves as a guard symbol.

For zero-based indexing, the SC-FDMA symbol indices used are {3,10} for normal cyclic prefix and {2,8} for extended cyclic prefix. The same symbols are used by the `ltePUSCHDRSIndices` function.

Note: The indicated symbol indices are based on TS 36.211, Section 9.8. However to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see "Resource Grid Indexing".

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSCCH` | `ltePSCCHDecode` | `ltePSCCHDRSIndices` | `ltePSCCHIndices`

Introduced in R2016b

ltePSCCHDRSIndices

PSCCH DM-RS resource element indices

Syntax

```
ind = ltePSCCHDRSIndices(ue)
ind = ltePSCCHDRSIndices(ue,opts)
```

Description

`ind = ltePSCCHDRSIndices(ue)` returns a 24-by-1 column vector of PSCCH demodulation reference signal (DM-RS) resource element indices for the specified UE settings structure. For more information, see "PSCCH Demodulation Reference Signal Indexing" on page 1-736.

`ind = ltePSCCHDRSIndices(ue,opts)` formats the returned indices using options specified in `opts`.

Examples

Create PSCCH DM-RS Values

Write the complex PSCCH DM-RS values into the PSCCH DM-RS resource elements in a PSCCH subframe with normal cyclic prefix. Display an image of their locations.

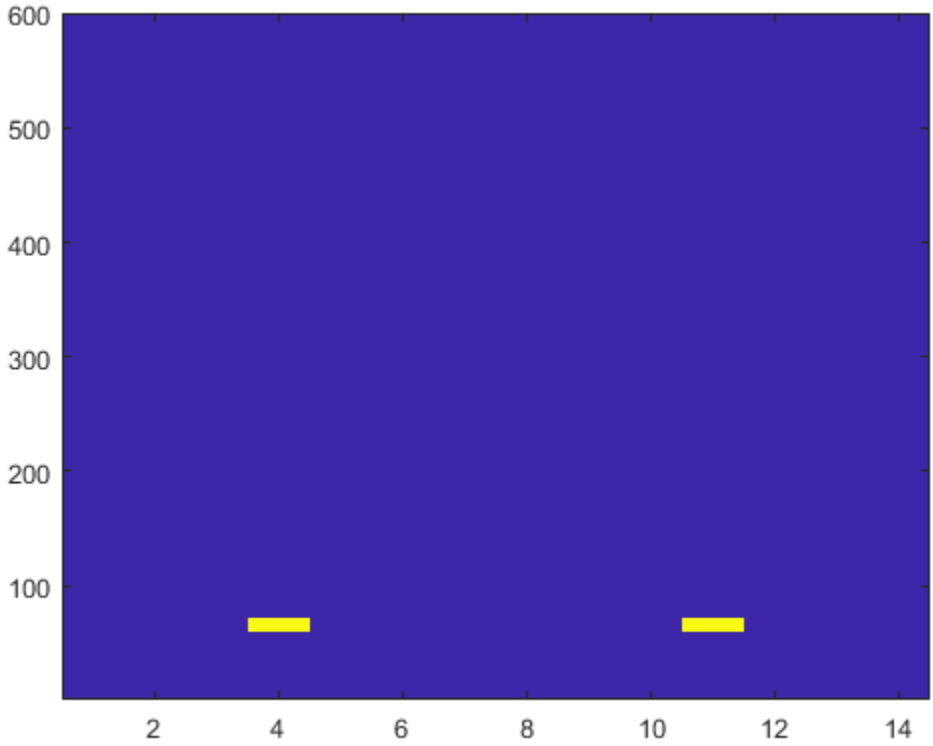
Create a user equipment settings structure and an empty resource grid subframe for 10 MHz bandwidth and normal cyclic prefix. Assign a PRB set index of 5.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 1;
subframe = lteSLResourceGrid(ue);
ue.PRBSet = 5;
```

Generate PSCCH DM-RS indices and write PSCCH DM-RS values into `subframe`. Display the PSCCH DM-RS locations.

```
pscchdrs_indices = ltePSCCHDRSIndices(ue);
```

```
subframe(pscchdrs_indices) = ltePSCCHDRS;
image(100*abs(subframe))
axis xy
```



Compare PSCCH DM-RS Resource Element Indexing

Compare PSCCH DM-RS resource element indexing formats.

Create a UE settings structure.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',5);
```

One-based linear indexing, this is the default output style

Generate PSCCH DM-RS indices, using the default one-based linear indexing style.

```
ind1 = ltePSCCHDRSIndices(ue);
ind1(1)
```

```
ans =

  uint32

   601
```

Zero-based linear indexing

Generate PSCCH DM-RS indices, using zero-based linear indexing style.

```
opts = '0based';
ind0 = ltePSCCHDRSIndices(ue,opts);
ind0(1)
```

```
ans =

  uint32

   600
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing.

One-based indexing in `[subcarrier,symbol,port]` subscript row style

Generate PSCCH DM-RS indices, one-based subscript row style.

```
opts = {'sub','1based'};
ind1sub = ltePSCCHDRSIndices(ue,opts);
size(ind1sub)
ind1sub(1,:)
```

```
ans =

    24     3


ans =
```

```
  1×3 uint32 row vector

   61    4    1
```

The subscript row style outputs a 24-by-3 matrix. Viewing the first row you can see symbol number 4 is occupied.

Two PSCCH subframe symbols are reserved for transmission of the PSCCH DM-RS. Inspecting the output matrix for unique symbol values, shows that the PSCCH DM-RS occupy symbols 4 and 11 for one-based indexing.

```
unique(ind1sub(:,2,:))
```

```
ans =

  2×1 uint32 column vector

    4
   11
```

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. (N_{RB}^{SL})

Example: 6, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

CyclicPrefixSL — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`PRBSet` — Zero-based physical resource block index

integer | integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) index, specified as an integer, an integer column vector, or a two-column integer matrix.

The PSCCH is intended to be transmitted in a single PRB in a subframe. Therefore, specifying `PRBSet` as a scalar PRB index is recommended. However, for a more general nonstandard multi-PRB allocation, `PRBSet` can be a set of indices specified as an integer column vector or as a two-column integer matrix corresponding to slot-wise resource allocations for PSCCH.

Data Types: `double`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PSCCH DM-RS resource element indices

integer column vector | three-column integer matrix

PSCCH DM-RS resource element indices, returned as an integer column vector or a three-column integer matrix. The returned vector or matrix has 24 PSCCH DM-RS resource element indices. For more information, see "PSCCH Demodulation Reference Signal Indexing" on page 1-736.

Data Types: `uint32`

Definitions

PSCCH Demodulation Reference Signal Indexing

Use the indexing function, `ltePSCCHDRSIndices`, and the corresponding sequence function, `ltePSCCHDRS`, to populate the resource grid for any PSCCH subframe. The PSCCH DM-RS is transmitted in the available SC-FDMA symbols in a PSCCH subframe, using a single layer on antenna port 1000.

The indices are ordered as the PSCCH DM-RS QPSK modulation symbols should be, applying frequency-first mapping. One-based linear indexing is the default return format but you can also generate alternative indexing formats by using the `opts` input.

The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates the last symbol, which serves as a guard symbol.

For zero-based indexing, the SC-FDMA symbol indices used are {3,10} for normal cyclic prefix and {2,8} for extended cyclic prefix. The same symbols are used by the `ltePUSCHDRSIndices` function.

Note: The indicated symbol indices are based on TS 36.211, Section 9.8. However to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

PSCCH Demodulation Reference Signal

The PSCCH demodulation reference signal (DM-RS) sequence is transmitted alongside the `ltePSCCH` values using the two SC-FDMA symbols allocated to DM-RS in a PSCCH subframe. The output vector is the repetition of a 12-element sequence and specified in TS 36.211, Section 9.8. The output vector is mapped onto the 12 subcarriers of the DM-RS SC-FDMA symbol in each slot of the single PSCCH physical resource block (PRB) transmission on antenna port 1000.

The single-PRB PSCCH DM-RS is transmitted using a short base QPSK reference sequence instead of the Zadoff-Chu sequence that is normally used for reference signals. Because the Zadoff-Chu sequence is not used, the `RootSeq` and `NZC` fields are set to –1 in the `info` structure returned by `ltePSCCHDRS`.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSCCH` | `ltePSCCHDecode` | `ltePSCCHDRS`

Introduced in R2016b

ltePSCCHIndices

PSCCH resource element indices

Syntax

```
[ind] = ltePSCCHIndices(ue)
[ind,info] = ltePSCCHIndices(ue)
[___] = ltePSCCHIndices(ue,opts)
```

Description

`[ind] = ltePSCCHIndices(ue)` returns a column vector of physical sidelink control channel (PSCCH) resource element (RE) indices for the specified UE settings structure. By default, the indices are returned in one-based linear indexing form. You can use this form to directly index elements of a matrix representing the subframe resource grid for antenna port 1000. For more information, see "Physical Sidelink Control Channel Indexing" on page 1-745.

`[ind,info] = ltePSCCHIndices(ue)` also returns a structure containing PSCCH-related information for the specified UE settings structure.

`[___] = ltePSCCHIndices(ue,opts)` formats the returned indices using options specified in `opts`. This syntax supports output options from prior syntaxes.

Examples

Map PSCCH Resource Elements

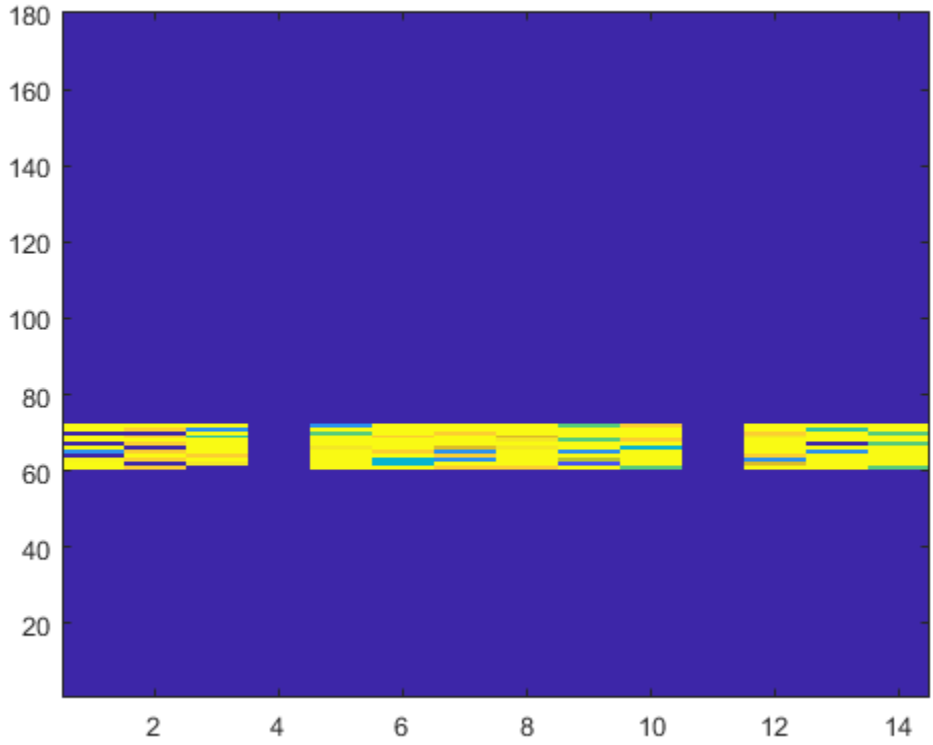
Write the complex PSCCH values into the PSCCH resource elements in a PSCCH subframe with normal cyclic prefix. Display an image of their locations. This mapping writes PSCCH values into the last SC-FDMA guard symbol within a subframe. The sidelink SC-FDMA modulator removes these values before transmission of the waveform.

Create a UE settings structure and an empty sidelink resource grid. Assign a PRB set index of 5.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal');
subframe = lteSLResourceGrid(ue);
ue.PRBSet = 5;
```

Generate PSCCH indices. Populate the PSCCH resource elements in the subframe using a codeword filled with zeros. For normal cyclic prefix, a PSCCH subframe contains 144 REs. Because the PSCCH uses QPSK modulation, there are 2 bits per symbol. View the resource grid.

```
pscch_indices = ltePSCCHIndices(ue);

cw = zeros(2*144,1);
subframe(pscch_indices) = ltePSCCH(cw);

image(100*abs(subframe))
axis xy
```



View PSCCH Information Structure

View the information structure output by the PSCCH resource element indexing function.

Create a UE settings structure.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',5);
```

Generate PSCCH indices and the information structure. View the information structure.

```
[pscch_indices,info] = ltePSCCHIndices(ue);
info
```

```
info =

  struct with fields:

     G: 288
    Gd: 144
```

Compare PSCCH Resource Element Indexing

Compare PSCCH resource element indexing formats. Options include one-based or zero-based indices in linear or subscript row indexing style.

Create a UE settings structure.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',5);
```

One-based linear indexing, this is the default output style

Generate PSCCH indices using the default one-based linear indexing.

```
pscch1ind = ltePSCCHIndices(ue);
pscch1ind(1)
```

```
ans =

  uint32

   61
```

Zero-based linear indexing

Generate PSCCH indices using zero-based linear indexing.

```
opts = 'Obased';
pscch0ind = ltePSCCHIndices(ue,opts);
pscch0ind(1)
```

```
ans =

  uint32
```

```
   60
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing.

One-based indices in `[subcarrier,symbol,port]` subscript row style

Generate PSCCH indices using one-based subscript row style.

```
opts = {'sub','1based'};
pscch1sub = ltePSCCHIndices(ue,opts);
pscch1sub(1,:)
```

```
ans =

  1×3 uint32 row vector

   61    1    1
```

The subscript row style outputs a 24-by-3 matrix. Viewing the first row you see from the second column value that symbol number 1 is occupied.

Inspecting the output matrix for unique symbol values, shows the symbols 4 and 11 are not occupied by PSCCH. Two PSCCH subframe symbols are reserved for transmission of PSCCH DM-RS. When one-based indexing is specified, symbols 4 and 11 transmit the PSCCH DM-RS.

```
unique(pscch1sub(:,2,:))
```

```
ans =

  12×1 uint32 column vector

    1
    2
    3
    5
    6
    7
    8
```

```
 9
10
12
13
14
```

Input Arguments

`ue` — User equipment settings
structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks
integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`PRBSet` — Zero-based physical resource block index
integer | integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) index, specified as an integer, an integer column vector, or a two-column integer matrix.

The PSCCH is intended to be transmitted in a single PRB in a subframe. Therefore, specifying `PRBSet` as a scalar PRB index is recommended. However, for a more general nonstandard multi-PRB allocation, `PRBSet` can be a set of indices specified as an integer column vector or as a two-column integer matrix corresponding to slot-wise resource allocations for PSCCH.

Data Types: `double`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PSCCH resource element indices

integer column vector | three-column integer matrix

PSCCH resource element indices, returned as an integer column vector or a three-column integer matrix. The returned vector or matrix has 288 PSCCH resource element indices for normal cyclic prefix or 240 PSCCH resource element indices for extended cyclic prefix. For more information, see “Physical Sidelink Control Channel Indexing” on page 1-745.

Data Types: `uint32`

`info` — PSCCH subframe resource information

structure

PSCCH subframe resource information, returned as a parameter structure containing these fields:

`G` — PSCCH bit capacity

integer

PSCCH bit capacity, returned as an integer. Nominally, this value is 288 for normal cyclic prefix or 240 for extended cyclic prefix.

Data Types: `double`

`Gd` — PSCCH QPSK symbol capacity

integer

PSCCH QPSK symbol capacity, returned as an integer. Nominally, this value is 144 for normal cyclic prefix or 120 for extended cyclic prefix.

Data Types: `double`

Data Types: `struct`

Definitions

Physical Sidelink Control Channel Indexing

Use the `ltePSCCHIndices` indexing function and the corresponding `ltePSCCH` sequence function to populate the PSCCH subframe resource grid. The PSCCH is transmitted in the available SC-FDMA symbols in a PSCCH subframe, using a single layer representing antenna port 1000. It excludes each symbol per slot assigned to PSCCH DM-RS. For more information on PSCCH DM-RS, see the `ltePSCCHDRSIndices` function.

The indices are ordered as the PSCCH QPSK modulation symbols should be mapped, applying frequency-first mapping. The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates this guard symbol.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

Physical Sidelink Control Channel Processing

Physical sidelink control channel (PSCCH) processing includes PSCCH-specific scrambling, QPSK modulation, and SC-FDMA transform precoding. PSCCH processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.4.

For PSCCH, the input codeword length is $M_{\text{bits}} = N_{\text{RE}} \times N_{\text{bps}}$, where N_{RE} is the number of PSCCH resource elements in a subframe and N_{bps} is the number of bits per symbol. Because the PSCCH is QPSK modulated, there are 2 bits per symbol. Nominally, the codeword length for PSCCH is 288 bits for normal cyclic prefix or 240 bits for extended cyclic prefix. Nominally, N_{RE} is 144 for normal cyclic prefix or 120 for extended cyclic prefix. Specifically, $N_{\text{RE}} = N_{\text{PRB}} \times N_{\text{REperPRB}} \times N_{\text{SYM}}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission. PSCCH is transmitted on a single PRB.
- N_{REperPRB} is the number of resource elements in a PRB. Each PRB has 12 resource elements.
- N_{SYM} is the number of SC-FDMA symbols in a PSCCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols is a PSCCH subframe is 12 for normal cyclic prefix or 10 for extended cyclic prefix.

When an SCI message is sent as a sidelink shared grant, it is transmitted twice on two separate PSCCH instances within the associated PSCCH resource pool.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSCCH` | `ltePSCCHDecode` | `ltePSCCHPRBS`

Introduced in R2016b

ltePSCCHPRBS

PSCCH pseudorandom binary scrambling sequence

Syntax

```
seq = ltePSCCHPRBS(n)
seq = ltePSCCHPRBS(n,mapping)
```

Description

`seq = ltePSCCHPRBS(n)` returns a column vector containing the first `n` outputs of the PSCCH pseudorandom binary scrambling sequence (PRBS).

The scrambling sequence generated should be applied to the coded PSCCH data carried by the associated subframe. The PRBS sequence generator used is initialized with $c_{\text{init}} = 510$.

`seq = ltePSCCHPRBS(n,mapping)` specifies the format of the returned sequence through the `mapping` input.

Examples

Scramble PSCCH Codeword

Scramble a PSCCH codeword by generating the PSCCH pseudorandom binary sequence (PRBS) and applying an exclusive OR operation on the two sequences.

Generate the required length of the PRBS and scramble the PSCCH codeword with the PRBS sequence using `xor`.

```
codeword = ones(288,1);
pscchPrbs = ltePSCCHPRBS(length(codeword));
scrambled = xor(pscchPrbs,codeword);
```

Descramble PSCCH Codeword

Descramble a received PSCCH codeword.

Scramble PSCCH Codeword

- Generate the required length of the PRBS and scramble the PSCCH codeword with the PRBS sequence using `xor`.
- Modulate the logical scrambled data.

```
codeword = ones(288,1);
pscchPrbs = ltePSCCHPRBS(length(codeword));
scrambled = xor(pscchPrbs,codeword);

txsym = lteSymbolModulate(scrambled,'QPSK');
```

Descramble Recovered Codeword

- Add noise to transmitted symbols and demodulate received soft data.
- Generate the PSCCH PRBS in signed form.
- Descramble a vector of noisy demodulated symbols representing a sequence of soft bits. To do so, perform a pointwise multiplication between the PRBS sequence and the recovered data.
- Compare the transmitted codeword to the recovered codeword.

```
sym = awgn(txsym,30,'measured');
softdata = lteSymbolDemodulate(sym,'QPSK');

scramblingSeq = ltePSCCHPRBS(length(softdata),'signed');
descrambled = softdata.*scramblingSeq;

isequal(codeword,descrambled > 0)


ans =

  logical

   1
```

The transmitted codeword matches the hard decision on the descrambled data.

Input Arguments

n — Number of outputs

nonnegative integer

Number of outputs, specified as a nonnegative integer.

Data Types: `double`

mapping — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

seq — PSCCH pseudorandom scrambling sequence

logical column vector | numeric column vector

PSCCH pseudorandom scrambling sequence, returned as a column vector. `seq` contains the first `n` outputs of the physical control channel (PCCH) scrambling sequence.

- When `mapping` is set to `'signed'`, then `seq` is a `double` column vector.
- When `mapping` is set to `'binary'`, then `seq` is a `logical` column vector.

See Also

See Also

`ltePRBS` | `ltePSCCH` | `ltePSCCHDecode` | `ltePSCCHIndices`

Introduced in R2016b

ltePSSCH

Physical sidelink shared channel

Syntax

```
sym = ltePSSCH(ue,cw)
```

Description

`sym = ltePSSCH(ue,cw)` returns a complex symbol column vector containing the physical sidelink shared channel (PSSCH) for the specified UE settings structure and codeword bits. Channel processing performed by the function includes PSSCH-specific scrambling, QPSK or 16-QAM modulation, and SC-FDMA transform precoding, as defined in TS 36.211 [1], Section 9.3.

For more information, see “Physical Sidelink Shared Channel Processing” on page 1-755.

Examples

Create PSSCH Symbols

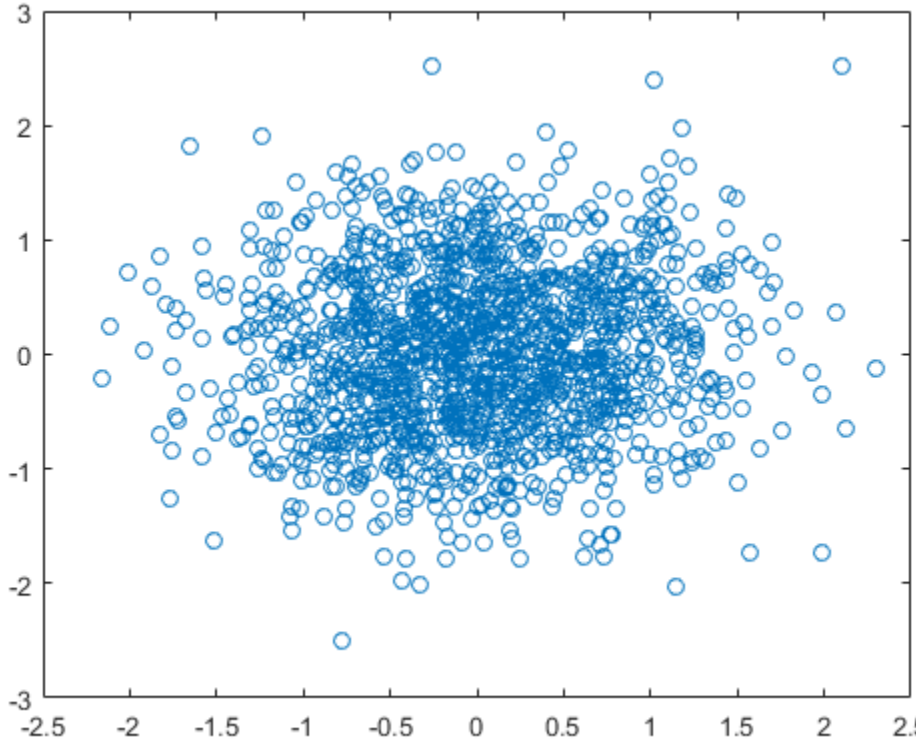
Create a codeword using the SL-SCH transport channel and encode the bits on the PSSCH.

Initialze a UE settings structure. Specify the codeword length to use for the SL-SCH. Choose a length that is a multiple of 12 symbols for normal cyclic prefix and has 4 bits per symbol for 16-QAM modulation. Pick a standard number of resource blocks, such as 10.

```
ue = struct('CyclicPrefixSL','Normal');
ue.RV = 0;
ue.Modulation = '16QAM';
ue.NSAID = 255;
ue.NSubframePSSCH = 0;

codewordlength = 5760; % (12 symbols)(4 bps)(12 REperRB)(10 PRB)
```

Create a codeword using `lteSLSCH` and encode the bits on the PSSCH. Plot the constellation to show the effects of the SC-FDMA precoding on the 16-QAM modulation symbols.

```
codeword = lteSLSCH(ue,codewordlength,zeros(100,1));
symbols = ltePSSCH(ue,codeword);

plot(symbols,'o')
```



Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`CyclicPrefixSL` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Modulation` — Modulation type
`'QPSK'` | `'16QAM'`

Modulation type, specified as `'QPSK'` or `'16QAM'`.

Data Types: `char`

`NSAID` — Sidelink group destination identity
integer scalar from 0 to 255

Sidelink group destination identity, specified as an integer scalar from 0 to 255. ($n_{\mathrm{ID}}^{\mathrm{SA}}$)

`NSAID` is the lower 8 bits of the full 24-bit ProSe Layer-2 group destination ID. `NSAID` and `NSubframePSSCH` control the value of the scrambling sequence at the start of each subframe.

Data Types: `double`

`NSubframePSSCH` — PSSCH subframe number
integer scalar

PSSCH subframe number in the PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

`NSubframePSSCH` and `NSAID` control the values of the scrambling sequence.

Data Types: `double`

Data Types: `struct`

`cw` — PSSCH codeword
integer vector

PSSCH codeword, specified as an M_{bit}-by-1 integer vector. M_{bit} is the number of bits transmitted on the physical sidelink shared channel in one subframe and must be a

multiple of 12. For more information, see "Physical Sidelink Shared Channel Processing" on page 1-755.

Output Arguments

`sym` — Modulated PSSCH symbols

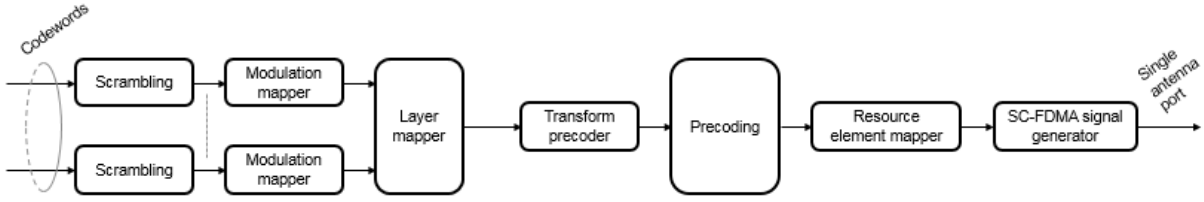
column vector

Modulated PSSCH symbols, returned as an N_{RE}-by-1 column vector. N_{RE} is number of PSSCH resource elements in a subframe. For more information, see "Physical Sidelink Shared Channel Processing" on page 1-755.

Definitions

Physical Sidelink Shared Channel Processing

Physical sidelink shared channel (PSSCH) processing includes PSSCH-specific scrambling, QPSK or 16-QAM modulation, and SC-FDMA transform precoding. PSSCH processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.3.



For PSSCH, the input codeword length is $M_{bits} = N_{RE} \times N_{bps}$, where N_{bps} is the number of bits per symbol. PSSCH modulation is either QPSK (2 bits per symbol) or 16 QAM (4 bits per symbol).

The number of PSSCH resource elements (N_{RE}) in a subframe is $N_{RE} = N_{PRB} \times N_{REperPRB} \times N_{SYM}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission.
- $N_{REperPRB}$ is the number of resource elements in a PRB. Each PRB has 12 resource elements.
- N_{SYM} is the number of SC-FDMA symbols in a PSSCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols in a PSSCH subframe is 12 for normal cyclic prefix or 10 extended cyclic prefix.

The `info` structure output by `ltePSSCHIndices` provides M_{bits} and N_{RE} as `info.G` and `info.Gd` respectively.

The scrambling sequence generator is initialized with $c_{init} = n_{ID}^{SA} \times 2^{14} + n_{ssf}^{PSSCH} \times 2^9 + 510$ at the start of every PSSCH subframe. n_{ID}^{SA} is the destination identity (`NSAID`) obtained from the sidelink shared channel. n_{ssf}^{PSSCH} is the subframe number in the PSSCH subframe pool (`NSubframePSSCH`).

`ltePSSCH` requires `CyclicPrefixSL` to deduce the number of resource blocks allocated for SC-FDMA precoding symbols.

Physical Sidelink Shared Channel Indexing

Use the `ltePSSCHIndices` function and the corresponding `ltePSSCH` sequence function to populate the PSSCH subframe resource grid. The PSSCH is transmitted in the available SC-FDMA symbols in a PSSCH subframe, using a single layer on antenna port 1000. It excludes each symbol per slot assigned to PSSCH DM-RS. For more information on PSSCH DM-RS, see the `ltePSSCHDRSIndices` function. The indices are ordered as the PSSCH modulation symbols should be mapped, applying frequency-first mapping. The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates this guard symbol. For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSCHDecode` | `ltePSSCHDRS` | `ltePSSCHIndices`

Introduced in R2016b

ltePSSCHDecode

PSSCH decoding

Syntax

```
[softbits,symbols] = ltePSSCHDecode(ue,sym)
```

Description

`[softbits,symbols] = ltePSSCHDecode(ue,sym)` returns a vector of log-likelihood ratio (LLR) soft bits and the intermediate QPSK or 16QAM modulation symbols for the specified UE settings structure and modulated PSSCH symbols.

The PSSCH decoder performs the inverse of the `ltePSSCH` function processing, as defined in TS 36.211 [1], Section 9.3. The `ltePSSCHDecode` processing includes SC-FDMA transform deprecoding, symbol demodulation, and PSSCH-specific descrambling. For more information, see “Physical Sidelink Shared Channel Decoding” on page 1-762.

Examples

Demodulate PSSCH Symbols

Demodulate PSSCH symbols plus noise for an SL-SCH codeword created by encoding a vector of information bits. Plot the noisy RE symbols, the symbols prior to QPSK demodulation, and the resulting LLR soft bits.

Create a UE settings structure

Specify normal cyclic prefix and 16-QAM modulation.

```
ue = struct('CyclicPrefixSL','Normal');
ue.RV = 0;
ue.Modulation = '16QAM';
ue.NSAID = 255;
```

```
ue.NSubframePSSCH = 0;
```

Generate symbols to recover

- Specify the codeword length to use for the SL-SCH. Choose a length that is a multiple of 12 symbols for normal cyclic prefix and has 4 bits per symbol for 16-QAM modulation. Pick a standard number of resource blocks, such as 10.
- Create the SL-SCH codeword.
- Create the PSSCH symbols and add noise.

```
codewordlength = 5760; % (12 symbols)(4 bps)(12 REperRB)(10 PRB)
cw = lteSLSCH(ue,codewordlength,ones(100,1));

sym = ltePSSCH(ue,cw);
rxsym = sym + 0.1*randn(size(sym));
```

Decode received PSSCH symbols

Recover the soft bits representing the transmitted SL-SCH codeword. Compare the soft bits to the transmitted codeword.

```
[rxcw,rxmodsym] = ltePSSCHDecode(ue,rxsym);
isequal(cw,rxcw>0)
```

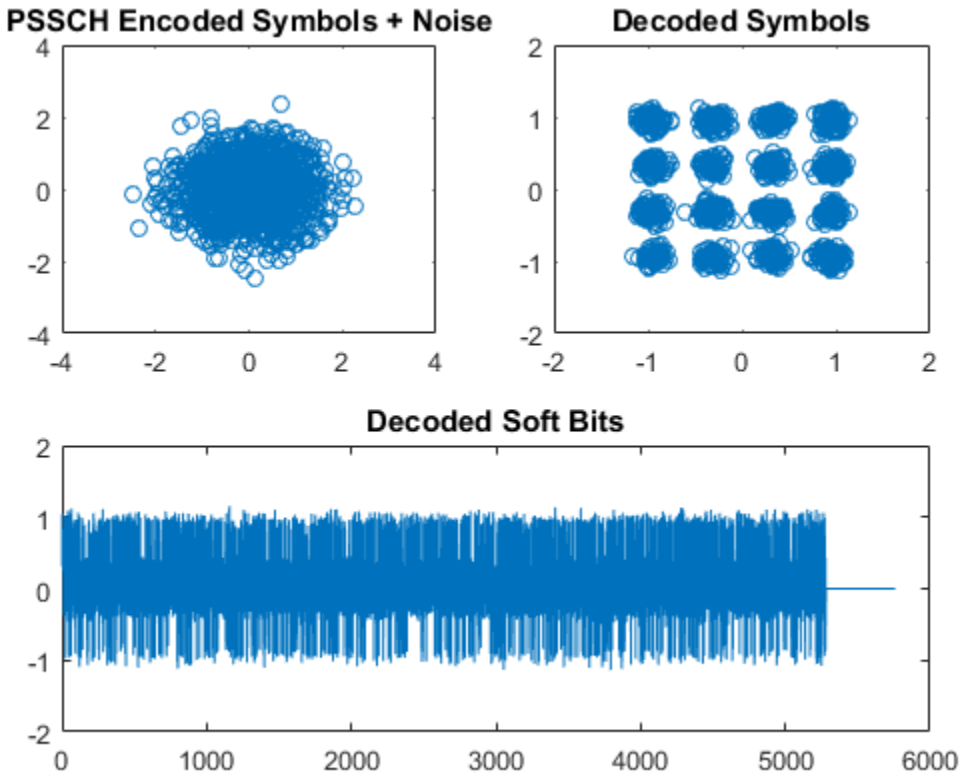
```
ans =

  logical

   0
```

Using a random noise seed and the level of noise added sometimes results in decoding errors. If the comparison returns '1' there were no decoding errors. If the comparison returns '0' there were decoding errors.

Plot the received and recovered signals.

```
subplot(2,2,1)
plot(rxsym,'o')
title('PSSCH Encoded Symbols + Noise')

subplot(2,2,2)
plot(rxmodsym,'o')
```

```
title('Decoded Symbols')

subplot(2,2,[3,4])
plot(rxcw)
title('Decoded Soft Bits')
```



Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Modulation` — Modulation type

`'QPSK'` | `'16QAM'`

Modulation type, specified as `'QPSK'` or `'16QAM'`.

Data Types: `char`

`NSAID` — Sidelink group destination identity

integer scalar from 0 to 255

Sidelink group destination identity, specified as an integer scalar from 0 to 255. ($n_{\mathrm{ID}}^{\mathrm{SA}}$)

`NSAID` is the lower 8 bits of the full 24-bit ProSe Layer-2 group destination ID. `NSAID` and `NSubframePSSCH` control the value of the scrambling sequence at the start of each subframe.

Data Types: `double`

`NSubframePSSCH` — PSSCH subframe number

integer scalar

PSSCH subframe number in the PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

`NSubframePSSCH` and `NSAID` control the values of the scrambling sequence.

Data Types: `double`

Data Types: `struct`

`sym` — Encoded modulated PSSCH symbols

column vector

Encoded modulated PSSCH symbols, specified as an N_{RE}-by-1 column vector. N_{RE} is the number of RE in a subframe associated with the PSSCH allocation for normal and extended cyclic prefix (including the SC-FDMA guard symbol) and NPRB resource blocks.

N_{RE} is $N_{PRB} \times 144$ for normal cyclic prefix or $N_{PRB} \times 120$ for extended cyclic prefix. N_{PRB} is the number of physical resource blocks (PRB) used for transmission.

The function requires the contents of all PSSCH resource elements to be input, including those in the last guard symbol. For more information, see "Physical Sidelink Shared Channel Decoding" on page 1-762.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`softbits` — Log-likelihood ratio soft bits

vector

Log-likelihood ratio (LLR) soft bits, returned as a vector with $N_{bps} \times N_{RE}$ softbits. N_{bps} is the number of bits per symbol. PSSCH modulation is either QPSK (2 bits per symbol) or 16 QAM (4 bits per symbol). N_{RE} is the number of PSSCH resource elements in the subframe.

For more information, see "Physical Sidelink Shared Channel Decoding" on page 1-762.

`symbols` — Decoded modulated PSSCH symbols

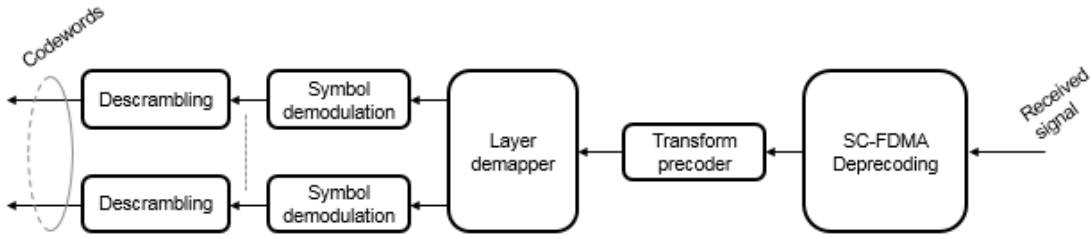
column vector

Decoded modulated PSSCH symbols, returned as a column vector with N_{RE} elements. N_{RE} is the number of PSSCH resource elements in the subframe. For more information, see "Physical Sidelink Shared Channel Decoding" on page 1-762.

Definitions

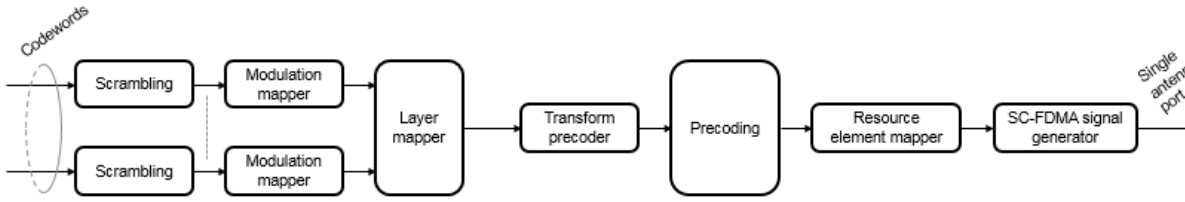
Physical Sidelink Shared Channel Decoding

The physical sidelink shared channel (PSSCH) decoder performs the inverse of the `ltePSSCH` function processing. For more information, see "Physical Sidelink Shared Channel Processing" on page 1-763. PSSCH decoding includes SC-FDMA transform deprecoding, symbol demodulation, and PSSCH-specific descrambling.



Physical Sidelink Shared Channel Processing

Physical sidelink shared channel (PSSCH) processing includes PSSCH-specific scrambling, QPSK or 16-QAM modulation, and SC-FDMA transform precoding. PSSCH processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.3.



For PSSCH, the input codeword length is $M_{\text{bits}} = N_{\text{RE}} \times N_{\text{bps}}$, where N_{bps} is the number of bits per symbol. PSSCH modulation is either QPSK (2 bits per symbol) or 16 QAM (4 bits per symbol).

The number of PSSCH resource elements (N_{RE}) in a subframe is $N_{\text{RE}} = N_{\text{PRB}} \times N_{\text{REperPRB}} \times N_{\text{SYM}}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission.
- N_{REperPRB} is the number of resource elements in a PRB. Each PRB has 12 resource elements.

- N_{SYM} is the number of SC-FDMA symbols in a PSSCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols in a PSSCH subframe is 12 for normal cyclic prefix or 10 extended cyclic prefix.

The `info` structure output by `ltePSSCHIndices` provides M_{bits} and N_{RE} as `info.G` and `info.Gd` respectively.

The scrambling sequence generator is initialized with $c_{init} = n_{ID}^{SA} \times 2^{14} + n_{ssf}^{PSSCH} \times 2^9 + 510$ at the start of every PSSCH subframe. n_{ID}^{SA} is the destination identity (`NSAID`) obtained from the sidelink shared channel. n_{ssf}^{PSSCH} is the subframe number in the PSSCH subframe pool (`NSubframePSSCH`).

`ltePSSCH` requires `CyclicPrefixSL` to deduce the number of resource blocks allocated for SC-FDMA precoding symbols.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSCH` | `ltePSSCHDRS` | `ltePSSCHDRSIndices` | `ltePSSCHIndices`

Introduced in R2016b

ltePSSCHDRS

PSSCH demodulation reference signal

Syntax

```
[seq,info] = ltePSSCHDRS(ue)
```

Description

`[seq,info] = ltePSSCHDRS(ue)` returns a complex column vector sequence containing PSSCH demodulation reference signal (DM-RS) values and an associated information structure for the specified UE settings structure. For more information, see “PSSCH Demodulation Reference Signal Processing” on page 1-769.

Examples

Generate PSSCH DM-RS Sequence

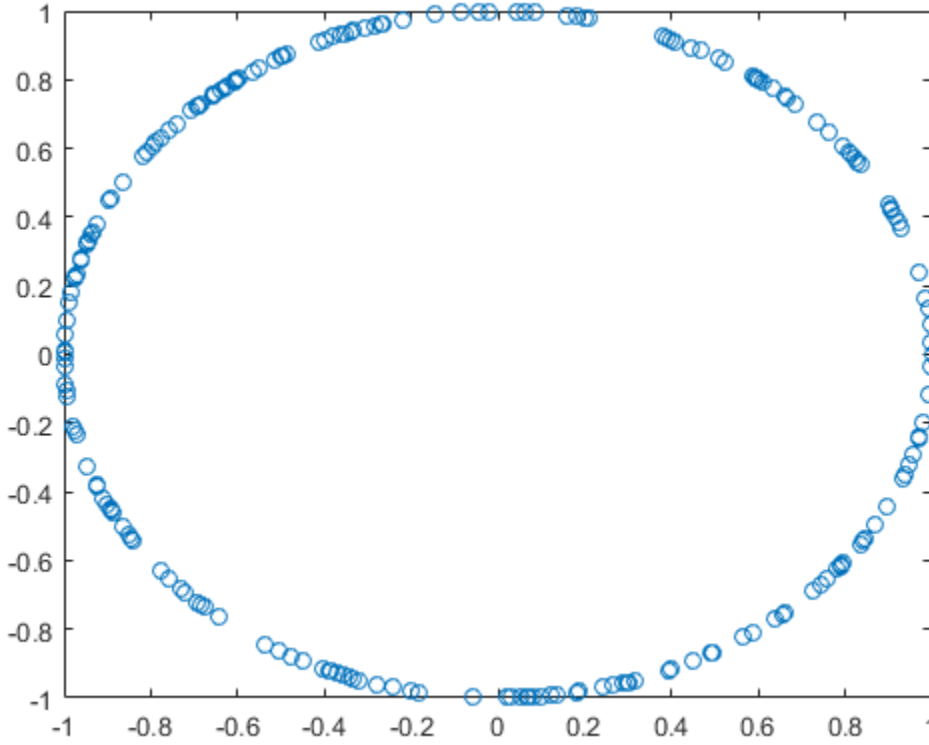
Generate a PSSCH DM-RS sequence associated with both DM-RS SC-FDMA symbols in a subframe. Plot the constellation of the sequence.

Create a user equipment settings structure.

```
ue = [];
ue.NSAID = 34;
ue.NSubframePSSCH = 5;
ue.PRBSet = (1:10)';
```

Generate a PSSCH DM-RS sequence. Plot the constellation.

```
[psschDrsSeq,info] = ltePSSCHDRS(ue);

plot(psschDrsSeq,'o')
```



Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

NSAID — Sidelink group destination identity

integer scalar from 0 to 255

Sidelink group destination identity, specified as an integer scalar from 0 to 255. ($n_{\mathrm{ID}}^{\mathrm{SA}}$)

`NSAID` is the lower 8 bits of the full 24-bit ProSe Layer-2 group destination ID. `NSAID` and `NSubframePSSCH` control the value of the scrambling sequence at the start of each subframe.

Data Types: `double`

`NSubframePSSCH` — PSSCH subframe number

integer scalar

PSSCH subframe number in the PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

`NSubframePSSCH` and `NSAID` control the values of the scrambling sequence.

Data Types: `double`

`PRBSet` — Zero-based physical resource block indices

integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) indices, specified as an integer column vector or a two-column integer matrix.

The PSSCH is intended to be transmitted in the same PRB in each slot of a subframe. Therefore, specifying `PRBSet` as a single column of PRB indices is recommended. However, for a nonstandard slot-hopping PRB allocation, `PRBSet` can be specified as a two-column matrix of indices corresponding to slot-wise resource allocations for PSSCH.

Data Types: `double`

Data Types: `struct`

Output Arguments

`seq` — PSSCH DM-RS values

column vector

PSSCH DM-RS values, returned as a $(24 \times N_{\mathrm{PRB}})$-by-1 column vector. For more information, see “PSSCH Demodulation Reference Signal Processing” on page 1-769.

`info` — PSSCH DM-RS information

structure

PSSCH DM-RS information about the intermediate variables used to create the DM-RS, returned as a parameter structure containing these fields:

`Alpha` — Reference signal cyclic shift for each slot
two-column vector

Reference signal cyclic shift for each slot, returned as a two-column vector. (a)

`Alpha` is proportional to `NCS`, where $\alpha = \frac{2\pi n_{cs,\lambda}}{12}$.

`SeqGroup` — Base sequence group number for each slot
two-column vector

Base sequence group number for each slot, returned as a two-column vector. (u)

`SeqIdx` — Base sequence number for each slot
two-column vector

Base sequence number for each slot, returned as a two-column vector. (v)

`RootSeq` — Root Zadoff-Chu sequence index for each slot
two-column vector

Root Zadoff-Chu sequence index for each slot, returned as a two-column vector. (q)

`NCS` — Cyclic shift values for each slot
two-column vector

Cyclic shift values for each slot, returned as a two-column vector. ($n_{\mathrm{cs},\lambda}$)

`NZC` — Zadoff-Chu sequence length
integer

Zadoff-Chu sequence length, returned as an integer. ($N_{\mathrm{ZC}}^{\mathrm{RS}}$)

`OrthSeq` — Orthogonal cover value for each slot
matrix

Orthogonal cover value for each slot, returned as a matrix. ($\overline{w}$)

Data Types: `struct`

Definitions

PSSCH Demodulation Reference Signal Processing

The PSSCH demodulation reference signal (DM-RS) sequence is transmitted alongside the `ltePSSCH` values using the two SC-FDMA symbols allocated to DM-RS in a PSSCH subframe. The output vector is the repetition of a 12-element sequence and specified in TS 36.211, Section 9.8. The vector is mapped onto the 12 DM-RS SC-FDMA symbol subcarriers in each subframe slot for each PSSCH physical resource block (PRB) transmission on antenna port 1000.

The output PSSCH DM-RS sequence is the concatenation of the two sequences to be mapped onto the DM-RS SC-FDMA symbol subcarriers in each subframe slot carrying a `ltePSSCH` transmission. Its length is $2 \times 12 \times N_{\mathrm{PRB}}$, where N_{PRB} is the number of PRBs associated with the PSSCH.

PSSCH Demodulation Reference Signal Indexing

Use the `ltePSSCHDRSIndices` indexing function and the corresponding `ltePSCCHDRS` sequence function to populate the resource grid for any PSSCH subframe. The PSSCH DM-RS is transmitted in the available SC-FDMA symbols in a PSSCH subframe, using a single layer on antenna port 1000.

The indices are ordered as the PSSCH DM-RS QPSK modulation symbols should be, applying frequency-first mapping. One-based linear indexing is the default return format, but alternative indexing formats can also be generated.

The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates the last symbol, which serves as a guard symbol.

When indexing is zero-based, the SC-FDMA symbol indices used are {3,10} for normal cyclic prefix and {2,8} for extended cyclic prefix. The same symbols are used by the `ltePUSCHDRSIndices` function.

Note: The indicated symbol indices are based on TS 36.211, Section 9.8. However, to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSCH` | `ltePSSCHDecode` | `ltePSSCHDRSIndices` | `ltePSSCHIndices`

Introduced in R2016b

ltePSSCHDRSIndices

PSSCH DM-RS resource element indices

Syntax

```
ind = ltePSSCHDRSIndices(ue)
ind = ltePSSCHDRSIndices(ue,opts)
```

Description

`ind = ltePSSCHDRSIndices(ue)` returns a column vector of PSSCH demodulation reference signal (DM-RS) resource element indices for the specified UE settings structure. For more information, see "PSSCH Demodulation Reference Signal Indexing" on page 1-776.

`ind = ltePSSCHDRSIndices(ue,opts)` formats the returned indices using options specified in cell array `opts`.

Examples

Create PSSCH DM-RS Values

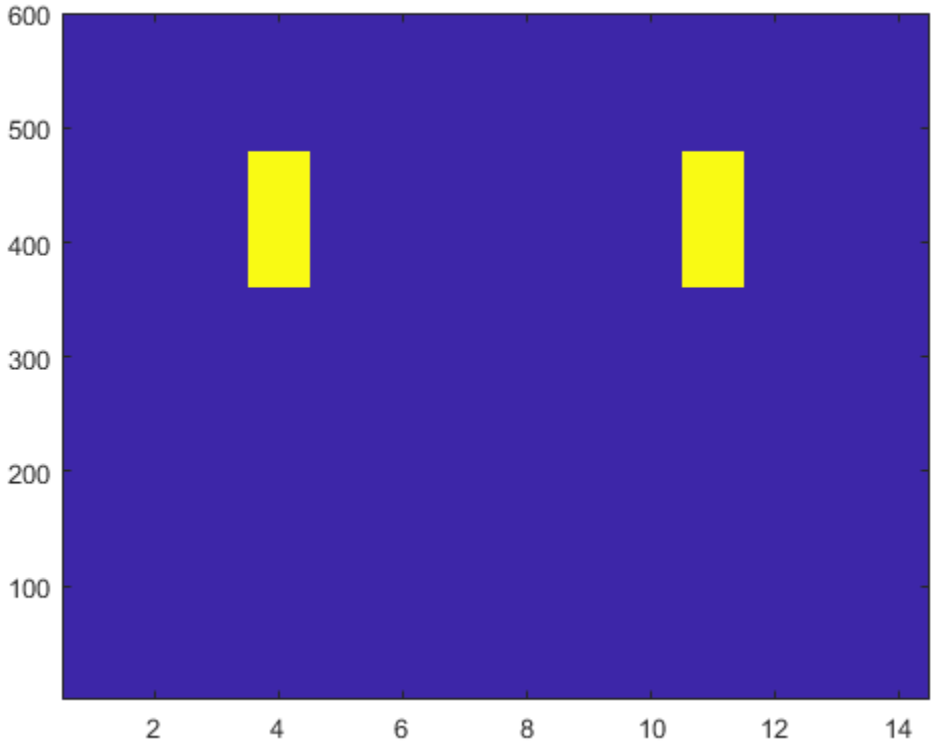
Write the complex PSSCH DM-RS values into the PSSCH DM-RS resource elements in a PSSCH subframe with normal cyclic prefix. Display an image of their locations.

Create a user equipment settings structure and an empty resource grid subframe for 10 MHz bandwidth and normal cyclic prefix. Define a PRB allocation, `ue.PRBSet`, with RB values from 30 to 39.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
ue.NSAID = 1;
ue.NSubframePSSCH = 1;
ue.PRBSet = [30:39]';
subframe = lteSLResourceGrid(ue);
```

Generate PSSCH DM-RS indices and load PSSCH DM-RS values into the subframe. Display the PSSCH DM-RS locations.

```
psschdrs_indices = ltePSSCHDRSIndices(ue);
subframe(psschdrs_indices) = ltePSSCHDRS(ue);

image(100*abs(subframe))
axis xy
```



Compare PSSCH DM-RS Resource Element Indexing

Compare PSSCH DM-RS resource element indexing formats.

Create a UE settings structure.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',5);
```

Generate PSSCH DM-RS indices using one-based linear indexing (default), zero-based linear indexing, and one-based subscript row style.

One-based linear indexing

```
psschdmrs_indices = ltePSSCHDRSIndices(ue);
psschdmrs_indices(1)
```

```
ans =

  uint32

   601
```

Zero-based linear indexing

```
opts = 'Obased';
psschdmrs_indices_Obased = ltePSSCHDRSIndices(ue,opts);
psschdmrs_indices_Obased(1)
```

```
ans =

  uint32

   600
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing.

One-based indexing in `[subcarrier,symbol,port]` subscript row style

Inspect the unique symbol values to see which symbols are occupied by the PSSCH DM-RS.

```
opts = {'sub' '1based'};
psschdmrs_indices_sub = ltePSSCHDRSIndices(ue,opts);
unique(psschdmrs_indices_sub(:,2,:))
```

```
ans =
```

```
2×1 uint32 column vector

  4
 11
```

Only symbols 4 and 11 are occupied. For one-based indexing, these two PSSCH subframe symbols are always reserved for transmission of the PSSCH DM-RS.

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`PRBSet` — Zero-based physical resource block indices

integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) indices, specified as an integer column vector or a two-column integer matrix.

The PSSCH is intended to be transmitted in the same PRB in each slot of a subframe. Therefore, specifying `PRBSet` as a single column of PRB indices is recommended.

However, for a nonstandard slot-hopping PRB allocation, `PRBSet` can be specified as a two-column matrix of indices corresponding to slot-wise resource allocations for PSSCH.

Data Types: `double`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PSSCH DM-RS resource element indices

integer column vector | three-column integer matrix

PSSCH DM-RS resource element indices, returned as an integer column vector or a three-column integer matrix. The returned vector or matrix has $24 \times N_{\mathrm{PRB}}$ PSSCH DM-RS resource element indices. where N_{PRB} is the number of PRBs associated with the

PSSCH. For more information, see “PSSCH Demodulation Reference Signal Indexing” on page 1-776.

Definitions

PSSCH Demodulation Reference Signal Indexing

Use the `ltePSSCHDRSIndices` indexing function and the corresponding `ltePSCCHDRS` sequence function to populate the resource grid for any PSSCH subframe. The PSSCH DM-RS is transmitted in the available SC-FDMA symbols in a PSSCH subframe, using a single layer on antenna port 1000.

The indices are ordered as the PSSCH DM-RS QPSK modulation symbols should be, applying frequency-first mapping. One-based linear indexing is the default return format, but alternative indexing formats can also be generated.

The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates the last symbol, which serves as a guard symbol.

When indexing is zero-based, the SC-FDMA symbol indices used are {3,10} for normal cyclic prefix and {2,8} for extended cyclic prefix. The same symbols are used by the `ltePUSCHDRSIndices` function.

Note: The indicated symbol indices are based on TS 36.211, Section 9.8. However, to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

PSSCH Demodulation Reference Signal

The PSSCH demodulation reference signal (DM-RS) sequence is transmitted alongside the `ltePSSCH` values using the two SC-FDMA symbols allocated to DM-RS in a PSSCH subframe. The output vector is the repetition of a 12-element sequence and specified in TS 36.211, Section 9.8. The vector is mapped onto the 12 DM-RS SC-FDMA symbol

subcarriers in each subframe slot for each PSSCH physical resource block (PRB) transmission on antenna port 1000.

The output PSSCH DM-RS sequence is the concatenation of the two sequences to be mapped onto the DM-RS SC-FDMA symbol subcarriers in each subframe slot carrying a `ltePSSCH` transmission. Its length is $2 \times 12 \times N_{PRB}$, where N_{PRB} is the number of PRBs associated with the PSSCH.

See Also

See Also

`ltePSSCH` | `ltePSSCHDecode` | `ltePSSCHDRS`

Introduced in R2016b

ltePSSCHIndices

PSSCH resource element indices

Syntax

```
[ind] = ltePSSCHIndices(ue)
[ind,info] = ltePSSCHIndices(ue)
[___] = ltePSSCHIndices(ue,opts)
```

Description

`[ind] = ltePSSCHIndices(ue)` returns a column vector of physical sidelink shared channel (PSSCH) resource element (RE) indices for the specified UE settings structure. By default, the indices are returned in one-based linear indexing form. You can use this form to directly index elements of a matrix representing the subframe resource grid for antenna port 1000. For more information, see "Physical Sidelink Shared Channel Indexing" on page 1-785.

`[ind,info] = ltePSSCHIndices(ue)` also returns a structure containing PSSCH-related information for the specified UE settings structure.

`[___] = ltePSSCHIndices(ue,opts)` formats the returned indices using options specified in cell array `opts`. This syntax supports output options from prior syntaxes.

Examples

Map PSSCH Resource Elements

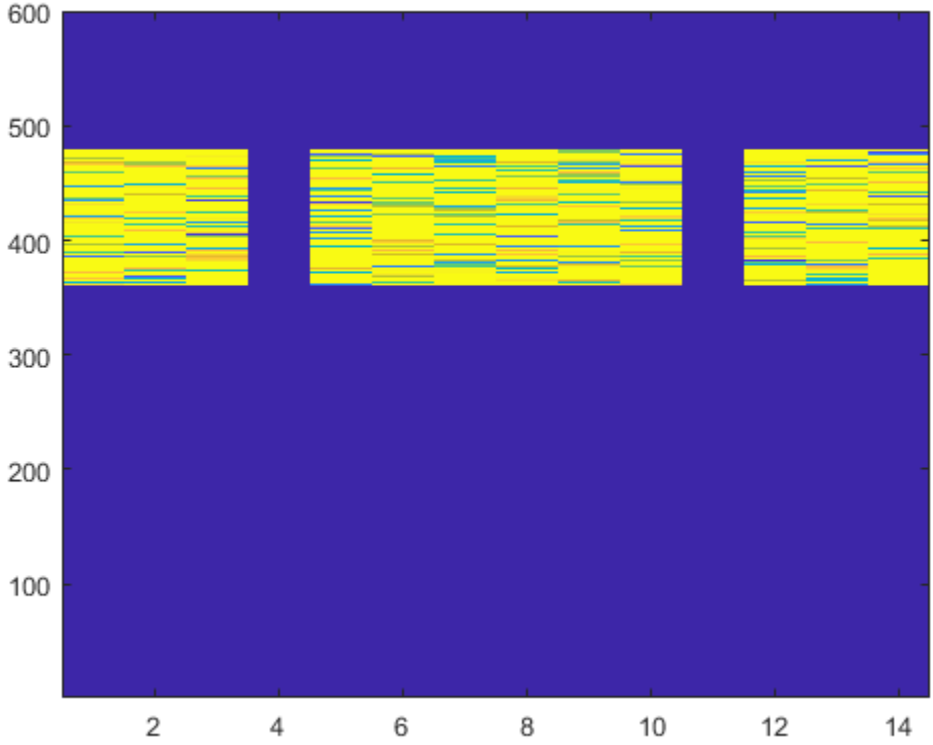
Write the complex PSSCH values into the PSSCH resource elements in a PSSCH subframe with normal cyclic prefix. Display an image of their locations. This mapping writes PSSCH values into the last SC-FDMA guard symbol within a subframe. The sidelink SC-FDMA modulator removes these values before transmission of the waveform.

Create a UE settings structure and an empty sidelink resource grid. Define a PRB allocation, `ue.PRBSet`, with RB values from 30 to 39.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
ue.NSAID = 1;
ue.NSubframePSSCH = 1;
ue.PRBSet = [30:39]';
ue.Modulation = 'QPSK';

subframe = lteSLResourceGrid(ue);
```

Generate PSSCH indices. Populate the PSSCH resource elements in the subframe using a codeword filled with zeros. For normal cyclic prefix a PSSCH subframe contains (144 * `nprb`) REs. The number of resource blocks is set to 10. Because the PSSCH uses QPSK modulation, there are 2 bits per symbol. View the resource grid.

```
pssch_indices = ltePSSCHIndices(ue);
nprb = 10;
cw = zeros(144*nprb*2,1); % (12 symbols)(12 REperRB)(10 PRB)(2 bps)

subframe(pssch_indices) = ltePSSCH(ue,cw);

image(100*abs(subframe))
axis xy
```



View PSSCH Information Structure

View the information structure output by the PSSCH resource element indexing function.

Create a UE settings structure.

```
ue = struct('NSLRB',25,'CyclicPrefixSL','Normal','PRBSet',[5:22]', ...
    'Modulation','16QAM');
```

Generate PSSCH indices and the information structure. View the information structure to see the bit and symbol capacity of the PSSCH for this configuration.

```
[pssch_indices,info] = ltePSSCHIndices(ue);
```

```
info
```

```
info =

  struct with fields:

     G: 10368
    Gd: 2592
```

Compare PSSCH Resource Element Indexing

Compare PSSCH resource element indexing formats.

Create a UE settings structure.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',12);
```

Generate PSSCH indices using one-based linear indexing (default), zero-based linear indexing, and one-based subscript row style.

One-based linear indexing

```
pssch_indices = ltePSSCHIndices(ue);
pssch_indices(1)
```

```
ans =

  uint32

   145
```

Zero-based linear indexing

```
opts = 'Obased';
pssch_indices_Obased = ltePSSCHIndices(ue,opts);
pssch_indices_Obased(1)
```

```
ans =

  uint32
```

```
   144
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing.

One-based indexing in `[subcarrier,symbol,port]` subscript row style

Inspect the unique symbol values to see which symbols are occupied by the PSSCH.

```
opts = {'sub' '1based'};
pssch_indices_sub = ltePSSCHIndices(ue,opts);
unique(pssch_indices_sub(:,2,:))
```

```
ans =

  12×1 uint32 column vector

    1
    2
    3
    5
    6
    7
    8
    9
   10
   12
   13
   14
```

Only the symbols 4 and 11 are not occupied. For one-based indexing, these two PSSCH subframe symbols are always reserved for transmission of the PSSCH DM-RS.

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`PRBSet` — Zero-based physical resource block indices

integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) indices, specified as an integer column vector or a two-column integer matrix.

The PSSCH is intended to be transmitted in the same PRB in each slot of a subframe. Therefore, specifying `PRBSet` as a single column of PRB indices is recommended. However, for a nonstandard slot-hopping PRB allocation, `PRBSet` can be specified as a two-column matrix of indices corresponding to slot-wise resource allocations for PSSCH.

Data Types: `double`

`Modulation` — Modulation type

`'QPSK'` (default) | `'16QAM'`

Modulation type, specified as `'QPSK'` or `'16QAM'`. Only required when the `info` output is assigned. `Modulation` is used to set the `info.G` output field.

Data Types: `char`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — PSSCH resource element indices

integer column vector | three-column integer matrix

PSSCH resource element indices, returned as an integer column vector or a three-column integer matrix. The returned vector or matrix has $N_{PRB} \times 144$ PSSCH resource element indices for normal cyclic prefix or $N_{PRB} \times 120$ PSSCH resource element indices for extended cyclic prefix. N_{PRB} is the number of physical resource blocks (PRB) used for transmission. For more information, see "Physical Sidelink Shared Channel Indexing" on page 1-785 and "Physical Sidelink Shared Channel Processing" on page 1-785.

`info` — PSSCH subframe resource information

structure

PSSCH subframe resource information, returned as a structure containing these fields:

`G` — PSSCH bit capacity

integer

PSSCH bit capacity, returned as an integer. For more information, see "Physical Sidelink Shared Channel Processing" on page 1-785.

`Gd` — PSSCH symbol capacity

integer

PSSCH symbol capacity, returned as an integer. The number of PSSCH resource elements (N_{RE}) in a subframe. For more information, see “Physical Sidelink Shared Channel Processing” on page 1-785.

Data Types: `struct`

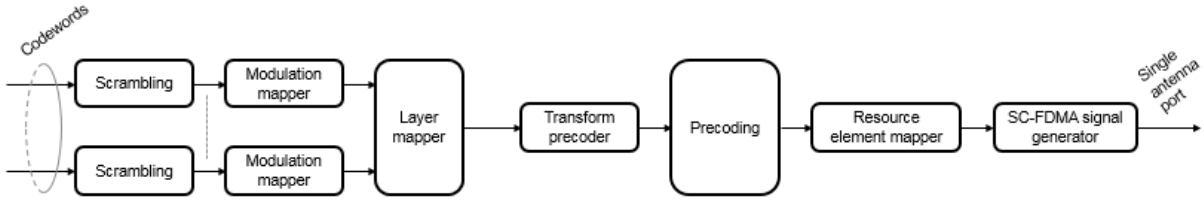
Definitions

Physical Sidelink Shared Channel Indexing

Use the `ltePSSCHIndices` function and the corresponding `ltePSSCH` sequence function to populate the PSSCH subframe resource grid. The PSSCH is transmitted in the available SC-FDMA symbols in a PSSCH subframe, using a single layer on antenna port 1000. It excludes each symbol per slot assigned to PSSCH DM-RS. For more information on PSSCH DM-RS, see the `ltePSSCHDRSIndices` function. The indices are ordered as the PSSCH modulation symbols should be mapped, applying frequency-first mapping. The resource elements in the last SC-FDMA symbol within a subframe are counted in the mapping process but should not be transmitted. The sidelink-specific SC-FDMA modulation creates this guard symbol. For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

Physical Sidelink Shared Channel Processing

Physical sidelink shared channel (PSSCH) processing includes PSSCH-specific scrambling, QPSK or 16-QAM modulation, and SC-FDMA transform precoding. PSSCH processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.3.



For PSSCH, the input codeword length is $M_{\text{bits}} = N_{\text{RE}} \times N_{\text{bps}}$, where N_{bps} is the number of bits per symbol. PSSCH modulation is either QPSK (2 bits per symbol) or 16 QAM (4 bits per symbol).

The number of PSSCH resource elements (N_{RE}) in a subframe is $N_{\text{RE}} = N_{\text{PRB}} \times N_{\text{REperPRB}} \times N_{\text{SYM}}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission.
- N_{REperPRB} is the number of resource elements in a PRB. Each PRB has 12 resource elements.
- N_{SYM} is the number of SC-FDMA symbols in a PSSCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols in a PSSCH subframe is 12 for normal cyclic prefix or 10 extended cyclic prefix.

The `info` structure output by `ltePSSCHIndices` provides M_{bits} and N_{RE} as `info.G` and `info.Gd` respectively.

The scrambling sequence generator is initialized with $c_{\text{init}} = n_{ID}^{SA} \times 2^{14} + n_{\text{ssf}}^{\text{PSSCH}} \times 2^{9} + 510$ at the start of every PSSCH subframe. $n_{\text{ID}}^{\text{SA}}$ is the destination identity (`NSAID`) obtained from the sidelink shared channel. $n_{\text{ssf}}^{\text{PSSCH}}$ is the subframe number in the PSSCH subframe pool (`NSubframePSSCH`).

`ltePSSCH` requires `CyclicPrefixSL` to deduce the number of resource blocks allocated for SC-FDMA precoding symbols.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSCH` | `ltePSSCHDecode` | `ltePSSCHPRBS`

Introduced in R2016b

ltePSSCHPRBS

PSSCH pseudorandom binary scrambling sequence

Syntax

```
seq = ltePSSCHPRBS(ue,n)
seq = ltePSSCHPRBS(ue,n,mapping)
```

Description

`seq = ltePSSCHPRBS(ue,n)` returns a column vector containing the first `n` outputs of the PSSCH pseudorandom binary scrambling sequence (PRBS) for the specified UE settings structure.

The scrambling sequence generated should be applied to the coded PSSCH data carried by the associated subframe. The PRBS sequence generator used is initialized with $c_{\text{init}} = n_{ID}^{SA} \times 2^{14} + n_{\text{ssf}}^{\text{PSSCH}} \times 2^{9} + 510$. For more information, see "Physical Sidelink Shared Channel Processing" on page 1-791 and `ue.NSAID`.

`seq = ltePSSCHPRBS(ue,n,mapping)` specifies the format of the returned sequence through the `mapping` input.

Examples

Scramble PSSCH Codeword

Scramble a PSSCH codeword by generating the PSSCH pseudorandom binary sequence (PRBS) and applying an exclusive OR operation on the two sequences.

Create a UE settings structure with required fields. Generate the required length of the PRBS. Scramble the PSSCH codeword with the PRBS sequence using `xor`.

```
ue = struct('NSAID',255,'NSubframePSSCH',0);
```

```
codeword = ones(1152,1);
psschPrbs = ltePSSCHPRBS(ue,length(codeword));

scrambled = xor(psschPrbs,codeword);
```

Descramble PSSCH Codeword

Descramble a received PSSCH codeword.

Scramble PSSCH Codeword

- Create a UE settings structure with required fields.
- Generate the required length of the PRBS.
- Scramble the PSSCH codeword with the PRBS sequence using `xor`.
- Modulate the logical scrambled data.

```
ue = struct('NSAID',255,'NSubframePSSCH',0);

codeword = ones(1152,1);
psschPrbs = ltePSSCHPRBS(ue,length(codeword));

scrambled = xor(psschPrbs,codeword);

txsym = lteSymbolModulate(scrambled,'16QAM');
```

Descramble Recovered Codeword

- Add noise to transmitted symbols and demodulate received soft data.
- Generate the PSSCH PRBS in signed form.
- Descramble the vector representing a sequence of soft bits by generating the PSSCH PRBS in signed form and performing a pointwise multiplication between the PRBS sequence and the recovered soft data.
- Compare the transmitted codeword to the recovered codeword.

```
sym = awgn(txsym,30,'measured');
softdata = lteSymbolDemodulate(sym,'16QAM');

scramblingSeq = ltePSSCHPRBS(ue,length(softdata),'signed');
descrambled = softdata.*scramblingSeq;
```

```
isequal(codeword,descrambled > 0)

ans =

  logical

   1
```

The transmitted codeword matches the hard decision on the descrambled data.

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

NSAID — Sidelink group destination identity

integer scalar from 0 to 255

Sidelink group destination identity, specified as an integer scalar from 0 to 255. ($n_{\mathrm{ID}}^{\mathrm{SA}}$)

`NSAID` is the lower 8 bits of the full 24-bit ProSe Layer-2 group destination ID. `NSAID` and `NSubframePSSCH` control the value of the scrambling sequence at the start of each subframe.

Data Types: `double`

NSubframePSSCH — PSSCH subframe number

integer scalar

PSSCH subframe number in the PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

`NSubframePSSCH` and `NSAID` control the values of the scrambling sequence.

Data Types: `double`

Data Types: `struct`

`n` — Length of the returned PSSCH scrambling sequence

nonnegative integer

Length of the returned PSSCH scrambling sequence, specified as a nonnegative integer.

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — PSSCH pseudorandom scrambling sequence

logical column vector | numeric column vector

PSSCH pseudorandom scrambling sequence, returned as a column vector. `seq` contains the first `n` outputs of the physical sidelink shared channel (PSSCH) scrambling sequence.

- When `mapping` is set to `'signed'`, then `seq` is a `double` column vector.
- When `mapping` is set to `'binary'`, then `seq` is a `logical` column vector.

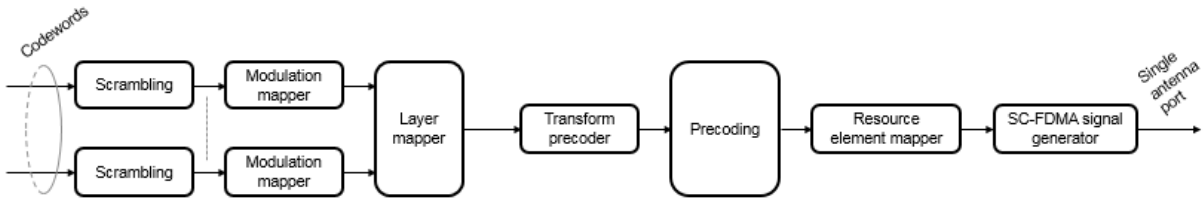
Data Types: `logical` | `double`

Definitions

Physical Sidelink Shared Channel Processing

Physical sidelink shared channel (PSSCH) processing includes PSSCH-specific scrambling, QPSK or 16-QAM modulation, and SC-FDMA transform precoding. PSSCH

processing follows the processing steps used for PUSCH, with variations defined in TS 36.211, Section 9.3.



For PSSCH, the input codeword length is $M_{\text{bits}} = N_{\text{RE}} \times N_{\text{bps}}$, where N_{bps} is the number of bits per symbol. PSSCH modulation is either QPSK (2 bits per symbol) or 16 QAM (4 bits per symbol).

The number of PSSCH resource elements (N_{RE}) in a subframe is $N_{\text{RE}} = N_{\text{PRB}} \times N_{\text{REperPRB}} \times N_{\text{SYM}}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission.
- N_{REperPRB} is the number of resource elements in a PRB. Each PRB has 12 resource elements.
- N_{SYM} is the number of SC-FDMA symbols in a PSSCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. The number of SC-FDMA symbols in a PSSCH subframe is 12 for normal cyclic prefix or 10 extended cyclic prefix.

The `info` structure output by `ltePSSCHIndices` provides M_{bits} and N_{RE} as `info.G` and `info.Gd` respectively.

The scrambling sequence generator is initialized with $c_{\text{init}} = n_{ID}^{SA} \times 2^{14} + n_{\text{ssf}}^{\text{PSSCH}} \times 2^{9} + 510$ at the start of every PSSCH subframe. $n_{\text{ID}}^{\text{SA}}$ is the destination identity (`NSAID`) obtained from the sidelink shared channel. $n_{\text{ssf}}^{\text{PSSCH}}$ is the subframe number in the PSSCH subframe pool (`NSubframePSSCH`).

`ltePSSCH` requires `CyclicPrefixSL` to deduce the number of resource blocks allocated for SC-FDMA precoding symbols.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePRBS` | `ltePSSCH` | `ltePSSCHDecode` | `ltePSSCHIndices`

Introduced in R2016b

ltePSS

Primary synchronization signal

Syntax

```
s = ltePSS(enb)
```

Description

`s = ltePSS(enb)` returns a complex column vector containing the primary synchronization signal (PSS) values for cell-wide settings in the `enb` structure.

This signal is only defined for subframes 0 and 5 in FDD, and subframes 1 and 6 in TDD. Therefore, an empty vector is returned for other values of `NSubframe`. This behavior allows this function and the corresponding sequence function `ltePSSIndices` to index the resource grid for any subframe number as described in "Resource Grid Indexing". However, the resource grid is only modified in subframes 0 and 5 in FDD, or subframes 1 and 6 in TDD.

Examples

Generate Primary Synchronization Signal Values

Generate the primary synchronization signal (PSS) values using the cell-wide settings provided.

```
pss = ltePSS(struct('NCellID',1,'NSubframe',0,'DuplexMode','FDD'));
pss(1:4)
```

```
ans =

   1.0000 + 0.0000i
  -0.9691 - 0.2468i
  -0.7331 - 0.6802i
   0.0747 + 0.9972i
```

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

`NCellID` — Physical layer cell identity number

nonnegative scalar integer

Physical layer cell identity number, specified as a nonnegative scalar integer.

Example: 6

Data Types: `double`

`NSubframe` — Subframe number

0 (default) | optional | nonnegative scalar integer

Subframe number, specified as nonnegative scalar integer.

Example: 8

Data Types: `double`

`DuplexMode` — Duplex mode type

`'FDD'` (default) | optional | `'TDD'`

Duplex mode type, specified as `'FDD'` or `'TDD'`. Used for separating the transmission signals.

Data Types: `char`

Output Arguments

`s` — Primary synchronization signal (PSS) values

complex-valued numeric column vector

Primary synchronization signal (PSS) values, returned as a complex-valued numeric column vector. These values are created for the cell-wide settings in the `enb` structure.

Example: 1.0000 + 0.0000i

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`ltePSSIndices` | `ltePSSS` | `lteSSS`

Introduced in R2014a

ltePSSIndices

PSS resource element indices

Syntax

```
ind = ltePSSIndices(enb)
ind = ltePSSIndices(enb,port)
ind = ltePSSIndices(enb,port,opts)
```

Description

`ind = ltePSSIndices(enb)` returns a column vector, `ind`, of resource element (RE) indices, Port 0 oriented, for the Primary Synchronization Signal (PSS) for the given cell-wide settings structure. By default, the indices are returned in one-based linear indexing form that can directly index elements of a 3-D array representing the resource array. These indices are ordered as the PSS modulation symbols should be mapped. Alternative indexing formats can also be generated.

Note: These indices are only defined for subframes 0 and 5 in FDD, and subframes 1 and 6 in TDD. Therefore, an empty vector is returned for other values of `NSubframe`. This behavior allows this function and the corresponding sequence function `ltePSS` to index the resource grid for any subframe number as described in "Resource Grid Indexing". However, the resource grid is only modified in subframes 0 and 5 in FDD, or subframes 1 and 6 in TDD.

`ind = ltePSSIndices(enb,port)` returns indices appropriate for antenna port, `port`.

`ind = ltePSSIndices(enb,port,opts)` formats the returned indices using options defined in `opts`.

Examples

Get PSS Resource Element Indices

Get PSS resource element indices in linear form for antenna port 0.

Create a cell-wide configuration sturcture initialed for RMC R.4. Generate PSS indices for RMC R.4 for antenna port 0.

```
enb = lteRMCDL('R.4');
ind = ltePSSIndices(enb,0);
ind(1:4)
```

```
ans =

  4×1 uint32 column vector

   438
   439
   440
   441
```

Get Zero-based PSS Resource Element Indices

Get zero-based PSS resource element indices in linear form for antenna port 0.

```
enb = lteRMCDL('R.4');
ind = ltePSSIndices(enb,0,{'Obased','ind'});
ind(1:4)
```

```
ans =

  4×1 uint32 column vector

   437
   438
   439
   440
```

Input Arguments

`enb` — Cell-wide settings
structure

Cell-wide settings, specified as a structure. `enb` contains the following fields.

`NDLRB` — Number of downlink resource blocks
integer from 6 to 110

Number of downlink resource blocks, specified as integer from 6 to 110.

Example: 9

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NSubframe` — Subframe number
0 (default) | nonnegative scalar integer | optional

Subframe number, specified as nonnegative scalar integer.

Example: 9

Data Types: `double`

`DuplexMode` — Duplex mode type
`'FDD'` (default) | `'TDD'` | optional

Duplex mode type, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`port` — Antenna port number
0 (default) | 1 | 2 | 3

Antenna port number, specified as 0, 1, 2, or 3.

Example: 2

Data Types: `double`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PSS resource element indices

integer column vector | 3-column integer matrix

PSS resource element indices, returned as an integer column vector or a three-column integer matrix. This output is generated using the cell-wide settings structure, `enb`.

Data Types: `uint32`

See Also

See Also

`ltePSS` | `ltePSSSIndices` | `lteSSSIndices`

Topics

"Resource Grid Indexing"

Introduced in R2014a

ltePSSS

Primary sidelink synchronization signal

Syntax

```
s = ltePSSS(ue)
```

Description

`s = ltePSSS(ue)` returns a 124-by-1 complex column vector containing the primary sidelink synchronization signal (PSSS) values for user equipment settings in the `ue` structure. For more information, see “Primary Sidelink Synchronization Signal” on page 1-804.

Examples

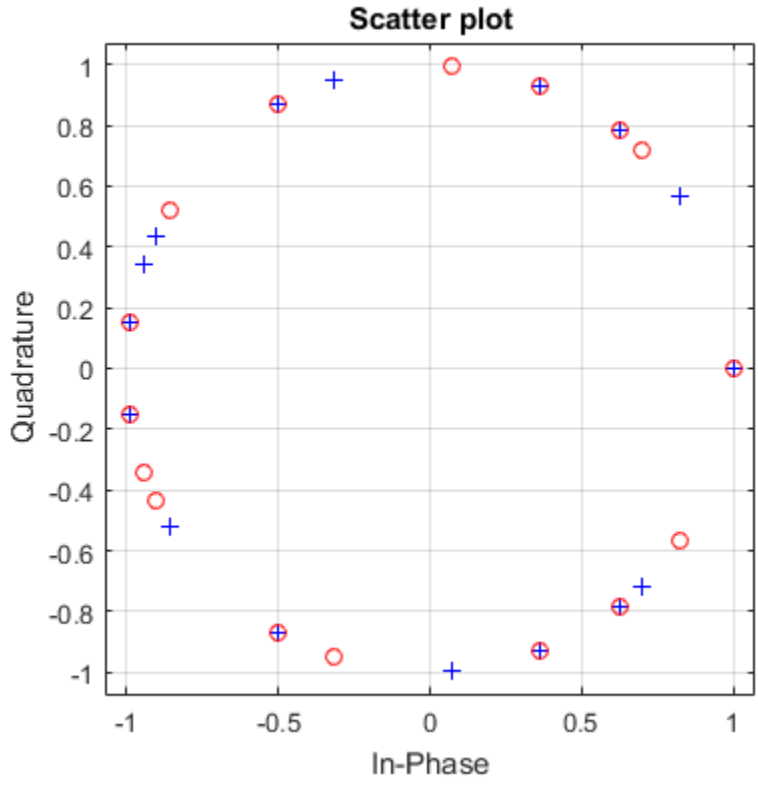
Generate PSSS

Generate PSSS values for in-coverage and out-of-coverage identities.

```
psss_net = ltePSSS(struct('NSLID',0));
psss_oon = ltePSSS(struct('NSLID',168));
```

Plot the returned synchronization signal for the in-coverage identities (blue, +) and the out-of-coverage identities (red, o).

```
scatPlot = scatterplot(psss_net,1,0,'b+');
grid
hold on
scatterplot(psss_oon,1,0,'ro',scatPlot)
```



Input Arguments

ue — User equipment settings

structure

UE-specific settings, specified as a structure containing this parameter field:

`NSLID` — Physical layer sidelink synchronization identity

integer from 0 to 335

Physical layer sidelink synchronization identity, specified as an integer from 0 to 335. ($N_{\mathrm{ID}}^{\mathrm{SL}}$)

For more information, see "Primary Sidelink Synchronization Signal" on page 1-804.

Example: 6

Data Types: `double`

Output Arguments

s — PSSS values

complex-valued numeric column vector

PSSS values, returned as a 124-by-1 complex-valued numeric column vector. These values are created for the user equipment settings in the `ue` structure. For more information, see "Primary Sidelink Synchronization Signal" on page 1-804.

Definitions

Primary Sidelink Synchronization Signal

The primary sidelink synchronization signal (PSSS) is transmitted in the central 62 resource elements of two adjacent SC-FDMA symbols in a synchronization subframe. The same sequence of 62 complex values is repeated in each of the symbols, resulting in a 124-by-1 element vector returned by the `ltePSSS` function. The values of this sequence are ordered as they should be mapped into the resource elements of the adjacent symbols using `ltePSSSIndices`. If a terminal is transmitting PSSS, then the PSSS should be sent every 40 ms with the exact subframe dependent on the RRC signaled subframe number offset (*syncOffsetIndicator-r12*).

The PSSS is sent on antenna port 1020, along with the secondary sidelink synchronization signal (SSSS). A synchronization subframe also contains the PSBCH, which is sent on antenna port 1010. The transmission power of the PSSS symbols should be the same as the PSBCH therefore they should be scaled by $\sqrt{72/62}$ in a subframe. No PSCCH or PSSCH transmission will occur in a sidelink subframe configured for synchronization purposes.

As specified in TS 36.211, Section 9.7, the PSSS identity assignment depends on the network coverage. The set of all $N_{\mathrm{ID}}^{\mathrm{SL}}$ is divided into two sets, id_net {0, ..., 167} and id_oon {168, ..., 335}, which are used by terminals that are in-network and out-of-network coverage, respectively. The sidelink physical layer cell identity number, $N_{\mathrm{ID}}^{\mathrm{SL}}$, corresponds to the `ltePSSS` input UE settings structure field `ue.NSLID`. Within each set, all identities result in the same PSSS. For an in-network terminal, the `ue.NSLID` value corresponds to the RRC sidelink synchronization signal identity (*slssid-r12*) associated with the cell.

Primary Sidelink Synchronization Signal Indexing

Use the indexing function, `ltePSSSIndices`, and the corresponding sequence function, `ltePSSS`, to populate the resource grid for the desired subframe number. The PSSS values are output by `ltePSSS`, ordered as they should be mapped, applying frequency-first mapping into the resource elements of the adjacent symbols using `ltePSSSIndices`. When indexing is zero-based, the SC-FDMA symbols used are {1,2} for normal cyclic prefix and {0, 1} for extended cyclic prefix.

Note: The indicated symbol indices are based on TS 36.211, Section 9.7. However to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePSBCH` | `ltePSS` | `ltePSSSIndices` | `lteSSSS`

Topics

"Resource Grid Indexing"

Introduced in R2016b

ltePSSSIndices

PSSS resource element indices

Syntax

```
ind = ltePSSSIndices(ue)
ind = ltePSSSIndices(ue,opts)
```

Description

`ind = ltePSSSIndices(ue)` returns a 124-by-1 complex column vector of resource element (RE) indices for the primary sidelink synchronization signal (PSSS) values for user equipment settings in the `ue` structure. By default, the indices are returned in one-based linear indexing form. You can use this form to directly index elements of a matrix representing the subframe resource grid for antenna port 1020. For more information, see “Primary Sidelink Synchronization Signal Indexing” on page 1-812.

`ind = ltePSSSIndices(ue,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PSSS Indices

Generate PSSS values and indices. Write the values into the PSSS resource elements in a synchronization subframe (normal cyclic prefix) and display an image of their locations.

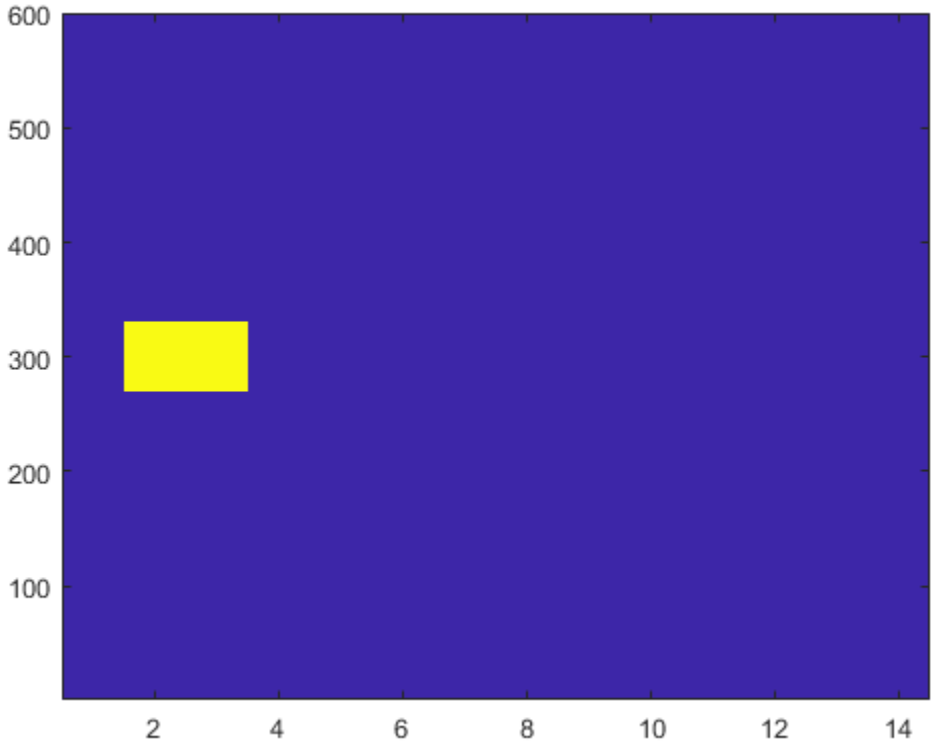
Create a user equipment settings structure and a resource grid that has a 10 MHz bandwidth and normal cyclic prefix.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 1;
subframe = lteSLResourceGrid(ue);
```

Generate PSSS indices and display the first five indices. Load the PSSS symbols into the resource grid. Display an image showing the PSSS symbol locations.

```
psss_indices = ltePSSSIndices(ue);
psss_indices(1:5)

subframe(psss_indices) = ltePSSS(ue);
image(100*abs(subframe))
axis xy
```

```
ans =

  5×1 uint32 column vector

   870
   871
   872
   873
   874
```



Generate Zero-Based PSSS Indices

Generate PSSS indices using zero-based indexing style. Compare these indices to one-based indices.

Create a user equipment settings structure and a resource grid that has a 10 MHz bandwidth and normal cyclic prefix.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 1;
subframe = lteSLResourceGrid(ue);
```

Generate PSSS zero-based indices and view the first five indices.

```
psss_indices = ltePSSSIndices(ue,'0based');
psss_indices_size = size(psss_indices)
psss_indices(1:5)
```

```
psss_indices_size =

   124     1


ans =

  5×1 uint32 column vector

   869
   870
   871
   872
   873
```

Generate PSSS one-based indices and view the first five indices.

```
psss_indices = ltePSSSIndices(ue,'1based');
psss_indices_size = size(psss_indices)
psss_indices(1:5)
```

```
psss_indices_size =

   124     1


ans =

  5×1 uint32 column vector

   870
   871
   872
   873
   874
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing style.

Input Arguments

`ue` — User equipment settings

structure

UE-specific settings, specified as a structure containing these parameter fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.

Category	Options	Description
	`'Obased'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PSSS resource element indices

integer column vector | three column integer matrix

PSSS resource element indices, returned as an integer column vector or a three-column integer matrix. This output is generated using the UE-settings structure, `ue`. For more information, see “Primary Sidelink Synchronization Signal Indexing” on page 1-812.

Definitions

Primary Sidelink Synchronization Signal Indexing

Use the indexing function, `ltePSSSIndices`, and the corresponding sequence function, `ltePSSS`, to populate the resource grid for the desired subframe number. The PSSS values are output by `ltePSSS`, ordered as they should be mapped, applying frequency-first mapping into the resource elements of the adjacent symbols using `ltePSSSIndices`. When indexing is zero-based, the SC-FDMA symbols used are {1,2} for normal cyclic prefix and {0, 1} for extended cyclic prefix.

Note: The indicated symbol indices are based on TS 36.211, Section 9.7. However to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

Primary Sidelink Synchronization Signal

The primary sidelink synchronization signal (PSSS) is transmitted in the central 62 resource elements of two adjacent SC-FDMA symbols in a synchronization subframe. The same sequence of 62 complex values is repeated in each of the symbols, resulting in a 124-by-1 element vector returned by the `ltePSSS` function. The values of this sequence are ordered as they should be mapped into the resource elements of the adjacent symbols using `ltePSSSIndices`. If a terminal is transmitting PSSS, then the PSSS should be sent every 40 ms with the exact subframe dependent on the RRC signaled subframe number offset (*syncOffsetIndicator-r12*).

The PSSS is sent on antenna port 1020, along with the secondary sidelink synchronization signal (SSSS). A synchronization subframe also contains the PSBCH, which is sent on antenna port 1010. The transmission power of the PSSS symbols should be the same as the PSBCH therefore they should be scaled by $\sqrt{72/62}$ in a subframe. No PSCCH or PSSCH transmission will occur in a sidelink subframe configured for synchronization purposes.

As specified in TS 36.211, Section 9.7, the PSSS identity assignment depends on the network coverage. The set of all $N_{\mathrm{ID}}^{\mathrm{SL}}$ is divided into two sets, id_net {0, ..., 167} and id_oon {168, ..., 335}, which are used by terminals that are in-network and out-of-network coverage, respectively. The sidelink physical layer cell identity number, $N_{\mathrm{ID}}^{\mathrm{SL}}$, corresponds to the `ltePSSS` input UE settings structure field `ue.NSLID`. Within each set, all identities result in the same PSSS. For an in-network terminal, the `ue.NSLID` value corresponds to the RRC sidelink synchronization signal identity (*slssid-r12*) associated with the cell.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSIndices` | `ltePSSS` | `lteSSSSIndices`

Topics

"Resource Grid Indexing"

Introduced in R2016b

ltePUCCH1

Physical uplink control channel format 1

Syntax

```
sym = ltePUCCH1(ue,chs,ack)
[sym,info] = ltePUCCH1(ue,chs,ack)
```

Description

`sym = ltePUCCH1(ue,chs,ack)` returns a matrix containing physical uplink control channel (PUCCH) format 1 symbols given a structure of UE-specific settings, a structure of channel transmission configuration settings, and hybrid ARQ (HARQ) indicator values.

If the configured PUCCH resource indices match indices configured for a scheduling request (SR), as specified in TS 36.213 [1], Section 10.1.5, you can also use this function to generate an SR.

`[sym,info] = ltePUCCH1(ue,chs,ack)` also returns a PUCCH information structure array, `info`.

Examples

Generate PUCCH Format 1 Symbols

Generate the PUCCH format 1 symbols for UE-specific settings.

```
ue.NCellID = 1;
ue.NSubframe = 0;
chs.ResourceIdx = 0;
pucch1Sym = ltePUCCH1(ue,chs,[]);
```

Generate PUCCH Format 1 Symbols for Two Antennas

Generate the physical uplink control channel (PUCCH) format 1 symbols for two transmit antenna paths.

Initialize parameters for a UE-specific configuration structure and a channel configuration structure. Generate PUCCH1 symbols and information outputs.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = [0 3];
chs.DeltaShift = 1;
chs.CyclicShifts = 0;
chs.Shortened = 0;

[pucch1Sym,info] = ltePUCCH1(ue,chs,[]);
```

Because there are two antennas, the symbols are output as a two-column vector, and the `info` output structure contains two elements.

```
pucch1Sym(1:10,:)
size(info)
```

```
ans =

   0.5000 + 0.5000i  -0.5000 + 0.5000i
  -0.6830 + 0.1830i   0.6830 - 0.1830i
   0.6830 + 0.1830i   0.1830 - 0.6830i
  -0.5000 + 0.5000i  -0.5000 + 0.5000i
  -0.1830 - 0.6830i   0.6830 - 0.1830i
  -0.6830 - 0.1830i   0.6830 + 0.1830i
   0.5000 + 0.5000i   0.5000 - 0.5000i
   0.6830 - 0.1830i   0.6830 - 0.1830i
  -0.1830 + 0.6830i  -0.6830 - 0.1830i
   0.5000 + 0.5000i  -0.5000 - 0.5000i


ans =

     1     2
```

View the contents of the `info` structure elements.

```
info(2)
```

```
ans =

  struct with fields:

              Alpha: [1×8 double]
           SeqGroup: [1 1]
             SeqIdx: [0 0]
        NResourceIdx: [3 11]
    NCellCyclicShift: [64 193 89 191 71 101 234 105]
          OrthSeqIdx: [0 0]
             Symbols: [1×8 double]
             OrthSeq: [4×2 double]
           ScrambSeq: [0.0000 + 1.0000i 0.0000 + 1.0000i]
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure containing these fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing these fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 2047 or vector of integers.	PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used for transmission. ($n_{PUCCH}^{(1)}$). Define one index for each transmission antenna.
`DeltaShift`	Optional	1 (default), 2, 3	Delta shift, specified as 1, 2, or 3. (Δ_{shift})
`DeltaOffset`	Optional	0 (default), 1, 2	(Δ_{offset}). Warning: The use of this parameter field is not advised. It applies only to 3GPP releases preceding v8.5.0. This parameter will be removed in a future release.
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{\text{cs}}^{(1)}$)

`ack` — Hybrid ARQ indicator values

nonnegative integer vector containing 0, 1 or 2 elements

Hybrid ARQ indicator values, specified as a nonnegative integer vector. This vector is expected to be the block of bits $b(0),...,b(M_{bit}-1)$ specified in TS 36.211 [2], Section 5.4.1. An M_{bit} value of 0, 1, or 2 corresponds to PUCCH format 1, 1a, or 1b, respectively, as described in TS 36.211 [2], Table 5.4-1.

Example: [ ] indicates that no HARQ are transmitted in the subframe.

Output Arguments

`sym` — PUCCH format 1 symbols

numeric column vector

PUCCH format 1 symbols, returned as a numeric column vector. The symbols for each antenna are in the columns of `sym`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [0.7071 + 0.7071i,...]

`info` — PUCCH format 1 resource information

structure array

PUCCH format 1 resource information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`Alpha` — Reference signal cyclic shift for each OFDM symbol

two-column vector

Reference signal cyclic shift for each OFDM symbol, returned as a two-column vector. (α)

`SeqGroup` — PUCCH base sequence group number for each slot

two-column vector

PUCCH base sequence group number for each slot, returned as a two-column vector. (u)

`SeqIdx` — PUCCH base sequence group number indices

two-column vector

PUCCH base sequence group number indices for each slot, returned as a two-column vector. (v)

`NResourceIdx` — PUCCH resource indices for each slot

two-column vector

PUCCH resource indices for each slot, returned as a two-column vector. (n')

`NCellCyclicShift` — Cell-specific cyclic shift for each OFDM symbol
vector

Cell-specific cyclic shift for each OFDM symbol, returned as a vector. (n_{cs}^{cell})

`OrthSeqIdx` — Orthogonal sequence index for each slot
vector

Orthogonal sequence index for each slot, returned as a two-element vector. (n_{oc})

`Symbols` — Modulated data symbols for each OFDM symbol
vector

Modulated data symbols for each OFDM symbol, returned as a vector. (*d(0)*)

Example: [0.7071 + 0.7071i,...]

`OrthSeq` — Orthogonal sequence of each slot
numeric matrix

Orthogonal sequence of each slot, returned as a numeric matrix. Each column in the matrix contains the orthogonal sequence ($w_{n_{oc}}$) for each slot.

Note: When `ue.Shortened` is 1, the transmission is shortened and the second column of `info.OrthSeq` has a 0 in the last row. This 0 value occurs because, in this case, the spreading factor for the second slot is 3 rather than 4.

Example: [1.000 + 1.000i,...]

`ScrambSeq` — Scrambling value
two-element vector

Scrambling value for each slot (*S*), returned as two-element vector.

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH1Decode` | `ltePUCCH1DRS` | `ltePUCCH1DRSIndices` | `ltePUCCH1Indices` | `ltePUCCH2` | `ltePUCCH3`

Introduced in R2014a

ltePUCCH1Decode

Physical uplink control channel format 1 decoding

Syntax

```
ack = ltePUCCH1Decode(ue,chs,oack,sym)
```

Description

`ack = ltePUCCH1Decode(ue,chs,oack,sym)` returns a vector of hybrid-ARQ (HARQ) indicator values, `ack`, obtained by performing PUCCH Format 1 decoding of the complex matrix `sym`. The decoder uses a maximum likelihood (ML) approach, assuming that `sym` has already been equalized to best restore the original transmitted complex values. The symbols for each antenna are in the columns of `sym`. The number of columns in `sym` should match the number of PUCCH resource indices specified in the structure `chs`.

The output argument `ack` is a vector containing `oack` hybrid-ARQ indicator values.

Examples

Decode PUCCH Format 1B Symbols

Decoding of a PUCCH Format 1b received symbol vector `pucch1Sym`.

Initialize a UE-specific configuration structure (`ue`), channel configuration structure (`chs`) and ACK vector (`txAck`)

```
ue.NCellID = 0;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';
ue.Shortened = 0;

chs.DeltaShift = 1;
```

```
chs.ResourceIdx = 0;
chs.CyclicShifts = 0;

txAck = [0;1];
```

Generate PUCCH symbols. Then decode the symbols and verify that the Rx ACK vector matches the Tx ACK vector.

```
pucch1Sym = ltePUCCH1(ue,chs,txAck);

rxAck = ltePUCCH1Decode(ue,chs,length(txAck),pucch1Sym)
```

```
rxAck =

  2×1 logical array

   0
   1
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol,

Parameter Field	Required or Optional	Values	Description
			specified as 0 or 1. If 1, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

`chs` — Channel transmission configuration

structure

PUCCH channel settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 2047 or vector of integers.	PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used for transmission. ($n^{(1)}_{PUCCH}$). Define one index for each transmission antenna.
`DeltaShift`	Optional	1 (default), 2, 3	Delta shift, specified as 1, 2, or 3. (Δ_{shift})
`DeltaOffset`	Optional	0 (default), 1, 2	(Δ_{offset}). Warning: The use of this parameter field is not advised. It applies only to 3GPP releases preceding v8.5.0. This parameter will be removed in a future release.

Parameter Field	Required or Optional	Values	Description
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{cs}^{(1)}$)

Data Types: `struct`

`oack` — Number of uncoded HARQ-ACK bits

0 (default) | nonnegative integer vector

Uncoded HARQ-ACK bits, specified as a nonnegative integer vector. `oack` specifies the number of Hybrid ARQ indicator values expected: 1 (PUCCH Format 1a) or 2 (PUCCH Format 1b).

Data Types: `double`

`sym` — Symbols of each antenna

complex numeric matrix

Symbols for each antenna, specified as complex numeric matrix. The number of columns in `sym` should match the number of PUCCH resource indices specified in the structure, `chs`.

Example: 0.25881 + 0.9659i

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`ack` — Hybrid ARQ indicator values

logical column vector or matrix

`oack` Hybrid ARQ indicator values, specified as a logical column vector or matrix. This vector is obtained by performing PUCCH Format 1 decoding of the complex matrix, `sym`. A Scheduling Request (SR), which is transmitted on PUCCH Format 1 (no ACK bits), can

be detected by setting `oack` = 1; in this case the received Hybrid ARQ indicator value, `ack`, is expected to be zero.

If multiple decoded Hybrid ARQ indicator vectors have a likelihood equal to the maximum, `ack` is a matrix where each column represents one of the equally likely Hybrid ARQ indicator vectors. If a minimum likelihood threshold is not met, `ack` is empty.

Data Types: `logical`

See Also

See Also

`ltePUCCH1` | `ltePUCCH1DRS` | `ltePUCCH1DRSIndices` | `ltePUCCH1Indices` | `ltePUCCH2Decode` | `ltePUCCH3Decode`

Introduced in R2014a

ltePUCCH1DRS

PUCCH format 1 demodulation reference signal

Syntax

```
seq = ltePUCCH1DRS(ue,chs)
[seq,info] = ltePUCCH1DRS(ue,chs)
```

Description

`seq = ltePUCCH1DRS(ue,chs)` returns a matrix containing demodulation reference signal (DRS) associated with PUCCH format 1 transmission, given structures containing the UE-specific settings, and the channel transmission configuration settings.

`[seq,info] = ltePUCCH1DRS(ue,chs)` also returns a PUCCH information structure array, `info`.

Examples

Generate PUCCH Format 1 DM-RS

Generate PUCCH format 1 DM-RS values for UE-specific settings.

Initialize UE-specific and channel configuration structures. Generate PUCCH format 1 DM-RS values.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;
```

```
drsSeq = ltePUCCH1DRS(ue,chs);
```

Generate PUCCH Format 1 DM-RS Using Virtual Cell ID

Demonstrate Uplink Release 11 cooordinated multipoint (CoMP) operation. Intercell interference can be avoided by using a virtual cell identity and a distinct DM-RS cyclic shift hopping identity for a potentially interfering UE in a neighboring cell.

Configuration for UE of interest, UE 1 in cell 1.

```
ue1.NCellID = 1;
ue1.NSubframe = 0;
ue1.CyclicPrefixUL = 'Normal';
ue1.Hopping = 'Off';

chs1.ResourceIdx = 0;
chs1.DeltaShift = 1;
chs1.CyclicShifts = 0;
```

Configuration for interferer, UE 2 in cell 2.

```
ue2.NCellID = 2;
ue2.NSubframe = 0;
ue2.CyclicPrefixUL = 'Normal';
ue2.Hopping = 'Off';

chs2.ResourceIdx = 1;
chs2.DeltaShift = 1;
chs2.CyclicShifts = 0;
```

Measure the interference between the DM-RS signals.

```
interferenceNoCoMP = abs(sum(ltePUCCH1DRS(ue1,chs1).*conj(ltePUCCH1DRS(ue2,chs2))))
```

```
interferenceNoCoMP =

    2.0706
```

Reconfigure interferer for CoMP operation: use virtual cell identity equal to the cell identity for the UE of interest.

```
ue2.NPUCCHID = ue1.NCellID;
```

Measure the interference between the DM-RS signals when using CoMP:

```
interferenceUsingCoMP = abs(sum(ltePUCCH1DRS(ue1,chs1).*conj(ltePUCCH1DRS(ue2,chs2))))
```

```
interferenceUsingCoMP =

   2.3213e-14
```

Compare the correlations between the DM-RS signals for two UEs with and without CoMP, `interferenceUsingCoMP` and `interferenceNoCoMP` respectively. Using CoMP, the interference is reduced to effectively zero.

Generate PUCCH Format 1 DM-RS for Two Antennas

Generate the PUCCH format 1 DM-RS for two transmit antenna paths.

Initialize UE-specific and channel configuration structures. Generate PUCCH1 DM-RS and information outputs.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = [0 3];
chs.DeltaShift = 1;
chs.CyclicShifts = 0;

[drsSeq,info] = ltePUCCH1DRS(ue,chs);
```

Because there are two antennas, the DM-RS sequences are output as a two-column vector and the `info` output structure contains two elements. View `ind` and the size of `info` to confirm this.

```
drsSeq(1:10,:)
size(info)
```

```
ans =

   0.5000 + 0.5000i   0.5000 + 0.5000i
   0.5000 + 0.5000i  -0.5000 + 0.5000i
  -0.5000 + 0.5000i   0.5000 - 0.5000i
```

```
  -0.5000 + 0.5000i   0.5000 + 0.5000i
  -0.5000 + 0.5000i  -0.5000 + 0.5000i
   0.5000 - 0.5000i   0.5000 + 0.5000i
   0.5000 + 0.5000i  -0.5000 - 0.5000i
  -0.5000 - 0.5000i  -0.5000 + 0.5000i
  -0.5000 - 0.5000i  -0.5000 - 0.5000i
   0.5000 + 0.5000i  -0.5000 + 0.5000i


ans =

     1     2
```

View the contents of the two `info` structure elements.

```
info(1)
info(2)
```

```
ans =

  struct with fields:

              Alpha: [0 5.2360 4.1888 4.7124 1.0472 1.5708]
           SeqGroup: [1 1]
             SeqIdx: [0 0]
       NResourceIdx: [0 2]
    NCellCyclicShift: [192 46 212 91 84 25]
          OrthSeqIdx: [0 0]
             Symbols: [1×6 double]
             OrthSeq: [3×2 double]


ans =

  struct with fields:

              Alpha: [1.5708 0.5236 5.7596 3.1416 5.7596 0]
           SeqGroup: [1 1]
             SeqIdx: [0 0]
       NResourceIdx: [3 11]
    NCellCyclicShift: [192 46 212 91 84 25]
          OrthSeqIdx: [0 0]
             Symbols: [1×6 double]
```

```
    OrthSeq: [3×2 double]
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure containing these fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`NPUCCHID`	Optional	`NCellID` (default) Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

chs — Channel transmission configuration

structure

PUCCH channel settings, specified as a structure containing the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 2047 or vector of integers.	PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used

Parameter Field	Required or Optional	Values	Description
			for transmission. ($n_{PUCCH}^{(1)}$). Define one index for each transmission antenna.
`DeltaShift`	Optional	1 (default), 2, 3	Delta shift, specified as 1, 2, or 3. (Δ_{shift})
`DeltaOffset`	Optional	0 (default), 1, 2	(Δ_{offset}). Warning: The use of this parameter field is not advised. It applies only to 3GPP releases preceding v8.5.0. This parameter will be removed in a future release.
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{\text{cs}}^{(1)}$)

Output Arguments

`seq` — PUCCH format 1 DRS values

numeric matrix

PUCCH format 1 DRS values, returned as a numeric matrix. The symbols for each antenna are in the columns of `seq`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [0.707+0.707i,...]

`info` — PUCCH format 1 DRS information

structure array

PUCCH format 1 DRS information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`Alpha` — Reference signal cyclic shift for each OFDM symbol
two-column vector

Reference signal cyclic shift for each OFDM symbol, returned as a two-column vector. (a)

`SeqGroup` — PUCCH base sequence group number for each slot
two-column vector

PUCCH base sequence group number for each slot, returned as two-column vector. (u)

`SeqIdx` — PUCCH base sequence number for each slot
two-column vector

PUCCH base sequence number for each slot, returned as two-column vector. (v)

`NResourceIdx` — PUCCH resource indices for each slot
vector

PUCCH resource indices for each slot, returned as two-column vector. (n')

`NCellCyclicShift` — Cell-specific cyclic shift for each OFDM symbol
vector

Cell-specific cyclic shift for each OFDM symbol, returned as vector. ($n_{\mathrm{cs}}^{\mathrm{cell}}$)

`OrthSeqIdx` — Orthogonal sequence index for each slot
two-column vector

Orthogonal sequence index for each slot, returned as two-column vector. ($\bar{n}_{\mathrm{oc}}$)

`Symbols` — Modulated data symbols
vector

Modulated data symbols, returned as a vector. There is one element for each OFDM symbol. (z)

Example: [0.7071 + 0.7071i,...]

`OrthSeq` — Orthogonal sequence for each slot
numeric matrix

Orthogonal sequence for each slot, returned as a numeric matrix. ($\bar{w}$)

Example: [1.000 + 1.000i,...]

See Also

See Also

`ltePUCCH1` | `ltePUCCH1Decode` | `ltePUCCH1DRSIndices` | `ltePUCCH1Indices` | `ltePUCCH2DRS` | `ltePUCCH3DRS`

Introduced in R2014a

ltePUCCH1DRSIndices

PUCCH format 1 DRS resource element indices

Syntax

```
ind = ltePUCCH1DRSIndices(ue,chs)
[ind,info] = ltePUCCH1DRSIndices(ue,chs)
[ ___ ] = ltePUCCH1DRSIndices(ue,chs,opts)
```

Description

`ind = ltePUCCH1DRSIndices(ue,chs)` returns a matrix of resource element indices for the demodulation reference signal (DRS) associated with PUCCH format 1 transmission given structures containing the UE-specific settings, and the channel transmission configuration settings.

`[ind,info] = ltePUCCH1DRSIndices(ue,chs)` also returns a PUCCH information structure array, `info`.

`[ ___ ] = ltePUCCH1DRSIndices(ue,chs,opts)` formats the returned indices using options defined in `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate PUCCH Format 1 DM-RS Indices

Generate PUCCH format 1 DM-RS RE indices for a 1.4 MHz bandwidth and PUCCH resource index 0. Use default values for all other parameters.

Initialize UE-specific and channel configuration structures. Generate PUCCH format 1 DM-RS indices.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';
```

```
chs.ResourceIdx = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;
chs.ResourceSize = 0;

ind = ltePUCCH1DRSIndices(ue,chs);
ind(1:4)
```

```
ans =

  4×1 uint32 column vector

   145
   146
   147
   148
```

Generate PUCCH Format 1 DM-RS Indices for Two Antennas

Generate the PUCCH format 1 DM-RS indices for two transmit antenna paths.

Initialize UE-specific and channel configuration structures. Generate PUCCH1 DRS indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 4];
chs.ResourceSize = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;

[ind,info] = ltePUCCH1DRSIndices(ue,chs);
```

Becasue there are two antennas, the DM-RS indices are output as a two-column vector, and the `info` output structure contains two elements. View `ind` and the size of `info` to confirm this.

```
ind(1:6,:)
size(info)
```

```
ans =
```

```
  6×2 uint32 matrix

    145   1153
    146   1154
    147   1155
    148   1156
    149   1157
    150   1158


ans =

     1     2
```

View the contents of the two `info` structure elements.

```
info(1)
info(2)
```

```
ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0


ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Generate PUCCH Format 1 DM-RS Indices for Two Antennas Varying Indexing Style

Generate the PUCCH format 1 DM-RS indices for two transmit antenna paths, and output in subscript indexing form.

Initialize UE-specific and channel configuration structures, and the indexing option parameter. Generate PUCCH1 DM-RS indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 4];
chs.ResourceSize = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;

opts = {'sub'};

[ind,info] = ltePUCCH1DRSIndices(ue,chs,opts);
```

Using 'sub' indexing style, the indices are output in [subcarrier, symbol, antenna] subscript form. View the midpoint of ind and observe the antenna index change.

```
size(ind)
ind(70:74,:)
size(info)
```

```
ans =

   144     3


ans =

  5×3 uint32 matrix

   70   12    1
   71   12    1
   72   12    1
    1    3    2
    2    3    2


ans =

     1     2
```

Because there are two antennas, the info output structure contains two elements. View one of the `info` structure elements.

```
info(1)
```

```
ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Input Arguments

ue — UE-specific settings
structure

UE-specific settings, specified as a structure containing these fields.

NULRB — Number of uplink resource blocks
integer from 6 to 110

Number of uplink resource blocks, specified as ainteger from 6 to 110.

Data Types: `double`

CyclicPrefixUL — Cyclic prefix length for uplink channels
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

chs — Channel transmission configuration
structure

Channel transmission configuration, specified as a structure containing these fields.

ResourceIdx — PUCCH resource indices
0 (default) | 0,...,2047 | integer | vector of integers | optional

PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used for transmission. ($n_{PUCCH}^{(1)}$). Define one index for each transmission antenna.

Data Types: `double`

`ResourceSize` — Size of resources allocated to PUCCH format 2

0 (default) | 0,...,98 | integer | optional

Size of resources allocated to PUCCH format 2, specified as an integer from 0 to 98. This parameter affects the location of this transmission. ($N_{\mathrm{RB}}^{(2)}$)

Data Types: `double`

`DeltaShift` — Delta shift

1 (default) | 2 | 3 | optional

Delta shift, specified as 1, 2, or 3. (Δ_{shift})

Data Types: `double`

`CyclicShifts` — Number of cyclic shifts used for format 1

0 (default) | optional | 0,...,7 | integer

Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{\mathrm{cs}}^{(1)}$)

Data Types: `double`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.

Category	Options	Description
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — Resource element indices

integer column vector | three-column integer matrix

Resource element indices, returned as an integer column vector or a three-column integer matrix. By default the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to PUCCH format 1 DRS modulation symbol mapping. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [145,146,147,...]

Data Types: `uint32`

`info` — PUCCH format 1 DRS information

structure array

PUCCH format 1 DRS information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`PRBSet` — Indices occupied by PRB in each slot of subframe

nonnegative integer vector

Indices occupied by PRB in each slot of the subframe, returned as a nonnegative integer vector. The indices are zero-based.

Example: [0,5]

Data Types: `double`

`RBIdx` — PUCCH logical resource block index

nonnegative integer

PUCCH logical resource block index, returned as a nonnegative integer. (m)

Data Types: `double`

Data Types: `struct`

See Also

See Also

`ltePUCCH1` | `ltePUCCH1Decode` | `ltePUCCH1DRS` | `ltePUCCH1Indices` | `ltePUCCH2DRSIndices` | `ltePUCCH3DRSIndices`

Introduced in R2014a

ltePUCCH1Indices

PUCCH format 1 resource element indices

Syntax

```
ind = ltePUCCH1Indices(ue,chs)
[ind,info] = ltePUCCH1Indices(ue,chs)
[ ___ ] = ltePUCCH1Indices(ue,chs,opts)
```

Description

`ind = ltePUCCH1Indices(ue,chs)` returns a matrix of resource element (RE) indices for the physical uplink control channel (PUCCH) format 1 transmission, given structures containing the UE-specific settings, and the channel transmission configuration.

`[ind,info] = ltePUCCH1Indices(ue,chs)` also returns a PUCCH information structure array.

`[ ___ ] = ltePUCCH1Indices(ue,chs,opts)` formats the returned indices using options defined in the cell array, `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate PUCCH Format 1 Indices

Generate PUCCH format 1 RE indices for a 1.4 MHz bandwidth, PUCCH resource index 0. Use default values for all other parameters.

Initialize UE-specific and channel configuration structures (`ue` and `chs`). Generate PUCCH format 1 indices (`ind`).

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';
```

```
chs.ResourceIdx = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;
chs.ResourceSize = 0;
chs.Shortened = 0;

ind = ltePUCCH1Indices(ue,chs);
ind(1:4)
```

```
ans =

  4×1 uint32 column vector

   1
   2
   3
   4
```

Generate PUCCH Format 1 Indices for Three Antennas

Generate the physical uplink control channel (PUCCH) format 1 indices for three transmit antenna paths, and display the information structure output.

Initialize UE-specific and channel configuration structures. Generate PUCCH 1 indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.ResourceIdx = [0 129 2];
chs.ResourceSize = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;

[ind,info] = ltePUCCH1Indices(ue,chs);
```

Because there are three antennas, the indices are output as a three-column vector, and the `info` output structure contains three elements. View `ind` and the size of `info` to confirm this.

```
ind(1:5,:)
size(info)
```

```
ans =

  5×3 uint32 matrix

     1   1057   2017
     2   1058   2018
     3   1059   2019
     4   1060   2020
     5   1061   2021


ans =

     1     3
```

View the contents of one of the `info` structure elements.

```
info(3)
```

```
ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Generate PUCCH Format 1 Indices Varying Indexing Style

Generate the physical uplink control channel (PUCCH) format 1 indices for two transmit antenna paths and output in subscript indexing form.

Initialize UE-specific and channel configuration structures (`ue` and `chs`) and the indexing option parameter, `opt`. Generate PUCCH1 indices and information outputs (`ind` and `info`).

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 4];
chs.ResourceSize = 0;
chs.DeltaShift = 1;
```

```
chs.CyclicShifts = 0;
chs.Shortened = 0;

[ind,info] = ltePUCCH1Indices(ue,chs,{'sub'});
```

Using `'sub'` indexing style, the indices are output in `[subcarrier, symbol, antenna]` subscript form. View the midpoint of `ind` and observe the antenna index change.

```
size(ind)
ind(94:99,:)
```

```
ans =

   192     3


ans =

  6×3 uint32 matrix

   70   14    1
   71   14    1
   72   14    1
    1    1    2
    2    1    2
    3    1    2
```

Because there are two antennas, the `info` output structure contains two elements. View the contents of the second `info` structure element.

```
size(info)
info(2)
```

```
ans =

     1     2


ans =

  struct with fields:
```

```
PRBSet: [0 5]
 RBIdx: 0
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure containing these fields.

NULRB — Number of uplink resource blocks

nonnegative integer

Number of uplink resource blocks, specified as a nonnegative integer.

Data Types: `double`

CyclicPrefixUL — Cyclic prefix length for uplink channels

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Shortened — Option to shorten the subframe

0 (default) | 1 | optional

Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

chs — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing these fields.

ResourceIdx — PUCCH resource indices

0 (default) | 0,...,2047 | integer | vector of integers | optional

PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. There is one index for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. ($n_{PUCCH}^{(1)}$)

`ResourceSize` — Size of resources allocated to PUCCH format 2

0 (default) | 0,...,98 | integer | optional

Size of resources allocated to PUCCH format 2, specified as an integer from 0 to 98. This parameter affects the location of this transmission. ($N_{\mathrm{RB}}^{(2)}$)

`DeltaShift` — Delta shift

1 (default) | 2 | 3 | optional

Delta shift, specified as 1, 2, or 3. (Δ_{shift})

`CyclicShifts` — Number of cyclic shifts used for format 1

0 (default) | 0,...,7 | integer | optional

Number of cyclic shifts used for format 1 in RBs with a mixture of Format 1 and Format 2 PUCCH, specified as an integer from 0 to 7. ($N_{\mathrm{cs}}^{(1)}$)

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — PUCCH format 1 resource element indices

integer column vector | three-column integer matrix

PUCCH format 1 resource element indices, returned as an integer column vector or a three-column integer matrix. By default, the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to PUCCH format 1 modulation symbol mapping as specified in TS 36.211 [1], Section 5.4. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [1,2,3,4...]

Data Types: `uint32`

`info` — PUCCH format 1 information

structure array

PUCCH format 1 information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`PRBSet` — Set of PRB indices

column vector | two-column matrix

Set of PRB indices, returned as a column vector or two-column matrix corresponding to the resource allocations.

- When returned as a column integer vector, the resource allocation is the same in both slots of the subframe.
- When returned as a two-column integer matrix, the resource allocations can vary for each slot in the subframe.

The PRB indices are zero-based.

Example: [0,5]

Data Types: `double`

`RBIdx` — PUCCH logical resource block index
nonnegative integer

PUCCH logical resource block index, returned as a nonnegative integer. (*m*)

Data Types: `double`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH1` | `ltePUCCH1Decode` | `ltePUCCH1DRS` | `ltePUCCH1DRSIndices` | `ltePUCCH2Indices` | `ltePUCCH3Indices`

Introduced in R2014a

ltePUCCH2

Physical uplink control channel format 2

Syntax

```
sym = ltePUCCH2(ue,chs,bits)
[sym,info] = ltePUCCH2(ue,chs,bits)
```

Description

`sym = ltePUCCH2(ue,chs,bits)` returns a matrix containing physical uplink control channel (PUCCH) format 2 symbols given a structure of UE-specific settings, a structure with channel transmission configuration settings, and a vector of coded CQI/PMI or RI `bits`.

`[sym,info] = ltePUCCH2(ue,chs,bits)` also returns a PUCCH information structure array, `info`.

Examples

Generate PUCCH Format2 symbols

Generate PUCCH format 2 symbol values, using `NCellID` set to 1 and `NSubframe` set to 0.

Initialize `ue` and `chs` configuration structures. Generate symbols.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = 0;
chs.ResourceSize = 0;
chs.CyclicShifts = 0;

sym = ltePUCCH2(ue,chs,ones(20,1));
```

```
sym(1:5)
```

```
ans =

   0.0000 + 1.0000i
  -0.5000 - 0.8660i
  -0.5000 + 0.8660i
  -0.0000 - 1.0000i
   0.5000 + 0.8660i
```

Generate PUCCH Format 2 Symbols for Two Antennas

Generate the physical uplink control channel (PUCCH) format 2 symbols for two transmit antenna paths.

Initialize parameters for a UE-specific configuration structure and a channel configuration structure. Generate PUCCH 2 symbols and the information structure.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = [0 3];
chs.ResourceSize = 0;
chs.CyclicShifts = 0;

[pucch2Sym,info] = ltePUCCH2(ue,chs,[]);
```

Because there are two antennas, the symbols are output as a two-column vector, and the `info` output structure contains two elements.

```
pucch2Sym(1:10,:)
size(info)
```

```
ans =

   0.5000 + 0.5000i   0.5000 + 0.5000i
  -0.6830 - 0.1830i   0.1830 - 0.6830i
   0.1830 + 0.6830i  -0.1830 - 0.6830i
  -0.5000 - 0.5000i  -0.5000 + 0.5000i
```

```
   0.6830 + 0.1830i   0.6830 + 0.1830i
   0.6830 - 0.1830i   0.1830 + 0.6830i
  -0.5000 - 0.5000i   0.5000 + 0.5000i
  -0.6830 - 0.1830i  -0.1830 + 0.6830i
   0.6830 - 0.1830i   0.6830 - 0.1830i
   0.5000 - 0.5000i   0.5000 + 0.5000i


ans =

     1     2
```

View the contents of the second `info` structure element.

```
info(2)
```

```
ans =

  struct with fields:

              Alpha: [1×10 double]
           SeqGroup: [1 1]
             SeqIdx: [0 0]
        NResourceIdx: [4 7]
    NCellCyclicShift: [64 192 46 212 191 71 91 84 25 105]
             Symbols: [1×10 double]
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure containing these fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number

Parameter Field	Required or Optional	Values	Description
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
CyclicPrefixUL	Optional	'Normal' (default), 'Extended'	Cyclic prefix length
Hopping	Optional	'Off' (default), 'Group'	Frequency hopping method.

chs — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing these fields.

Parameter Field	Required or Optional	Values	Description
ResourceIdx	Optional	0 (default), integer from 0 to 1185 or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission. ($n^{(2)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.
ResourceSize	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N^{(2)}_{\mathrm{RB}}$)
CyclicShifts	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N^{(1)}_{\mathrm{cs}}$)

bits — Coded CQI/PMI or RI bits

vector

Coded CQI/PMI or RI bits (coded UCI), specified as a vector that is formed by performing UCI encoding of a bit vector representing the CQI/PMI or RI information fields described

in TS 36.212 [2], Section 5.2.3.3. This 20 bit long coded bit vector is denoted block of bits *b(0),...,b(19)* in TS 36.211 [1], Section 5.4.2. If M_{bit} is 21 or 22, corresponding to PUCCH format 2a or 2b, respectively, as described in TS 36.211 [1], Table 5.4-1, the further bits, $b(20),...,b(M_{bit}-1)$, should be provided as input to the `ltePUCCH2DRS` function for transmission. An M_{bit} value of 20 corresponds to PUCCH format 2, with no additional bits being transmitted on the PUCCH format 2 DRS.

Data Types: `logical` | `double`

Output Arguments

`sym` — PUCCH format 2 symbols

numeric column vector

PUCCH format 2 symbols, returned as numeric column vector. The symbols for each antenna are in the columns of `sym`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: 0.7071 + 0.7071i

Data Types: `double`
Complex Number Support: Yes

`info` — PUCCH format 2 information

structure array

PUCCH format 2 information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`Alpha` — Reference signal cyclic shift for each OFDM symbol

two-column vector

Reference signal cyclic shift for each OFDM symbol, returned as a two-column vector. (α)

`SeqGroup` — PUCCH base sequence group number for each slot

two-column vector

PUCCH base sequence group number for each slot, returned as a two-column vector. (u)

`SeqIdx` — PUCCH base sequence group number indices

two-column vector

PUCCH base sequence group number indices for each slot, returned as a two-column vector. (v)

`NResourceIdx` — PUCCH resource indices for each slot
two-column vector

PUCCH resource indices for each slot, returned as a two-column vector. (n')

`NCellCyclicShift` — Cell-specific cyclic shift for each OFDM symbol
vector

Cell-specific cyclic shift for each OFDM symbol, returned as a vector. (n_{cs}^{cell})

`Symbols` — Modulated data symbols for each OFDM symbol
vector

Modulated data symbols for each OFDM symbol, returned as a vector. (*d(0)*)

Example: [0.7071 + 0.7071i,...]

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH1` | `ltePUCCH2Decode` | `ltePUCCH2DRS` | `ltePUCCH2DRSIndices` | `ltePUCCH2Indices` | `ltePUCCH3` | `lteUCIEncode`

Introduced in R2014a

ltePUCCH2DRS

PUCCH format 2 demodulation reference signal

Syntax

```
seq = ltePUCCH2DRS(ue,chs,ack)
[seq,info] = ltePUCCH2DRS(ue,chs,ack)
```

Description

`seq = ltePUCCH2DRS(ue,chs,ack)` returns a matrix containing demodulation reference signal (DRS) associated with PUCCH format 2 transmission, given a structure of UE-specific settings, a structure with channel transmission configuration settings, and hybrid ARQ (HARQ) indicator values, `ack`.

`[seq,info] = ltePUCCH2DRS(ue,chs,ack)` also returns a PUCCH information structure array, `info`.

Examples

Generate PUCCH Format 2 DM-RS

Generate PUCCH Format 2 DM-RS symbols for UE specific settings.

Initialize input configuration structures (`ue` and `chs`). Here no HARQ bits will be sent by inputting an empty `ack` vector. Generate the PUCCH Format 2 DM-RS symbols.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = 0;
chs.ResourceSize = 0;
chs.CyclicShifts = 0;
```

```
sym = ltePUCCH2DRS(ue,chs,[]);
```

Generate PUCCH Format 2 DM-RS Using Virtual Cell ID

Demonstrate Uplink Release 11 cooordinated multipoint (CoMP) operation. Intercell interference can be avoided by using a virtual cell identity for a potentially interfering UE in a neighboring cell.

Configuration for UE of interest, UE 1 in cell 1.

```
ue1.NCellID = 1;
ue1.NSubframe = 0;
ue1.CyclicPrefixUL = 'Normal';
ue1.Hopping = 'Off';

chs1.ResourceIdx = 0;
chs1.ResourceSize = 0;
chs1.CyclicShifts = 0;

ack1 = 0;
```

Configuration for interferer, UE 2 in cell 2.

```
ue2.NCellID = 2;
ue2.NSubframe = 0;
ue2.CyclicPrefixUL = 'Normal';
ue2.Hopping = 'Off';

chs2.ResourceIdx = 1;
chs2.ResourceSize = 0;
chs2.CyclicShifts = 0;

ack2 = 0;
```

Measure the interference between the DM-RS signals.

```
interferenceNoCoMP = abs(sum(ltePUCCH2DRS(ue1,chs1,ack1).*conj(ltePUCCH2DRS(ue2,chs2,ac


interferenceNoCoMP =

    5.4903
```

Reconfigure interferer for CoMP operation: use virtual cell identity equal to the cell identity for the UE of interest.

```
ue2.NPUCCHID = ue1.NCellID;
```

Measure the interference between the DM-RS signals when using CoMP.

```
interferenceUsingCoMP = abs(sum(ltePUCCH2DRS(ue1,chs1,ack1).*conj(ltePUCCH2DRS(ue2,chs2
```

```
interferenceUsingCoMP =

   4.3540e-15
```

Comparing the correlations between the DM-RS signals for two UEs with and without CoMP, `interferenceUsingCoMP` and `interferenceNoCoMP` respectively. Using CoMP, the interference is reduced to effectively zero.

Generate PUCCH Format 2 DM-RS for Two Antennas

Generate the PUCCH format 2 DM-RS sequences for two transmit antenna paths.

Initialize UE-specific and channel configuration structures. Provide an empty vector for the `ack`, indicating there are no HARQ bits for this PUCCH transmission. Generate PUCCH 2 DM-RS and information outputs.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';

chs.ResourceIdx = [0 3];
chs.ResourceSize = 0;
chs.CyclicShifts = 0;

ack = [];

[drsSeq,info] = ltePUCCH2DRS(ue,chs,ack);
```

Because there are two antennas, the DM-RS sequences are output as a two- column vector, and the `info` output structure contains two elements.

```
drsSeq(1:10,:)
```

```
size(info)
```

```
ans =

   0.5000 + 0.5000i   0.5000 + 0.5000i
  -0.1830 + 0.6830i  -0.6830 - 0.1830i
  -0.1830 - 0.6830i   0.1830 + 0.6830i
   0.5000 - 0.5000i  -0.5000 - 0.5000i
   0.6830 + 0.1830i   0.6830 + 0.1830i
  -0.1830 - 0.6830i   0.6830 - 0.1830i
   0.5000 + 0.5000i  -0.5000 - 0.5000i
   0.1830 - 0.6830i  -0.6830 - 0.1830i
   0.6830 - 0.1830i   0.6830 - 0.1830i
  -0.5000 - 0.5000i   0.5000 - 0.5000i


ans =

     1     2
```

View the contents of the two `info` structure elements.

```
info(1)
info(2)
```

```
ans =

  struct with fields:

              Alpha: [1.0472 3.1416 1.5708 2.0944]
           SeqGroup: [1 1]
             SeqIdx: [0 0]
       NResourceIdx: [1 10]
   NCellCyclicShift: [193 89 101 234]
            Symbols: [1×4 double]
            OrthSeq: [2×2 double]


ans =

  struct with fields:
```

```
            Alpha: [2.6180 4.7124 0 0.5236]
         SeqGroup: [1 1]
           SeqIdx: [0 0]
      NResourceIdx: [4 7]
  NCellCyclicShift: [193 89 101 234]
           Symbols: [1×4 double]
           OrthSeq: [2×2 double]
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`NPUCCHID`	Optional	`NCellID` (default), Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

chs — Channel transmission configuration

structure

PUCCH channel settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 1185 or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission. ($n^{(2)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.
`ResourceSize`	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N^{(2)}_{\mathrm{RB}}$)
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N^{(1)}_{\mathrm{cs}}$)

`ack` — Hybrid ARQ indicator values

binary vector containing 0, 1 or 2 elements

Hybrid ARQ indicator values, specified as nonnegative integer vector. This vector is expected to be the block of bits $b(0),...,b(M_{\mathrm{bit}}-1)$ specified in TS 36.211 [1], Section 5.4.2. An M_{bit} value of 20, 21, or 22 corresponds to PUCCH format 2, 2a, or 2b, respectively, as described in TS 36.211 [1], Table 5.4-1.

Example: [ ] indicates that no HARQ are transmitted in the subframe.

Output Arguments

`seq` — PUCCH format 2 DRS values

numeric matrix

PUCCH format 2 DRS values, returned as a numeric matrix. The symbols for each antenna are in the columns of `seq`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Note: The standard does not support format 2a or 2b transmission with extended cyclic prefix. If the `ack` setting corresponds to format 2a or 2b transmission and extended cyclic prefix is set for `ue.CyclicPrefixUL`, the function returns an empty matrix for `seq`.

Data Types: `double`
Complex Number Support: Yes

`info` — PUCCH format 2 information

structure array

PUCCH format 2 information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields. When configured for format 2a or 2b transmission with extended cyclic prefix, the `info` structure contains all fields, but each field is empty.

`Alpha` — Reference signal cyclic shift for each OFDM symbol

two-column vector

Reference signal cyclic shift for each OFDM symbol, returned as a two-column vector. (α)

`SeqGroup` — PUCCH base sequence group number for each slot

two-column vector

PUCCH base sequence group number for each slot, returned as two-column vector. (u)

`SeqIdx` — PUCCH base sequence number for each slot

two-column vector

PUCCH base sequence number for each slot, returned as two-column vector. (v)

`NResourceIdx` — PUCCH resource indices for each slot

vector

PUCCH resource indices for each slot, returned as two-column vector. (n')

`NCellCyclicShift` — Cell-specific cyclic shift for each OFDM symbol

vector

Cell-specific cyclic shift for each OFDM symbol, returned as vector. ($n_{\mathrm{cs}}^{\mathrm{cell}}$)

`Symbols` — Modulated data symbols

vector

Modulated data symbols, returned as a vector. There is one element for each OFDM symbol. (z)

Example: [0.7071 + 0.7071i,...]

`OrthSeq` — Orthogonal sequence for each slot

4-by-2 numeric matrix

Orthogonal sequence for each slot, returned as a 4-by-2 numeric matrix. ($\bar{w}$)

Example: [1.000 + 1.000i,...]

Data Types: `struct`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH1DRS` | `ltePUCCH2` | `ltePUCCH2Decode` | `ltePUCCH2DRSDecode` | `ltePUCCH2DRSIndices` | `ltePUCCH2Indices` | `ltePUCCH3DRS`

Introduced in R2014a

ltePUCCH2DRSDecode

PUCCH format 2 DRS decoding

Syntax

```
ack = ltePUCCH2DRSDecode(ue,chs,oack,sym)
```

Description

`ack = ltePUCCH2DRSDecode(ue,chs,oack,sym)` returns a vector of hybrid automatic repeat request (HARQ) indicator values, `ack`, obtained by performing PUCCH format 2 DRS decoding of the complex matrix, `sym`. The decoder uses a maximum likelihood (ML) approach, assuming that `sym` has already been equalized, to best restore the originally transmitted complex values. The symbols for each antenna are in the columns of `sym`. The number of columns in `sym` should match the number of PUCCH resource indices specified in the `chs` structure.

`oack` specifies the number of HARQ indicator values expected.

`ack` is a column vector containing `oack` HARQ indicator (HI) values.

Examples

Decode PUCCH Format 2A DM-RS

Decode a PUCCH format 2A DM-RS from a synchronized and equalized resource array.

Initialize input configuration structures demonstrating use of `'Name',Value` pair assignment and direct field assignment.

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
pucch2 = struct('ResourceIdx',0);

ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
pucch2.ResourceSize = 0;
```

```
pucch2.CyclicShifts = 0;
```

For the transmitter, create the PUCCH format 2A DM-RS.

```
reGrid = lteULResourceGrid(ue);
drsIndices = ltePUCCH2DRSIndices(ue,pucch2);
txAck = [1;0];
reGrid(drsIndices) = ltePUCCH2DRS(ue,pucch2,txAck);
```

On the receiver side, decode the PUCCH format 2 DM-RS symbols and view `rxAck` to confirm it matches `txAck`

```
drsSymbols = reGrid(drsIndices);
rxAck = ltePUCCH2DRSDecode(ue,pucch2,length(txAck),drsSymbols)
```

```
rxAck =

  2×1 logical array

   1
   0
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.

Parameter Field	Required or Optional	Values	Description
NPUCCHID	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

chs — Channel transmission configuration

structure

PUCCH channel settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
ResourceIdx	Optional	0 (default), integer from 0 to 1185 or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission. ($n_{\mathrm{PUCCH}}^{(2)}$). Define one index for each transmission antenna.
ResourceSize	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N_{\mathrm{RB}}^{(2)}$)
CyclicShifts	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{\mathrm{cs}}^{(1)}$)

oack — Number of uncoded HARQ-ACK bits

1 | 2

`oack` specifies the number of HARQ indicator values expected, specified as nonnegative integer vector. The number of HARQ indicator values is 1 for PUCCH format 2A and 2 for PUCCH format 2B.

Data Types: `double`

`sym` — Symbols of each antenna

complex numeric matrix

Symbols for each antenna, specified as complex numeric matrix. The number of columns in `sym` should match the number of PUCCH resource indices specified in the `chs` structure.

Example: 0.25881 + 0.9659i

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`ack` — Hybrid ARQ indicator values

logical column vector

Hybrid ARQ indicator values, returned as a logical column vector. This output is obtained by performing PUCCH format 1 decoding of the complex matrix, `sym`.

Data Types: `logical`

See Also

See Also

`ltePUCCH1DRS` | `ltePUCCH2` | `ltePUCCH2Decode` | `ltePUCCH2DRS` | `ltePUCCH2DRSIndices` | `ltePUCCH2Indices` | `ltePUCCH2PRBS` | `ltePUCCH3DRS`

Introduced in R2014a

ltePUCCH2DRSIndices

PUCCH format 2 DRS resource element indices

Syntax

```
ind = ltePUCCH2DRSIndices(ue,chs)
[ind,info] = ltePUCCH2DRSIndices(ue,chs)
[ ___ ] = ltePUCCH2DRSIndices(ue,chs,opts)
```

Description

`ind = ltePUCCH2DRSIndices(ue,chs)` returns a matrix of resource element indices for the demodulation reference signal (DRS) associated with the PUCCH format 2 transmission given structures containing the UE-specific settings, and the channel transmission configuration.

`[ind,info] = ltePUCCH2DRSIndices(ue,chs)` also returns a PUCCH information structure array, `info`.

`[ ___ ] = ltePUCCH2DRSIndices(ue,chs,opts)` formats the returned indices using the options defined in a cell array, `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate PUCCH Format 2 DM-RS Indices

Generate PUCCH format 2 DM-RS RE indices for a 1.4 MHz bandwidth and PUCCH resource index 0. Use default values for all other parameters.

Initialize UE-specific and channel configuration structures. Generate PUCCH format 2 DM-RS indices.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';
```

```
chs.ResourceIdx = 0;

ind = ltePUCCH2DRSIndices(ue,chs);
ind(1:4)
```

```
ans =

  4×1 uint32 column vector

   73
   74
   75
   76
```

Generate PUCCH Format 2 DM-RS Indices for Four Antennas

Generate the PUCCH format 2 DM-RS indices for four transmit antenna paths, and display the output information structure.

Initialize UE-specific and channel configuration structures. Generate PUCCH 2 DM-RS indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 37 4 111];

[ind,info] = ltePUCCH2DRSIndices(ue,chs);
```

Because there are four antennas, the DM-RS indices are output as a four-column vector and the `info` output structure contains four elements. View `ind` and the size of `info` to confirm.

```
ind(1:6,:)
size(info)
```

```
ans =

  6×4 uint32 matrix

     73   1129   2089   3109
```

```
     74   1130   2090   3110
     75   1131   2091   3111
     76   1132   2092   3112
     77   1133   2093   3113
     78   1134   2094   3114


ans =

     1     4
```

View the contents of one of the `info` structure elements.

```
info(4)
```

```
ans =

  struct with fields:

    PRBSet: [1 4]
     RBIdx: 9
```

Generate PUCCH Format 2 DM-RS Indices Varying Indexing Style

Generate the PUCCH format 2 DM-RS indices for two transmit antenna paths, and output in subscript indexing form.

Initialize UE-specific and channel configuration structures and the indexing option parameter. Generate PUCCH 2 DM-RS indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 4];

[ind,info] = ltePUCCH2DRSIndices(ue,chs,{'sub'});
```

Using 'sub' indexing style, the indices are output in [subcarrier, symbol, antenna] subscript form. View the midpoint of ind and observe the antenna index change.

```
size(ind)
ind(46:51,:)
```

```
size(info)
```

```
ans =

    96     3


ans =

  6×3 uint32 matrix

   70   13    1
   71   13    1
   72   13    1
    1    2    2
    2    2    2
    3    2    2


ans =

     1     2
```

Because there are two antennas, the info output structure contains two elements. View one of the `info` structure elements.

```
info(2)
```

```
ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure containing these fields.

`NULRB` — Number of uplink resource blocks

integer from 6 to 110.

Number of uplink resource blocks, specified as an integer from 6 to 110.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length for uplink channels

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing the following fields.

`ResourceIdx` — PUCCH resource indices

0 (default) | 0,...,1185 | integer | vector of integers | optional

PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 1185. There is one index for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. ($n_{\mathrm{PUCCH}}^{(2)}$)

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.

Category	Options	Description
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — Resource element indices

integer column vector | three-column integer matrix

Resource element indices, returned as an integer column vector or a three-column integer matrix. By default the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to PUCCH format 2 DRS modulation symbol mapping. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [145,146,147,...]

Data Types: `uint32`

`info` — PUCCH format 2 DRS information

structure array

PUCCH format 2 DRS information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`PRBSet` — Indices occupied by PRB in each slot of subframe

nonnegative integer vector

Indices occupied by PRB in each slot of the subframe, returned as a nonnegative integer vector. The indices are zero-based.

Example: [0,5]

Data Types: `double`

`RBIdx` — PUCCH logical resource block index

nonnegative integer

PUCCH logical resource block index, returned as a nonnegative integer. (*m*)

Data Types: `double`

Data Types: `struct`

See Also

See Also

`ltePUCCH1DRSIndices` | `ltePUCCH2` | `ltePUCCH2Decode` | `ltePUCCH2DRS` | `ltePUCCH2DRSDecode` | `ltePUCCH2Indices` | `ltePUCCH2PRBS` | `ltePUCCH3DRSIndices`

Introduced in R2014a

ltePUCCH2Decode

Physical uplink control channel format 2 decoding

Syntax

```
out = ltePUCCH2Decode(ue,chs,sym)
```

Description

`out = ltePUCCH2Decode(ue,chs,sym)` performs decoding of the PUCCH format 2 given UE-specific settings `ue` and channel transmission configuration `chs`. `out` is a soft bit vector consisting of 20 bits, formed by decoding complex symbol matrix `sym`, performing demodulation with the PUCCH format 2 reference sequence, QPSK demodulation, and descrambling. The symbols for each antenna are in the columns of `sym`, and the number of columns should match the number of PUCCH Resource Indices specified in the structure, `chs`.

Examples

Decode PUCCH Format 2 Signal

Decode a PUCCH format 2 signal from an equalized resource array, `grid`.

First, create a UE configuration structure, `ue`, and a PUCCH configuration structure, `pucch2`.

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'RNTI',1);
pucch2 = struct('ResourceIdx',0);
```

For the transmitter, create a PUCCH format 2 resource grid.

```
rgrid = lteULResourceGrid(ue);
pucch2Indices = ltePUCCH2Indices(ue,pucch2);
tx = [1;0;0;0;0;1];
encoded = lteUCIEncode(tx);
rgrid(pucch2Indices) = ltePUCCH2(ue,pucch2,encoded);
```

On the receiver side, decode the PUCCH format 2 signal contained in equalized resource array, `grid`. Also decode the UCI bits.

```
rx = ltePUCCH2Decode(ue,pucch2,rgrid(pucch2Indices));
decoded = lteUCIDecode(rx,length(tx))
```

```
decoded =

  6×1 logical array

   1
   0
   0
   0
   0
   1
```

Input Arguments

`ue` — UE-specific settings

structure

`ue` is a structure having the following fields.

`NCellID` — Cell identity number

0 (default)

Physical layer cell identity number, specified as a nonnegative scalar integer.

Example: 4

Data Types: `double`

`NSubframe` — Subframe number

0 (default)

Position reference signal subframe number, specified as a nonnegative scalar integer.

Example: 8

Data Types: `double`

`RNTI` — Radio network temporary identifier (16-bit)
scalar integer

Radio network temporary identifier (16-bit), specified as a scalar integer.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length for uplink channels
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`. Optional.

Data Types: `char`

`Hopping` — Uplink frequency hopping
`'Off'` (default) | optional | `'Group'`

Uplink frequency hopping, specified as `'Off'` or `'Group'`. Optional.

Data Types: `char`

Data Types: `struct`

`chs` — Channel transmission configuration
structure

Channel transmission configuration, specified as a structure. `chs` contains the following fields.

`ResourceIdx` — PUCCH resource indices
0 (default) | optional | 0...1185

PUCCH resource indices, specified as a nonnegative vector with one element for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. (*n2_pucch*)

Example: 78

Data Types: `double`

`ResourceSize` — Size of resources allocated to PUCCH format 2
0 (default) | optional | 0...98

Size of resources allocated to PUCCH format 2, specified as nonnegative scalar integer. This parameter affects location of this transmission. (*N2RB*)

Data Types: `double`

`CyclicShifts` — Number of cyclic shifts for format 1 resource blocks

0 (default) | optional | 0...7

Number of cyclic shifts for format 1 resource blocks, in RBs, specified as a nonnegative scalar integer. This parameter can be used in a mixture of format 1 and format 2 PUCCH. (*N1cs*)

Example: 7

Data Types: `double`

`sym` — Symbols of each antenna

complex numeric matrix

Symbols for each antenna, specified as complex numeric matrix. The number of columns should match the number of PUCCH resource indices specified in the channel transmission configuration structure, `chs`.

Example: 0.25881 + 0.9659i

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`out` — PUCCH format 2 decoded soft bit output

logical column vector

PUCCH format 2 decoded soft bit output, returned as a logical column vector. This output contains the result of decoding `sym`.

Data Types: `logical`

See Also

See Also

`ltePUCCH1Decode` | `ltePUCCH2` | `ltePUCCH2DRS` | `ltePUCCH2DRSDecode` | `ltePUCCH2DRSIndices` | `ltePUCCH2Indices` | `ltePUCCH2PRBS` | `ltePUCCH3Decode` | `lteUCIDecode`

Introduced in R2014a

ltePUCCH2Indices

PUCCH format 2 resource element indices

Syntax

```
ind = ltePUCCH2Indices(ue,chs)
[ind,info] = ltePUCCH2Indices(ue,chs)
[___] = ltePUCCH2Indices(ue,chs,opts)
```

Description

`ind = ltePUCCH2Indices(ue,chs)` returns a matrix of resource element indices for the Physical Uplink Control Channel (PUCCH) Format 2 transmission given structures containing the UE-specific settings, and the channel transmission configuration.

`[ind,info] = ltePUCCH2Indices(ue,chs)` also returns a PUCCH information structure array `info`.

`[___] = ltePUCCH2Indices(ue,chs,opts)` formats the returned indices using options defined in the cell array, `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate PUCCH Format 2 Indices

Generate PUCCH format 2 RE indices for a 1.4 MHz bandwidth and PUCCH resource index 0. Use default values for all other parameters.

Initialize UE-specific and channel configuration structures. Generate PUCCH format 2 indices.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = 0;
```

```
ind = ltePUCCH2Indices(ue,chs);
ind(1:4)


ans =

  4×1 uint32 column vector

   1
   2
   3
   4
```

Generate PUCCH Format 2 Indices for Three Antennas

Generate the physical uplink control channel (PUCCH) format 2 indices for three transmit antenna paths, and display the information structure output.

Initialize UE-specific and channel configuration structures. Generate PUCCH 2 indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 129 2];

[ind,info] = ltePUCCH2Indices(ue,chs);
```

Because there are three antennas, the indices are output as a three column vector and the `info` output structure contains three elements. View `ind` and the size of `info` to confirm this.

```
ind(1:5,:)
size(info)


ans =

  5×3 uint32 matrix

      1   1069   2017
      2   1070   2018
      3   1071   2019
```

```
      4   1072   2020
      5   1073   2021


ans =

     1     3
```

View the contents of one of the `info` structure elements.

```
info(1)
```

```
ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Generate PUCCH Format 2 Indices Varying Indexing Style

Generate the PUCCH format 2 indices for two transmit antenna paths, and output in subscript indexing form.

Initialize UE-specific and channel configuration structures, and the indexing option parameter. Generate PUCCH 2 indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 4];

opts = {'sub'};

[ind,info] = ltePUCCH2Indices(ue,chs,opts);
```

Using `'sub'` indexing style, the indices are output in `[subcarrier, symbol, antenna]` subscript form. View the midpoint of `ind` and observe the antenna index change.

```
size(ind)
ind(118:123,:)
```

```
ans =

   240     3


ans =

  6×3 uint32 matrix

   70   14    1
   71   14    1
   72   14    1
    1    1    2
    2    1    2
    3    1    2
```

Because there are two antennas, the `info` output structure contains two elements. View the contents of one of the `info` structure elements.

```
size(info)
info(2)
```

```
ans =

     1     2


ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure containing these fields.

`NULRB` — Number of uplink resource blocks

integer from 6 to 110

Number of uplink resource blocks, specified as a integer from 6 to 110.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length for uplink channels

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing the following fields.

`ResourceIdx` — PUCCH resource indices

0 (default) | 0,...,1185 | integer | vector of integers | optional

PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 1185. There is one index for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. ($n_{\mathrm{PUCCH}}^{(2)}$)

Data Types: `double`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.

Category	Options	Description
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PUCCH format 2resource element indices

integer column vector | three-column integer matrix

PUCCH format 2 resource element indices, returned as an integer column vector or a three-column integer matrix. By default, the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to PUCCH format 2 modulation symbol mapping as specified in TS 36.211 [1], Section 5.4. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [1,2,3,4...]

Data Types: `uint32`

`info` — PUCCH format 2 information

structure array

PUCCH format 2 information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`PRBSet` — Set of PRB indices

column vector | two-column matrix

Set of PRB indices, returned as an integer column vector or two-column integer matrix corresponding to the resource allocations.

- When returned as a column vector, the resource allocation is the same in both slots of the subframe.
- When returned as a two-column matrix, the resource allocations can vary for each slot in the subframe.

The PRB indices are zero-based.

Example: [0,5]

Data Types: `double`

`RBIdx` — PUCCH logical resource block index

nonnegative integer

PUCCH logical resource block index, returned as a nonnegative integer. (m)

Data Types: `uint32`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH1Indices` | `ltePUCCH2` | `ltePUCCH2Decode` | `ltePUCCH2DRS` | `ltePUCCH2DRSDecode` | `ltePUCCH2DRSIndices` | `ltePUCCH2PRBS` | `ltePUCCH3Indices`

Introduced in R2014a

ltePUCCH2PRBS

PUCCH format 2 pseudorandom scrambling sequence

Syntax

```
seq = ltePUCCH2PRBS(ue,n)
seq = ltePUCCH2PRBS(ue,n,mapping)
```

Description

`seq = ltePUCCH2PRBS(ue,n)` returns a column vector containing the first `n` outputs of the Physical Uplink Control Channel (PUCCH) Format 2 scrambling sequence when initialized according to UE-specific settings, `ue`.

`seq = ltePUCCH2PRBS(ue,n,mapping)` allows control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Scramble UCI bits

Scramble the encoded UCI bits representing RI=3 using 2 bits. According to Table 5.2.2.6-6 in TS 36.212 this maps to the set of input bits [1; 0].

Create user-specific configuration structure. Generate a UCI codeword and a pseudorandom scrambling sequence for the PUCCH2 the same length as the codeword.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;
cw = lteUCIEncode([1;0]);
seq = ltePUCCH2PRBS(ue,length(cw));
size(seq)
```

```
ans =
```

```
    20     1
```

Scramble the UCI codeword using the generated scrambling sequence.

```
scrambled = xor(seq,cw);
```

Generate PUCCH Format 2 Pseudorandom Scrambling Sequence

Generate unsigned and signed PUCCH format 2 pseudorandom scrambling sequences.

Create user-specific configuration structure.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;
```

Generate a PUCCH format 2 pseudorandom scrambling sequence.

```
seq = ltePUCCH2PRBS(ue,5)
```

```
seq =

  5×1 logical array

   1
   1
   0
   0
   1
```

Generate a signed PUCCH format 2 pseudorandom scrambling sequence.

```
seq = ltePUCCH2PRBS(ue,5,'signed')
```

```
seq =

    -1
    -1
     1
     1
```

-1

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure. `ue` contains the following fields.

NCellID — Physical layer cell identity number

nonnegative scalar integer

Physical layer cell identity number, specified as a nonnegative scalar integer.

Example: 1

Data Types: `double`

NSubframe — Subframe number

nonnegative scalar integer

Subframe number, specified as a nonnegative scalar integer.

Example: 0

Data Types: `double`

RNTI — Radio network temporary identifier

scalar integer

Radio network temporary identifier (16-bit), specified as a scalar integer.

Example: 1

Data Types: `double`

n — Length of PUCCH format 2 scrambling sequence

nonnegative scalar integer

Length of PUCCH format 2 scrambling sequence, specified as a nonnegative scalar integer.

Example: 10

Data Types: `double`

`mapping` — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

`seq` — PUCCH format 2 pseudorandom scrambling sequence

logical column vector | numeric column vector

PUCCH format 2 pseudorandom scrambling sequence, returned as a logical column vector or a numeric column vector. The length of this sequence is given by the input argument, `n`. If you set `mapping` to `'signed'`, the output data type is double. Otherwise, the output data type is logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePUCCH2` | `ltePUCCH2Decode` | `ltePUCCH2DRS` | `ltePUCCH2DRSDecode` | `ltePUCCH2DRSIndices` | `ltePUCCH2Indices` | `ltePUCCH3Indices` | `ltePUCCH3PRBS`

Introduced in R2014a

ltePUCCH3

Physical uplink control channel format 3

Syntax

```
sym = ltePUCCH3(ue,chs,bits)
[sym,info] = ltePUCCH3(ue,chs,bits)
```

Description

`sym = ltePUCCH3(ue,chs,bits)` returns a matrix containing Physical Uplink Control Channel (PUCCH) format 3 symbols given a structure of UE-specific settings, a structure with channel transmission configuration settings, and a vector of coded hybrid ARQ (HARQ) values, `bits`.

`[sym,info] = ltePUCCH3(ue,chs,bits)` also returns a PUCCH information structure array, `info`.

Examples

Generate PUCCH Format 3 Symbols

Generate PUCCH format 3 modulated symbols.

Initialize `ue` and `chs` configuration structures. Generate and view PUCCH Format 3 symbols.

```
ue.NCellID = 0;
ue.NSubframe = 0;
ue.RNTI = 1;
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.ResourceIdx = 0;

sym = ltePUCCH3(ue,chs,ones(48,1));
```

```
sym(1:5)
```

```
ans =

   1.6330 - 1.2247i
  -0.7071 + 0.7071i
  -0.5577 + 0.1494i
   0.4082 - 0.0000i
  -0.5577 - 0.9659i
```

Generate PUCCH Format 3 Symbols for Two Antennas

Generate the physical uplink control channel (PUCCH) format 3 symbols for two transmit antenna paths and display the information structure.

Initialize parameters for a UE-specific configuration structure and a channel configuration structure. Generate PUCCH1 symbols and information outputs.

```
ue.NCellID = 1;
ue.RNTI = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.ResourceIdx = [0 3];

[pucch3Sym,info] = ltePUCCH3(ue,chs,[]);
```

Becasue there are two antennas, the symbols are output as a two-column vector, and the `info` output structure contains two elements.

```
pucch3Sym(1:6,:)
size(info)
```

```
ans =

   0.0000 + 2.4495i   0.0000 + 2.4495i
   0.0000 - 0.0000i   0.0000 - 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i
   0.0000 - 0.0000i   0.0000 - 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i
```

```
ans =

     1     2
```

View the contents of the second `info` structure element.

```
info(2)
```

```
ans =

  struct with fields:

    NCellCyclicShift: [64 192 46 212 191 71 91 84 25 105]
          OrthSeqIdx: [3 4]
             Symbols: [1×24 double]
             OrthSeq: [5×2 double]
           NSymbSlot: [5 5]
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure that can contain these fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`RNTI`	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Parameter Field	Required or Optional	Values	Description
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing these fields.

`ResourceIdx` — PUCCH Resource Indices

0 (default) | optional | 0,...,549 | vector | vector of integers

PUCCH Resource Indices, specified as an integer or vector of integers with values from 0 to 549. There is one index for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. ($n^{(3)}_{\mathrm{PUCCH}}$).

Data Types: `struct`

`bits` — Coded HARQ-ACK bits

nonnegative integer column vector of length 48

Coded HARQ-ACK bits, specified as a nonnegative integer column vector of length 48. TS 36.211 [1], Table 5.4-1 specifies the vector length for PUCCH format 3 is $M_{bit} = 48$. `bits` is expected to be the block of bits $b(0)...b(M_{bit}-1)$specified in TS 36.211 [1], Section 5.4.2A. `bits` is also expected to be generated by performing uplink control information (UCI) channel coding as described TS 36.212 [2], Section 5.2.3.1. For PUCCH format 3, UCI includes encoding of concatenated HARQ-ACK bits and any appended periodic CSI bits plus Scheduling Request (SR) bit when present.

Data Types: `double`

Output Arguments

`sym` — PUCCH format 3 symbols

matrix

PUCCH format 3 symbols, returned as matrix. The symbols for each antenna are in the columns of `sym`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [0.7071 + 0.7071i,...]

Data Types: `double`
Complex Number Support: Yes

`info` — PUCCH format 3 information

structure

PUCCH format 3 information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`NCellCyclicShift` — Cell-specific cyclic shift for each OFDM symbol

vector

Cell-specific cyclic shift for each OFDM symbol, returned as a vector. (n_{cs}^{cell})

`OrthSeqIdx` — Orthogonal sequence index for each slot

vector

Orthogonal sequence index for each slot, returned as a two-element vector. (n_{oc})

`Symbols` — Modulated data symbols for each OFDM symbol

vector

Modulated data symbols for each OFDM symbol, returned as a vector. (d)

Example: [0.7071 + 0.7071i,...]

`OrthSeq` — Orthogonal sequence for each slot

numeric matrix

Orthogonal sequence of each slot, returned as a numeric matrix. Each column in the matrix contains the orthogonal sequence ($w_{n_{oc}}$) for each slot.

Note: When `ue.Shortened` = 1, transmissions are shortened, and the second column of `info.OrthSeq` has a zero in the last row because the spreading factor for the second slot is 4 instead of 5.

Example: [1.000 + 1.000i,...]

`NSymbSlot` — Number of OFDM symbols in each slot

vector of integers

The number of OFDM symbols in each slot, returned as a vector of integers.

$\left(\begin{bmatrix} N_{\mathrm{SF},0}^{\mathrm{PUCCH}} & N_{\mathrm{SF},1}^{\mathrm{PUCCH}} \end{bmatrix}\right)$

Data Types: `struct`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH3Decode` | `ltePUCCH3DRS` | `ltePUCCH3DRSIndices` | `ltePUCCH3Indices` | `ltePUCCH3PRBS` | `lteUCI3Encode`

Introduced in R2014a

ltePUCCH3Decode

Physical uplink control channel format 3 decoding

Syntax

```
out = ltePUCCH3Decode(ue,chs,sym)
```

Description

`out = ltePUCCH3Decode(ue,chs,sym)` decodes the PUCCH format 3 given UE-specific settings, `ue`, and channel transmission configuration, `chs`. `out` is a soft bit vector of coded UCI consisting of 48 bits, formed by decoding the complex symbol matrix, `sym`. The symbol decoding steps are SC-FDMA deprecoding, demodulation with the PUCCH Format 3 reference sequence, QPSK demodulation, and descrambling. The symbols for each antenna are in the columns of `sym`, and the number of columns should match the number of PUCCH Resource Indices specified in the structure `chs`.

Examples

Decode PUCCH Format 3 Signal

Decode a PUCCH format 3 signal contained in an equalized resource array for the specified UE and PUCCH configuration structures.

```
ue.NULRB = 6;
ue.NCellID = 0;
ue.RNTI = 1;
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
ue.Shortened = 0;
ue.NSubframe = 0;

pucch3.ResourceIdx = 0;
```

To model the transmitter, create an uplink resource grid and populate it with PUCCH format 3 symbols.

```
reGrid = lteULResourceGrid(ue);
pucch3Indices = ltePUCCH3Indices(ue,pucch3);
tx = [1; 0; 0; 1; 1; 1];
encoded = lteUCI3Encode(tx);
reGrid(pucch3Indices) = ltePUCCH3(ue,pucch3,encoded);
```

To model the receiver, decode the PUCCH format 3 symbols contained in an equalized resource array. Decode and display the UCI. Verify received `decoded` bits match `tx` bits.

```
eqGrid = reGrid;
rx = ltePUCCH3Decode(ue,pucch3,eqGrid(pucch3Indices));
decoded = lteUCI3Decode(rx,length(tx))
```

```
decoded =

  6×1 logical array

   1
   0
   0
   1
   1
   1
```

Input Arguments

ue — UE-specific settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`RNTI`	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number

Parameter Field	Required or Optional	Values	Description
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

`chs` — Channel transmission configuration

structure

PUCCH channel settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 549, or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission ($n^{(3)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.

Data Types: `struct`

`sym` — PUCCH format 3 symbols

complex-valued matrix

PUCCH format 3 symbols, specified as a complex-valued matrix. The symbols for each antenna are in the columns of `sym`, and the number of columns should match the number of PUCCH resource indices specified in the structure `chs`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`out` — Soft bit vector

48-by-1 real-valued column vector

Soft bit vector consisting of 48 bits, returned as a 48-by-1 real-valued column vector. The number of PUCCH Resource Indices specified in the structure `chs` determines the number of columns in `out`.

Data Types: `double`

See Also

See Also

`ltePUCCH3` | `ltePUCCH3DRS` | `ltePUCCH3DRSIndices` | `ltePUCCH3Indices` | `ltePUCCH3PRBS` | `lteUCI3Decode`

Introduced in R2014a

ltePUCCH3DRS

PUCCH format 3 demodulation reference signal

Syntax

```
seq = ltePUCCH3DRS(ue,chs)
[seq,info] = ltePUCCH3DRS(ue,chs)
```

Description

`seq = ltePUCCH3DRS(ue,chs)` returns a matrix containing demodulation reference signal (DRS) associated with PUCCH format 3 transmission given structures containing the UE-specific settings, and the channel transmission configuration settings.

`[seq,info] = ltePUCCH3DRS(ue,chs)` also returns a PUCCH information structure array, `info`.

Examples

Generate PUCCH Format 3 DM-RS

Generate the PUCCH Format 3 Demodulation Reference Signal (DM-RS) values for UE-specific settings.

Initialize UE specific (`ue`) and channel (`chs`) configuration structures. Generate PUCCH DM-RS values.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';
ue.Shortened = 0;

chs.ResourceIdx = 0;
chs.CyclicShifts = 0;

pucch3RefSig = ltePUCCH3DRS(ue,chs);
```

```
pucch3RefSig(1:4)
```

```
ans =

   0.7071 + 0.7071i
   0.2588 + 0.9659i
  -0.9659 - 0.2588i
  -0.7071 - 0.7071i
```

Generate PUCCH Format 3 DM-RS Using Virtual Cell ID

Demonstrate Uplink Release 11 cooordinated multipoint (CoMP) operation. Intercell interference can be avoided by using a virtual cell identity for a potentially interfering UE in a neighboring cell.

Configuration for UE of interest, UE 1 in cell 1.

```
ue1.NCellID = 1;
ue1.NSubframe = 0;
ue1.CyclicPrefixUL = 'Normal';
ue1.Hopping = 'Off';
ue1.Shortened = 0;

chs1.ResourceIdx = 0;
```

Configuration for interferer, UE 2 in cell 2.

```
ue2.NCellID = 2;
ue2.NSubframe = 0;
ue2.CyclicPrefixUL = 'Normal';
ue2.Hopping = 'Off';
ue2.Shortened = 0;

chs2.ResourceIdx = 1;
```

Measure the interference between the DM-RS signals.

```
interferenceNoCoMP = abs(sum(ltePUCCH3DRS(ue1,chs1).*conj(ltePUCCH3DRS(ue2,chs2))))
```

```
interferenceNoCoMP =

    6.3246
```

Reconfigure interferer for CoMP operation: use virtual cell identity equal to the cell identity for the UE of interest.

```
ue2.NPUCCHID = ue1.NCellID;
```

Measure the interference between the DM-RS signals when using CoMP.

```
interferenceUsingCoMP = abs(sum(ltePUCCH3DRS(ue1,chs1).*conj(ltePUCCH3DRS(ue2,chs2))))
```

```
interferenceUsingCoMP =

   8.5451e-15
```

Comparing the correlations between the DM-RS signals for two UEs with and without CoMP, `interferenceUsingCoMP` and `interferenceNoCoMP` respectively. Using CoMP, the interference is reduced to effectively zero.

Generate PUCCH Format 3 DM-RS for Two Antennas

Generate the PUCCH format 3 DM-RS sequences for two transmit antenna paths. Display the information structure.

Initialize UE-specific and channel configuration structures. Provide an empty vector for the `ack`, indicating there are no HARQ bits for this PUCCH transmision. Generate PUCCH 3 DM-RS and information outputs.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';
ue.Shortened = 0;

chs.ResourceIdx = [0 3];

ack = [];

[drsSeq,info] = ltePUCCH3DRS(ue,chs,ack);
```

Because there are two antennas, the DM-RS sequences are output as a two-column vector and the `info` output structure contains two elements. View `ind` and the size of `info` to confirm this.

```
drsSeq(1:6,:)
size(info)
```

```
ans =

   0.5000 + 0.5000i   0.5000 + 0.5000i
   0.1830 + 0.6830i   0.5000 - 0.5000i
  -0.6830 - 0.1830i   0.5000 - 0.5000i
  -0.5000 - 0.5000i  -0.5000 - 0.5000i
  -0.1830 - 0.6830i  -0.5000 + 0.5000i
  -0.1830 + 0.6830i  -0.5000 - 0.5000i


ans =

     1     2
```

View the contents of the two `info` structure elements.

```
info(1)
info(2)
```

```
ans =

  struct with fields:

              Alpha: [0.5236 2.6180 2.6180 3.1416]
           SeqGroup: [1 1]
             SeqIdx: [0 0]
        NResourceIdx: [0 0]
    NCellCyclicShift: [193 89 101 234]
          OrthSeqIdx: [0 0]
             Symbols: [1×4 double]
             OrthSeq: [2×2 double]
          NSymbSlot: [5 5]


ans =

  struct with fields:

              Alpha: [4.7124 0.5236 1.5708 2.0944]
```

```
          SeqGroup: [1 1]
            SeqIdx: [0 0]
       NResourceIdx: [8 10]
   NCellCyclicShift: [193 89 101 234]
         OrthSeqIdx: [3 4]
            Symbols: [1×4 double]
            OrthSeq: [2×2 double]
          NSymbSlot: [5 5]
```

Input Arguments

ue — UE-specific settings

structure

UE-specific cell-wide settings, specified as a structure containing the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer 0 (default)	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Parameter Field	Required or Optional	Values	Description
`NPUCCHID`	Optional	`NCellID` (default) Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

`chs` — Channel transmission configuration

structure

PUCCH channel settings, specified as a structure containing the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 549, or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission ($n^{(3)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.

Data Types: `struct`

Output Arguments

`seq` — PUCCH format 3 DRS values

numeric matrix

PUCCH format 3 DRS values, returned as a numeric matrix. The symbols for each antenna are in the columns of `seq`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

`info` — PUCCH format 3 DRS information

structure array

PUCCH format 3 DRS information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`Alpha` — Reference signal cyclic shift for each OFDM symbol
two-column vector

Reference signal cyclic shift for each OFDM symbol, returned as a two-column vector. (α)

`SeqGroup` — PUCCH base sequence group number for each slot
two-column vector

PUCCH base sequence group number for each slot, returned as two-column vector. (u)

`SeqIdx` — PUCCH base sequence number for each slot
two-column vector

PUCCH base sequence number for each slot, returned as two-column vector. (v)

`NResourceIdx` — PUCCH resource indices for each slot
vector

PUCCH resource indices for each slot, returned as two-column vector. (n')

`NCellCyclicShift` — Cell-specific cyclic shift for each OFDM symbol
vector

Cell-specific cyclic shift for each OFDM symbol, returned as vector. (n_{cs}^{cell})

`OrthSeqIdx` — Orthogonal sequence index for each slot
two-column vector

Orthogonal sequence index for each slot, returned as two-column vector. ($\bar{n}_{oc}$)

`Symbols` — Modulated data symbols
vector

Modulated data symbols, returned as a vector. There is one element for each OFDM symbol. (z)

Example: [0.7071 + 0.7071i,...]

`OrthSeq` — Orthogonal sequence for each slot
numeric matrix

Orthogonal sequence for each slot, returned as a numeric matrix. ($\overline{w}$)

Example: [1.000 + 1.000i,...]

`NSymbSlot` — Number of OFDM symbols in each slot

vector of integers

The number of OFDM symbols in each slot, returned as a vector of integers. ($\left[N_{\mathrm{SF},0}^{\mathrm{PUCCH}}\ N_{\mathrm{SF},1}^{\mathrm{PUCCH}}\right]$)

Data Types: `double`

Data Types: `struct`

See Also

See Also

`ltePUCCH1DRS` | `ltePUCCH2DRS` | `ltePUCCH3` | `ltePUCCH3Decode` | `ltePUCCH3DRSIndices` | `ltePUCCH3Indices` | `ltePUCCH3PRBS`

Introduced in R2014a

ltePUCCH3DRSIndices

PUCCH format 3 DRS resource element indices

Syntax

```
ind = ltePUCCH3DRSIndices(ue,chs)
[ind,info] = ltePUCCH3DRSIndices(ue,chs)
[ ___ ] = ltePUCCH3DRSIndices(ue,chs,opts)
```

Description

`ind = ltePUCCH3DRSIndices(ue,chs)` returns a matrix of resource element indices for the demodulation reference signal (DRS) associated with PUCCH format 3 transmission given structures containing the UE-specific settings, and the channel transmission configuration settings.

`[ind,info] = ltePUCCH3DRSIndices(ue,chs)` also returns a PUCCH information structure array, `info`.

`[ ___ ] = ltePUCCH3DRSIndices(ue,chs,opts)` formats the returned indices using the options defined in a cell array, `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate PUCCH Format 3 DM-RS Indices

Generate PUCCH format 3 DM-RS RE indices for a 5 MHz bandwidth and PUCCH resource index 0.

Initialize UE-specific and channel configuration structures. Generate PUCCH format 3 DM-RS indices.

```
ue.NULRB = 25;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = 0;
```

```
ind = ltePUCCH3DRSIndices(ue,chs);
ind(1:4)


ans =

  4×1 uint32 column vector

   301
   302
   303
   304
```

Generate PUCCH Format 3 DM-RS Indices for Four Antennas

Generate the PUCCH format 3 DM-RS indices for a 3 MHz bandwidth, and four transmit antenna paths. Display the output information structure.

Initialize UE-specific and channel configuration structures. Generate PUCCH 3 DM-RS indices and information outputs.

```
ue.NULRB = 15;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 37 4 111];

[ind,info] = ltePUCCH3DRSIndices(ue,chs);
```

Because there are four antennas, the DM-RS indices are output as a four-column vector, and the `info` output structure contains four elements. View `ind` and the size of `info` to confirm this.

```
ind(1:6,:)
size(info)


ans =

  6×4 uint32 matrix

    181   2833   5221   7873
    182   2834   5222   7874
    183   2835   5223   7875
```

```
    184   2836   5224   7876
    185   2837   5225   7877
    186   2838   5226   7878


ans =

     1     4
```

View one of the `info` structure elements.

```
info(4)
```

```
ans =

  struct with fields:

    PRBSet: [11 3]
     RBIdx: 22
```

Generate PUCCH Format 3 DM-RS Indices Varying Indexing Style

Generate the PUCCH format 3 DM-RS indices for two transmit antenna paths, and output in subscript indexing form.

Initialize UE-specific and channel configuration structures and the indexing option parameter. Generate PUCCH 3 DM-RS indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';

chs.ResourceIdx = [0 4];
chs.ResourceSize = 0;
chs.DeltaShift = 1;
chs.CyclicShifts = 0;

[ind,info] = ltePUCCH3DRSIndices(ue,chs,{'sub'});
```

Using 'sub' indexing style, the indices are output in [subcarrier, symbol, antenna] subscript form. View the midpoint of ind and observe the antenna index change.

```
size(ind)
ind(46:51,:)
```

```
size(info)


ans =

    96     3


ans =

  6×3 uint32 matrix

   70   13    1
   71   13    1
   72   13    1
    1    2    2
    2    2    2
    3    2    2


ans =

     1     2
```

Because there are two antennas, the info output structure contains two elements. View one of the `info` structure elements.

```
info(2)


ans =

  struct with fields:

    PRBSet: [0 5]
     RBIdx: 0
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure containing these fields.

`NULRB` — Number of uplink resource blocks

nonnegative integer

Number of uplink resource blocks, specified as a nonnegative integer.

`CyclicPrefixUL` — Cyclic prefix length for uplink channels

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure containing the following fields.

`ResourceIdx` — PUCCH resource indices

0 (default) | 0,...,549 | integer | vector of integers | optional

PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 549. There is one index for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. ($n_{\mathrm{PUCCH}}^{(3)}$)

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.

Category	Options	Description
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — Resource element indices

integer column vector | three-column integer matrix

Resource element indices, returned as an integer column vector or a three-column integer matrix. By default the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to PUCCH format 3 DRS modulation symbol mapping. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: 1,2,3....

Data Types: `uint32`

`info` — PUCCH format 3 DRS information

structure array

PUCCH format 3 DRS information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`PRBSet` — Indices occupied by PRB in each slot of subframe

nonnegative integer vector

Indices occupied by PRB in each slot of the subframe, returned as a nonnegative integer vector. The indices are zero-based.

Example: [0,5]

Data Types: `double`

`RBIdx` — PUCCH logical resource block index
nonnegative integer

PUCCH logical resource block index, returned as a nonnegative integer. (*m*)

Data Types: `double`

Data Types: `struct`

See Also

See Also
`ltePUCCH1DRSIndices` | `ltePUCCH2DRSIndices` | `ltePUCCH3` | `ltePUCCH3Decode` | `ltePUCCH3DRS` | `ltePUCCH3Indices` | `ltePUCCH3PRBS`

Introduced in R2014a

ltePUCCH3Indices

PUCCH format 3 resource element indices

Syntax

```
ind = ltePUCCH3Indices(ue,chs)
[ind,info] = ltePUCCH3Indices(ue,chs)
[ ___ ] = ltePUCCH3Indices(ue,chs,opts)
```

Description

`ind = ltePUCCH3Indices(ue,chs)` returns a column vector of physical uplink control channel (PUCCH) format 3 resource element indices given structures containing the UE-specific settings, and the channel transmission configuration settings.

`[ind,info] = ltePUCCH3Indices(ue,chs)` also returns a PUCCH information structure, `info`.

`[ ___ ] = ltePUCCH3Indices(ue,chs,opts)` formats the returned indices using options defined in the cell array, `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate PUCCH Format 3 Indices

Generate PUCCH format 3 RE indices for a 1.4 MHz bandwidth and PUCCH resource index 0. Use default values for all other parameters.

Initialize UE-specific and channel configuration structures. Generate PUCCH format 3 indices.

```
ue.NULRB = 6;
```

```
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.ResourceIdx = 0;

ind = ltePUCCH3Indices(ue,chs);
ind(1:4)
```

```
ans =

  4×1 uint32 column vector

   1
   2
   3
   4
```

Generate PUCCH Format 3 Indices for Two Antennas

Generate the PUCCH format 3 indices for three transmit antenna paths, and display the information structure output.

Initialize UE-specific and channel configuration structures. Generate PUCCH 3 indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.ResourceIdx = [0 2];

[ind,info] = ltePUCCH3Indices(ue,chs);
```

Because there are two antennas, the indices are output as a two-column vector, and the `info` output structure contains two elements.

```
ind(1:5,:)
size(info)
```

```
ans =
```

```
  5×2 uint32 matrix

       1    1009
       2    1010
       3    1011
       4    1012
       5    1013


ans =

     1     2
```

View one of the `info` structure elements.

```
info(1)
```

```
ans =

  struct with fields:

       PRBSet: [0 5]
        RBIdx: 0
    NSymbSlot: [5 5]
```

Generate PUCCH Format 3 Indices Varying Indexing Style

Generate the PUCCH format 3 indices for two transmit antenna paths, and output in subscript indexing form.

Initialize UE-specific and channel configuration structures, and the indexing option parameter. Generate PUCCH 3 indices and information outputs.

```
ue.NULRB = 6;
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.ResourceIdx = [0 9];

opts = {'sub'};
```

```
[ind,info] = ltePUCCH3Indices(ue,chs,opts);
```

Using `'sub'` indexing style, the indices are output in `[subcarrier, symbol, antenna]` subscript form. View the midpoint of `ind` and observe the antenna index change.

```
size(ind)
ind(118:123,:)
```

```
ans =

   240     3


ans =

  6×3 uint32 matrix

   70   14    1
   71   14    1
   72   14    1
   61    1    2
   62    1    2
   63    1    2
```

Because there are two antennas, the `info` output structure contains two elements. View one of the `info` structure elements.

```
size(info)
info(1)
```

```
ans =

     1     2


ans =

  struct with fields:

       PRBSet: [0 5]
        RBIdx: 0
```

```
    NSymbSlot: [5 5]
```

Input Arguments

ue — UE-specific settings
structure

UE-specific settings, specified as a structure, specified as a structure containing these fields.

NULRB — Number of uplink resource blocks
nonnegative integer

Number of uplink resource blocks, specified as a nonnegative integer.

CyclicPrefixUL — Cyclic prefix length for uplink channels
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length for uplink channels, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Shortened — Option to shorten the subframe
0 (default) | optional | 1

Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. For subframes with possible SRS transmission, this parameter is required. If 1, the last symbol of the subframe is not used.

Data Types: `struct`

chs — Channel transmission configuration
structure

Channel transmission configuration, specified as a structure containing the following fields.

ResourceIdx — PUCCH resource indices
0 (default) | optional | 0,...,549 | integer | vector of integers

PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 549. There is one index for each transmission antenna. These indices determine the cyclic shift and orthogonal cover used for transmission. ($n^{(3)}_{\mathrm{PUCCH}}$)

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PUCCH format 3 resource element indices

integer column vector | three-column integer matrix

PUCCH format 3 resource element indices, returned as an integer column vector or a three-column integer matrix. By default, the indices are returned in one-based linear

indexing form that can directly index elements of a resource matrix. These indices are ordered according to PUCCH format 3 modulation symbol mapping as specified in TS 36.211 [1], Section 5.4. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of PUCCH resource indices specified in `chs.ResourceIdx`.

Example: [1,2,3,4...]

`info` — PUCCH format 3 information

scalar structure | structure array

PUCCH format 3 information, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`PRBSet` — Set of PRB indices

column vector | two-column matrix

Set of PRB indices, returned as a column vector or two-column matrix corresponding to the resource allocations.

- When returned as a column vector, the resource allocation is the same in both slots of the subframe.
- When returned as a two-column matrix, the resource allocations can vary for each slot in the subframe.

The PRB indices are zero-based.

Example: [0,5]

`RBIdx` — PUCCH logical resource block index

nonnegative integer

PUCCH logical resource block index, returned as a nonnegative integer. (m)

`NSymbSlot` — Number of OFDM symbols in each slot

vector of integers

The number of OFDM symbols in each slot, returned as a vector of integers.
$\left(\begin{bmatrix} N_{\mathrm{SF},0}^{\mathrm{PUCCH}} & N_{\mathrm{SF},1}^{\mathrm{PUCCH}} \end{bmatrix}\right)$

Data Types: `struct`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH1Indices` | `ltePUCCH2Indices` | `ltePUCCH3` | `ltePUCCH3Decode` | `ltePUCCH3DRS` | `ltePUCCH3DRSIndices` | `ltePUCCH3PRBS`

Introduced in R2014a

ltePUCCH3PRBS

PUCCH format 3 pseudorandom scrambling sequence

Syntax

```
seq = ltePUCCH3PRBS(ue,n)
seq = ltePUCCH3PRBS(ue,n,mapping)
```

Description

`seq = ltePUCCH3PRBS(ue,n)` returns a column vector containing the first `n` outputs of the Physical Uplink Control Channel (PUCCH) format 3 scrambling sequence when initialized according to UE-specific settings, `ue`, which must be a structure.

`seq = ltePUCCH3PRBS(ue,n,mapping)` allows control over the format of the returned sequence, `seq`, with the input `mapping`.

Examples

Scramble Random PUCCH3 Codeword

Scramble a random PUCCH3 codeword.

Create a ue-specific configuration structure. Generate a codeword. Generate a PUCCH3 pseudorandom scrambling sequence the same length as the codeword.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;
cw = randi([0 1],48,1);
seq = ltePUCCH3PRBS(ue,length(cw));
```

Scramble codeword with PDCCH PRBS.

```
scrambled = xor(seq,cw);
```

Scramble UCI3 Codeword

Scramble a UCI3 codeword with a PUCCH3 pseudorandom scrambling sequence.

Create a ue-specific configuration structure. Generate a UCI3 codeword. The UCI3 codeword is 48 bits long.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;

txAck = [1;0;0;1];
cw = lteUCI3Encode(txAck);
cwLength = length(cw)
```

```
cwLength =

    48
```

Generate a PUCCH3 pseudorandom scrambling sequence the same length as the codeword. Scramble codeword with PDCCH PRBS.

```
seq = ltePUCCH3PRBS(ue,length(cw));
scrambled = xor(seq,cw);
```

Generate PUCCH Format 3 Pseudorandom Scrambling Sequence

This example shows the generation of unsigned and signed PUCCH format 3 pseudorandom scrambling sequences.

Initialize ue specific parameters.

```
ue = struct('NCellID',1,'NSubframe',0,'RNTI',1);
```

Generate a PUCCH format 3 pseudorandom scrambling sequence.

```
pucch3Seq = ltePUCCH3PRBS(ue,5)
```

```
pucch3Seq =

  5×1 logical array

   1
   1
   0
   0
```

```
    1
```

Generate a signed PUCCH format 3 pseudorandom scrambling sequence.

```
pucch3Seq = ltePUCCH3PRBS(ue,5,'signed')
```

```
pucch3Seq =

    -1
    -1
     1
     1
    -1
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure having the following fields.

NCellID — Physical layer cell identity

integer (0...503)

Physical layer cell identity, specified as an integer between 0 and 503.

Data Types: `double`

NSubframe — Subframe number

integer

Subframe number, specified as an integer.

Data Types: `double`

RNTI — Radio Network Temporary Identifier

integer

Radio Network Temporary Identifier (16-bit), specified as an integer.

Data Types: `double`

Data Types: `struct`

n — Length of PUCCH Format 3 scrambling sequence

integer

Length of PUCCH Format 3 scrambling sequence, specified as an integer. This parameter determines the length of the output argument vector, `seq`.

Example: 3

Data Types: `double`

mapping — Output sequence formatting

`'binary'` (default) | `'signed'`

Output sequence formatting, specified as `'binary'` or `'signed'`. `mapping` controls the format of the returned sequence, `seq`.

- `'binary'` maps `true` to 1 and `false` to 0.
- `'signed'` maps `true` to –1 and `false` to 1.

Data Types: `char`

Output Arguments

seq — PUCCH format 3 scrambling sequence

logical column vector | numeric column vector

PUCCH format 3 scrambling sequence, returned as a logical column vector or a numeric column vector of size `n`-by-1. The number of elements returned is determined by the argument `n`. If you set `mapping` to `'signed'`, the output data type is double. Otherwise, the output data type is logical.

Data Types: `logical` | `double`

See Also

See Also

`ltePRBS` | `ltePUCCH2PRBS` | `ltePUCCH3` | `ltePUCCH3Decode` | `ltePUCCH3DRS` | `ltePUCCH3DRSIndices` | `ltePUCCH3Indices`

Introduced in R2014a

ltePUSCH

Physical uplink shared channel

Syntax

```
sym=ltePUSCH(ue,chs,cws)
```

Description

`sym=ltePUSCH(ue,chs,cws)` returns a vector containing the Physical Uplink Shared Channel (PUSCH) complex symbols for UE-specific settings, `ue`, PUSCH channel-specific configuration, `chs`, and the codeword or codewords contained in `cws`. The size of the matrix `sym` is *N*-by-*P*. Where *N* is the number of modulation symbols for one antenna port and *P* is the number of transmission antennas.

Examples

Create PUSCH Complex Symbols

Generate PUSCH symbols for TS36.104 Uplink FRC A3-3 with 3MHz bandwidth.

Initialize UE specific (`ue`) and channel (`pusch`) configuration structures, and fixed reference channel (`frc`).

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.RNTI = 1;

pusch.Modulation = 'QPSK';
pusch.PRBSet = [0:14].';
pusch.RV = 0;

frc = lteRMCUL('A3-3');
```

Generate transport block (`trBlk`), UL-SCH codewords (`cw`), and PUSCH symbols (`puschSym`).

```
trBlk  = randi([0,1],frc.PUSCH.TrBlkSizes(1),1);
```

```
cw = lteULSCH(ue,pusch,trBlk );
puschSym = ltePUSCH(ue,pusch,cw);
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
NCellID	Required	Nonnegative integer	Physical layer cell identity
NSubframe	Required	Integer	Subframe number
RNTI	Required	Integer	Radio network temporary identifier (RNTI) value (16 bits)
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.

Data Types: `struct`

chs — PUSCH channel-specific configuration

structure

PUSCH channel-specific configuration, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
Modulatio	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`	Modulation format, specified as a character vector for one codeword or a cell array of one or more vectors for one or two codewords.
PRBSet	Required	Integer column vector or two-column matrix	Physical Resource Block (PRB) indices, specified as a column vector or two-column matrix, corresponding to the slot wise

Parameter Field	Required or Optional	Values	Description
			resource allocations for this PUSCH. If a column vector is provided for `PRBSet`, the resource allocation is the same in both slots of the subframe. The two-column matrix can be used to specify differing PRBs for each slot in a subframe. The PRB indices are zero-based.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.
The following field is required only when `ue.NTxAnts` is set to 2 or 4. Acceptable values for `PMI` depend upon `ue.NTxAnts` and `NLayers`.			
`PMI`	Optional	Numeric scalar (0...23) 0 (default)	Scalar precoder matrix indication (PMI) to be used during precoding

Data Types: `struct`

cws — Codeword bit values

vector | cell array

Codeword bit values to be modulated, specified as a vector of bit values for one codeword, or a cell array containing one or two vectors of bit values corresponding to the one or two codewords.

Data Types: `double`

Output Arguments

sym — PUSCH symbols

complex-valued numeric matrix

PUSCH symbols, returned as a complex-valued numeric matrix of size *N*-by-*P*. *N* is the number of modulation symbols for one antenna port. *P* is the number of transmission antennas.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCHDecode` | `ltePUSCHDRS` | `ltePUSCHDRSIndices` | `ltePUSCHIndices` | `ltePUSCHPrecode` | `lteULPMIInfo` | `lteULPrecode` | `lteULSCH` | `lteULScramble`

Introduced in R2013b

ltePUSCHDecode

Physical uplink shared channel decoding

Syntax

```
[cws,symbols] = ltePUSCHDecode(ue,chs,sym)
[cws,symbols] = ltePUSCHDecode(ue,chs,sym,hest,noiseest)
[cws,symbols] = ltePUSCHDecode(ue,chs,sym,hest,noiseest,alg)
```

Description

`[cws,symbols] = ltePUSCHDecode(ue,chs,sym)` returns a soft bit vector, or cell array of soft bit vectors, `cws`, containing the received codeword estimates and received constellation of complex symbol vector, `symbols`. The output results from decoding of the Physical Uplink Shared Channel (PUSCH) complex symbols, `sym`, for UE-specific settings, `ue`, and channel transmission configuration structure or structure array, `chs`. It performs the inverse of the Physical Uplink Shared Channel (PUSCH) processing. See TS 36.211, Section 5.3 [1] or `ltePUSCH` for details.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. For details, see “UL-SCH Parameterization” .

If UCI control information, such as RI or HARQ-ACK, is present in the received complex PUSCH symbols, then this function performs the descrambling of the placeholder bits by establishing the correct locations with the help of the UCI-related parameters present in `chs`.

`sym` is an *M*-by-*P* matrix or *M*-by-*NU* matrix. Where *M* is the number of symbols per antenna or layer, *P* is the number of transmission antennas, `NTxAnts`, and *NU* is the number of transmission layers, `NLayers`.

- For a single-antenna transmission (`NTxAnts = 1`), both *P* and *NU* are 1: `sym` must be *M*-by-1 and contain the single-antenna PUSCH symbols for decoding.

- When *P* is greater than 1 and `sym` is *M*-by-*P*: Decoding is performed using pseudoinverse-based deprecoding for spatial multiplexing.
- When *P* is greater than 1 and `sym` is *M*-by-*NU*: `sym` is assumed to be deprecoded, so.decoding is performed without deprecoding. For example, by having performed channel estimation against the transmit layer DRS sequences and equalizing the received symbols using that channel estimate to yield `sym`.

Note: This function does apply deprecoding. when the need for deprecoding is ambiguous, such as when *P*>1 and *P*=*NU*.

`[cws,symbols] = ltePUSCHDecode(ue,chs,sym,hest,noiseest)` uses additional inputs (`hest`,`noiseest`). The channel estimate, `hest`, and the noise estimate `noiseest`. In this case, `sym` is an *M*-by-`NRxAnts` matrix, where *M* is the number of symbols per antenna and `NRxAnts` is the number of receive antennas. When `ue.NTxAnts` is greater than 1, the reception is performed using an MMSE equalizer, equalizing between transmitted and received layers. When `ue.NTxAnts` is 1, the reception is performed using MMSE equalization on the received antennas.

`[cws,symbols] = ltePUSCHDecode(ue,chs,sym,hest,noiseest,alg)` provides control over weighting the output soft bits with Channel State Information (CSI) calculated during the equalization stage using algorithmic configuration structure, `alg`.

Examples

Decode PUSCH Symbols from FRC

Decode the PUSCH modulation symbols contained in the output of a Fixed Reference Channel (FRC).

```
frc = lteRMCUL('A3-2');
trData = randi([0,1],frc.PUSCH.TrBlkSizes(1),1);
[waveform,reGrid] = lteRMCULTool(frc,trData);
puschIndices = ltePUSCHIndices(frc,frc.PUSCH);
```

```
rxCw = ltePUSCHDecode(frc,frc.PUSCH,reGrid(puschIndices));
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
NCellID	Required	Integer	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
RNTI	Required	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
CyclicPre	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length.
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.
Shortened	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

chs — Channel transmission configuration

scalar structure | structure array

Channel transmission configuration, specified as a scalar structure or a structure array. `chs` is the PUSCH channel-specific structure having these fields. If `UCI` is present in the

transmitted PUSCH to be decoded, the optional fields, `ORI`, `OACK`, `QdRI`, and `QdACK`,must be configured in the `chs` structure.

Parameter Field	Required or Optional	Values	Description
`Modulatio`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`	Modulation format
`PRBSet`	Required	Integer column vector or two-column matrix	Physical Resource Block (PRB) indices, specified as a column vector or two-column matrix, corresponding to the slot wise resource allocations for this PUSCH. If a column vector is provided for `PRBSet`, the resource allocation is the same in both slots of the subframe. The two-column matrix can be used to specify differing PRBs for each slot in a subframe. The PRB indices are zero-based.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.
The following field is required only when `ue.NTxAnts` is set to 2 or 4. Acceptable values for `PMI` depend upon `ue.NTxAnts` and `NLayers`.			
`PMI`	Optional	Numeric scalar (0...23) 0 (default)	Scalar precoder matrix indication (PMI) to be used during precoding
`ORI`	Optional	Integer 0 (default)	Number of uncoded RI bits
`OACK`	Optional	nonnegative scalar integer, 0 (default)	Number of uncoded HARQ-ACK bits.
`QdRI`	Optional	Integer 0 (default)	Number of coded RI symbols in UL-SCH, specified as an integer. Optional. (*Q'_RI*)

Parameter Field	Required or Optional	Values	Description
`QdACK`	Optional	nonnegative scalar integer 0 (default)	Number of coded HARQ-ACK symbols in UL-SCH (*Q'_ACK*), specified as an integer. Optional.

Data Types: `struct`

`sym` — PUSCH symbols

complex-valued numeric matrix

PUSCH symbols, specified as a complex-valued numeric matrix of size *M*-by-*P* or *M*-by-*NU*. Where *M* is the number of symbols per antenna or layer, *P* is the number of transmission antennas, `NTxAnts`, and *NU* is the number of transmission layers, `NLayers`.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array

Channel estimate, specified as a 3-D numeric array of size *M*-by-`NRxAnts`-by-`NTxAnts`. Where *M* is the number of symbols per antenna, `NRxAnts` is the number of receive antennas, and `NTxAnts` is the number of transmit antennas ports, given by `ue.NTxAnts`.

Data Types: `double`

`noiseest` — Noise estimate

numeric scalar

Noise estimate, specified as a numeric scalar. This argument is an estimate of the noise power spectral density per RE on received subframe. The `lteULChannelEstimate` function provides such an estimate.

Data Types: `double`

`alg` — Algorithmic configuration

structure

Algorithmic configuration, specified as a structure having the following field.

Parameter Field	Required or Optional	Values	Description
`CSI`	Optional	`'On'` (default), `'Off'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.

Data Types: `struct`

Output Arguments

`cws` — Codewords

column vector | cell array of column vectors

Codewords, returned as a column vector or a cell array of column vectors. The soft bit vectors contain the received codeword estimates.

Data Types: `double`

`symbols` — Received constellation of symbols

complex-valued column vector

Received constellation of symbols, received as a complex-valued column vector.

Data Types: `double`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCH` | `ltePUSCHDeprecode` | `ltePUSCHDRS` | `ltePUSCHDRSIndices` | `ltePUSCHIndices` | `lteULDeprecode` | `lteULDescramble` | `lteULPMIInfo` | `lteULSCHDecode`

Introduced in R2013b

ltePUSCHDeprecode

PUSCH MIMO deprecoding onto transmission layers

Syntax

```
out = ltePUSCHDeprecode(in,nu,codebook)
out = ltePUSCHDeprecode(chs,in)
```

Description

`out = ltePUSCHDeprecode(in,nu,codebook)` deprecodes the precoded symbol matrix, `in`, onto `nu` layers. It performs deprecoding using matrix pseudo inversion, to undo the processing described in TS 36.211, Section 5.3.3A [1]. This function returns an *M*-by-`nu` matrix, `out`, containing `nu` layers with *M* symbols in each layer. The deprecoder transposes the operation defined in TS 36.211, Section 5.3.3A, specifically the symbols for layers and antennas lie in columns rather than rows. The input argument `in` is an *N*-by-*P* matrix, where *P* is the number of transmission antennas and *N* is the number of symbols per antenna. When *P* is 2 or 4, deprecoding for spatial multiplexing is applied with the scalar codebook index, `codebook`. TS 36.211, Section 5.3.3A [1] specifies the codebook matrix corresponding to a particular index.

`out = ltePUSCHDeprecode(chs,in)` deprecodes the precoded symbol matrix, `in`, according to channel transmission configuration, `chs`.

Examples

Deprecode PUSCH Symbols

By precoding with an identity matrix, we can gain access to the precoding matrices themselves. The precoded matrix is first generated with codebook index 0 for 4 layers and 4 antennas. The precoded matrix is then deprecoded, resulting in an identity matrix.

```
nLayers = 4;
nAntennas = 4;
codeBookIdx = 0;
precodingMatrix = ltePUSCHPrecode(eye(nLayers),nAntennas,codeBookIdx);
out = ltePUSCHDeprecode(precodingMatrix,nLayers,codeBookIdx)
```

```
out =

   1.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i
   0.0000 + 0.0000i   1.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i   1.0000 + 0.0000i   0.0000 + 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   1.0000 + 0.0000i
```

Input Arguments

`in` — Precoded symbol input

complex-valued numeric matrix

Precoded symbol input, specified as an *N*-by-*P* complex-valued numeric matrix. Where *P* is the number of transmission antennas and *N* is the number of symbols per antenna.

Example: `[0.5000 + 0.0000i 0.5000 + 0.0000i; 0.5000 + 0.0000i -0.5000 + 0.0000i]`

Data Types: `double`
Complex Number Support: Yes

`nu` — Number of layers

1 | 2 | 3 | 4

Number of layers, specified as 1, 2, 3, or 4.

Example: 2

Data Types: `double`

`codebook` — Codebook index

numeric scalar

Codebook index, specified as a numeric scalar. When the number of transmit antennas, *P*, is 1, this input argument is ignored.

Data Types: `double`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure having the following fields.

`NLayers` — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, specified as an integer from 1 through 4. Optional.

Data Types: `double`

`PMI` — Precoder matrix indication

0 (default) | optional | numeric scalar (0...23)

Precoder matrix indication, specified as a numeric scalar between 0 (default) and 23. Only required if the number of transmission antennas, *P*, is 2 or 4. Acceptable values for `PMI` depend upon *P* and the number of transmission layers, `NLayers`. The scalar PMI is used during deprecoding.

Data Types: `double`

Data Types: `struct`

Output Arguments

`out` — Deprecoded output

numeric matrix

Deprecoded output, returned as an *M*-by-`nu` matrix, containing `nu` layers with *M* symbols in each layer.

Data Types: `double`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCH` | `ltePUSCHDecode` | `ltePUSCHDRS` | `ltePUSCHDRSIndices` | `ltePUSCHIndices` | `ltePUSCHPrecode` | `lteULDeprecode` | `lteULPMIInfo`

Introduced in R2013b

ltePUSCHDRS

PUSCH demodulation reference signal

Syntax

```
[antseq,info,layerseq] = ltePUSCHDRS(ue,chs)
```

Description

`[antseq,info,layerseq] = ltePUSCHDRS(ue,chs)` returns the physical uplink shared channel (PUSCH) transmission demodulation reference signal (DM-RS) antenna sequence values,`antseq`, the layer sequence values, `layerseq`, and the information structure, `info`, given input structures containing UE-specific settings, and the channel transmission configuration settings.

When the number of transmission antennas is greater than one, the DM-RS is precoded using spatial multiplexing.

For short base reference sequences, such as those used with PUSCH allocations of 1 or 2 PRBs, and when `chs.PRBSet` is empty, Zadoff-Chu sequences are not used. In this case, `RootSeq` and `NZC` are set to –1. If `antseq` is empty, such as when the input `PRBSet` is empty, the `info` structure contains all fields, but each field is either empty for vector fields or –1 for scalar fields.

Examples

Generate PUSCH DM-RS

Generate the PUSCH Demodulation Reference Signal (DM-RS) values for UE-specific settings.

Initialize UE specific (`ue`) and channel (`chs`) configuration structures. Generate PUSCH DM-RS values.

```
ue.NCellID = 1;
ue.NSubframe = 0;
ue.CyclicPrefixUL = 'Normal';
ue.Hopping = 'Off';
```

```
ue.SeqGroup = 0;
ue.CyclicShift = 0;
ue.NTxAnts = 1;

chs.PRBSet = (0:5).';
chs.NLayers = 1;
chs.OrthCover = 'Off';
chs.DynCyclicShift = 0;

puschSeq = ltePUSCHDRS(ue,chs);
puschSeq(1:10)


ans =

   1.0000 + 0.0000i
  -0.0810 + 0.9967i
  -0.9610 + 0.2766i
  -0.8839 - 0.4677i
  -0.6886 - 0.7251i
  -0.7692 - 0.6390i
  -0.9912 - 0.1324i
  -0.6447 + 0.7645i
   0.6779 + 0.7352i
   0.4872 - 0.8733i
```

Generate PUSCH DM-RS Using Alternate IDs

Demonstrate Uplink Release 11 coordinated multipoint (CoMP) operation. To avoid intercell interference, use a virtual cell identity (NPUSCHID) and a distinct DM-RS cyclic shift hopping identity (NDMRSID) for a potentially interfering UE in a neighboring cell.

Configure the UE of interest: UE 1 in cell 1.

```
ue1.NCellID = 1;
ue1.NSubframe = 0;
ue1.CyclicPrefixUL = 'Normal';
ue1.NTxAnts = 1;
ue1.Hopping = 'Off';
ue1.SeqGroup = 0;
ue1.CyclicShift = 0;

chs1.PRBSet = (0:5).';
```

```
chs1.NLayers = 1;
chs1.DynCyclicShift = 0;
chs1.OrthCover = 'Off';
```

Configure the interferer: UE 2 in cell 2.

```
ue2.NCellID = 2;
ue2.NSubframe = 0;
ue2.CyclicPrefixUL = 'Normal';
ue2.NTxAnts = 1;
ue2.Hopping = 'Off';
ue2.SeqGroup = 0;
ue2.CyclicShift = 0;

chs2.PRBSet = (0:5).';
chs2.NLayers = 1;
chs2.DynCyclicShift = 0;
chs2.OrthCover = 'Off';
```

Measure the interference between the DM-RS signals.

```
interferenceNoCoMP = ...
    abs(sum(ltePUSCHDRS(ue1,chs1).*conj(ltePUSCHDRS(ue2,chs2))));
```

Reconfigure for CoMP operation. Use a virtual cell identity equal to the cell identity for the UE of interest. Configure the two UEs with different cyclic shift hopping patterns using the DM-RS identity parameter.

```
ue1.NDMRSID = 1;
ue2.NPUSCHID = ue1.NCellID;
ue2.NDMRSID = 2;
```

Measure the interference between the DM-RS signals when using CoMP.

```
interferenceUsingCoMP = ...
    abs(sum(ltePUSCHDRS(ue1,chs1).*conj(ltePUSCHDRS(ue2,chs2))));
```

Compare the correlations between the DM-RS signals for the two UEs with and without CoMP, `interferenceUsingCoMP` and `interferenceNoCoMP`, respectively.

```
interferenceUsingCoMP
interferenceNoCoMP


interferenceUsingCoMP =
```

```
    1.0313e-13

interferenceNoCoMP =

    21.3188
```

With CoMP, the interference is reduced to effectively zero.

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure. `ue` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Nonnegative integer	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPre`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length for uplink.
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`, or `'Sequence'`	Frequency hopping method.
`SeqGroup`	Optional	0 (default), integer from 0 to 29	PUSCH sequence group assignment (Δ_{SS}). Used only if `NDMRSID` or `NPUSCHID` is absent.
`CyclicShi`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for PUSCH DM-RS (yields $n_{DMRS}^{(1)}$).

Parameter Field	Required or Optional	Values	Description
NPUSCHID	Optional	0 (default), nonnegative scalar integer from 0 to 509	PUSCH virtual cell identity. If this field is not present, `NCellID` is used for group hopping sequence-shift pattern initialization. See Note 1.
NDMRSID	Optional	0 (default), nonnegative scalar integer from 0 to 509	DM-RS identity for cyclic shift hopping ($n_{\mathrm{ID}}^{\mathrm{csh\_DMRS}}$). If this field is not present, `NCellID` is used for cyclic shift hopping initialization. See Note 1.
Note: **1** The pseudorandom sequence generator for cyclic shift hopping is initialized according to `NDMRSID`, if present — otherwise it is initialized according to the cell identity `NCellID` and the sequence group assignment `SeqGroup`. Similarly, the sequence-shift pattern for group hopping is initialized according to `NPUSCHID`, if present — otherwise it is initialized according to `NCellID` and `SeqGroup`.			

Data Types: `struct`

chs — Channel transmission configuration

structure

PUSCH channel configuration, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
PRBSet	Required	Integer column vector or two-column matrix	Physical resource block set, specified as an integer column vector or two-column matrix. This parameter field contains the zero-based physical resource block (PRB) indices corresponding to the slot-wise resource allocations for this PUSCH.

Parameter Field	Required or Optional	Values	Description
			If `PRBSet` is a column vector, the resource allocation is the same in both slots of the subframe. To specify differing PRBs for each slot in a subframe, use a two-column matrix. The PRB indices are zero-based.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.
`DynCyclicSh`	Optional	0 (default), integer from 0 to 7	Cyclic shift for DM-RS (yields $n_{\mathrm{DMRS}}^{(2)}$).
`OrthoCover`	Optional	`'Off'` (default), `'On'`	Applies (`'On'`), or does not apply (`'Off'`), orthogonal cover sequence w (*Activate-DMRS-with OCC*).
The following field is applicable only when `ue.NTxAnts` is set to `2` or `4`.			
`PMI`	Optional	0 (default), integer from 0 to 23	Scalar precoder matrix indication (PMI) used during precoding of the DM-RS reference symbols.

Data Types: `struct`

Output Arguments

`antseq` — PUSCH DM-RS sequence

M-by-*P* matrix

PUSCH DM-RS sequence values, returned as an *M*-by-*P* complex-valued matrix. *M* is the number of DM-RS symbols per antenna, and *P* is the number of transmission antennas. When *P* is greater than one, the DM-RS is precoded using spatial multiplexing.

Data Types: `double`
Complex Number Support: Yes

`info` — Information about PUSCH DM-RS

structure array

Information about PUSCH DM-RS, returned as a structure array, with one element per transmission layer, having the following fields.

`Alpha` — Reference signal cyclic shift

row vector

Reference signal cyclic shift for each slot, returned as a row vector. (α)

`Alpha` is proportional to `NCS`, $\alpha = \frac{2\pi n_{cs,\lambda}}{12}$.

Data Types: `double`

`SeqGroup` — Base sequence group number

row vector

Base sequence group number for each slot, returned as a row vector. (u)

Data Types: `double`

`SeqIdx` — Base sequence number

row vector

Base sequence number for each slot, returned as a row vector. (v)

Data Types: `double`

`RootSeq` — Root Zadoff-Chu sequence index

row vector

Root Zadoff-Chu sequence index for each slot, returned as a row vector. (q)

Data Types: `double`

`NCS` — Cyclic shift values for each slot

two-column vector

Cyclic shift values for each slot, returned as a two-column vector ($n_{\mathrm{cs},\lambda}$).

Data Types: `double`

`NZC` — Zadoff-Chu sequence length

integer

Zadoff-Chu sequence length, returned as an integer. ($N_{\mathrm{ZC}}^{\mathrm{RS}}$)

Data Types: `double`

`N1DMRS` — Component of reference signal cyclic shift
integer

Component of the reference signal cyclic shift signaled from higher layers, returned as an integer. ($n_{\mathrm{DMRS}}^{(1)}$)

Data Types: `double`

`N2DMRS` — Component of the reference signal cyclic shift
integer

Component of the reference signal cyclic shift signaled from the most recent DCI format 0 message, returned as an integer. ($n_{\mathrm{DMRS}}^{(2)}$)

Data Types: `double`

`NPRS` — Cell-specific component of reference signal cyclic shift
row vector

Cell-specific component of the reference signal cyclic shift for each slot, returned as a row vector. (n_{PRS} in LTE Release 8 and 9, n_{PN} in LTE Release 10 and beyond)

Data Types: `double`

`OrthSeq` — Orthogonal cover value
row vector

Orthogonal cover value for each slot, specified as a row vector. (w)

Data Types: `double`

Data Types: `struct`

`layerseq` — PUSCH DM-RS sequence by layers
M-by-*NU* matrix

PUSCH DM-RS sequence by layers, returned as an *M*-by-*NU* complex matrix. *M* is the number of DM-RS symbols per layer, and *NU* is the number of transmission layers. If the number of transmission antennas is greater than one, the DM-RS is precoded using spatial multiplexing.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`ltePUSCH` | `ltePUSCHDecode` | `ltePUSCHDeprecode` | `ltePUSCHDRSIndices` | `ltePUSCHIndices` | `ltePUSCHPrecode` | `lteULPMIInfo`

Introduced in R2013b

ltePUSCHDRSIndices

PUSCH DM-RS resource element indices

Syntax

```
ind = ltePUSCHDRSIndices(ue,chs)
ind = ltePUSCHDRSIndices(ue,chs,opts)
```

Description

`ind = ltePUSCHDRSIndices(ue,chs)` returns a matrix of resource element (RE) indices for the demodulation reference signal (DM-RS) associated with the physical uplink shared channel (PUSCH) transmission, given structures containing the UE-specific settings and the channel transmission configuration settings.

If indices for a number of layers, *NU*, are required, rather than indices for `NTxAnts`, the first *NU* columns of the output can be used. The first *NU* columns of `ind` are the appropriate indices for the `layerseq` output from the `ltePUSCHDRS` function.

`ind = ltePUSCHDRSIndices(ue,chs,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PUSCH DM-RS RE Indices

Generate PUSCH DM-RS resource element indices for the uplink reference measurement channel A3-1.

```
ue = lteRMCUL('A3-1');
puschInd = ltePUSCHDRSIndices(ue,ue.PUSCH);
puschInd(1:4)


ans =
```

```
  4×1 uint32 column vector

   217
   218
   219
   220
```

Generate PUSCH DM-RS RE Indices Varying Output Format

Generate the zero-based PUSCH DM-RS indices for the uplink reference measurement channel A3-3.

```
ue = lteRMCUL('A3-3');
puschInd = ltePUSCHDRSIndices(ue,ue.PUSCH,{'0based','ind'});
puschInd(1:4)
```

```
ans =

  4×1 uint32 column vector

   540
   541
   542
   543
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure having the following fields.

NULRB — Number of uplink resource blocks

integer

Number of uplink resource blocks, specified as an integer.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length for uplink

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length for uplink (UL), specified as either `'Normal'` or `'Extended'`.

Data Types: `char`

`NTxAnts` — Number of transmission antennas

1 (default) | 2 | 4 | optional

Number of transmission antennas, specified as 1, 2, or 4.

Data Types: `double`

Data Types: `struct`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure having the following fields.

`PRBSet` — Physical resource block indices

column vector | two-column matrix

Physical resource block (PRB) indices, specified as a column integer vector or two-column integer matrix. The PRB indices correspond to the slot-wise resource allocations for this PUSCH.

- When specified as a column vector, the resource allocation is the same in both slots of the subframe.
- When specified as a two-column matrix, the resource allocations can vary for each slot in the subframe.

The PRB indices are zero-based.

Data Types: `double`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — PUSCH DM-RS resource element indices

integer matrix

PUSCH DM-RS resource element indices, returned as an N_{SC}-by-N_{TX} integer matrix. N_{SC} is the number of DM-RS indices per antenna, and N_{TX} is the number of transmission antennas. The resource element (RE) indices for the demodulation reference signal (DM-RS) are associated with PUSCH transmission. By default, the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to the PUSCH DM-RS modulation symbol mapping specified in TS 36.211 [1], Section 5.5.2. The `opts` input offers alternative indexing formats.

Data Types: `uint32`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCH` | `ltePUSCHDecode` | `ltePUSCHDeprecode` | `ltePUSCHDRS` | `ltePUSCHIndices` | `ltePUSCHPrecode`

Introduced in R2014a

ltePUSCHIndices

PUSCH resource element indices

Syntax

```
[ind,info] = ltePUSCHIndices(ue,chs)
[ind,info] = ltePUSCHIndices(ue,chs,opts)
```

Description

`[ind,info] = ltePUSCHIndices(ue,chs)` returns a column vector of resource element indices given the UE-specific settings structure, `ue`, and channel transmission configuration, `chs`. It returns a column vector of Physical Uplink Shared Channel (PUSCH) resource element (RE) indices and a structure, `info`, containing information related to the PUSCH indices. By default, the indices are returned in 1-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered as the PUSCH modulation symbols should be mapped. Alternative indexing formats can also be generated.

Support of PUSCH frequency hopping is provided by the function `lteDCIResourceAllocation`, which creates `PRBSet` from a DCI Format 0 message.

`[ind,info] = ltePUSCHIndices(ue,chs,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate PUSCH RE Indices

Generate 0-based PUSCH resource element (RE) indices in linear form.

```
frc = lteRMCUL('A1-1');
puschIndices = ltePUSCHIndices(frc,frc.PUSCH,{'Obased','ind'});
puschIndices(1:4)
```

```
ans =

  4×1 uint32 column vector

   0
   1
   2
   3
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure having the following fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
CyclicPre	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length.
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.
Shortened	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

Data Types: `struct`

chs — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure. It contains the following fields.

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	PRB indices, specified as a column vector or a 2-column matrix, containing the Physical Resource Block indices (PRBs) corresponding to the resource allocations for this PUSCH.
`Modulatio`	Optional	`'QPSK'`, `'16QAM'`, `'64QAM'`, or a cell array of these character vectors	Modulation format, specified as a character vector for one codeword or a cell array of one or more vectors for one or two codewords.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — PUSCH resource element indices

column vector of integers

PUSCH resource element (RE) indices, returned as column vector of integers.

Data Types: `uint32`

`info` — Information related to PUSCH indices

structure

Information related to the PUSCH indices, returned as a structure having the following fields.

Parameter Field	Values	Description
`G`	1- or 2-element vector of integers	A one- or two-element vector, specifying the number of coded and rate matched UL-SCH data bits for each codeword
`Gd`	Integer	Number of coded and rate matched UL-SCH data symbols, equal to the number of rows in the PUSCH indices

Data Types: `struct`

See Also

See Also

`lteDCIResourceAllocation` | `ltePUSCH` | `ltePUSCHDecode` | `ltePUSCHDeprecode` | `ltePUSCHDRS` | `ltePUSCHDRSIndices` | `ltePUSCHPrecode`

Introduced in R2014a

ltePUSCHPrecode

PUSCH MIMO precoding of transmission layers

Syntax

```
out = ltePUSCHPrecode(in,p,codebook)
out = ltePUSCHPrecode(ue,chs,in)
```

Description

`out = ltePUSCHPrecode(in,p,codebook)` precodes the matrix of layers, `in`, onto `p` antennas. When `p` is 2 or 4, precoding for spatial multiplexing is applied with the scalar codebook index, `codebook`. It performs precoding according to TS 36.211, Section 5.3.3A [1]. This function returns an *M*-by-*P* matrix. Where *M* is the number of symbols per antenna and *P* is the number of transmission antennas. The precoder transposes the operation defined in TS 36.211, Section 5.3.3A, specifically the symbols for layers and antennas lie in columns rather than rows.

`out = ltePUSCHPrecode(ue,chs,in)` precodes the matrix of layers, `in`, according to UE-specific settings, `ue`, and channel transmission configuration, `chs`.

Examples

Perform PUSCH MIMO Precoding

Generate a PUSCH precoding matrix with codebook index 1 for 3 layers and 4 antennas. By precoding an identity matrix, we can gain access to the precoding matrices themselves.

```
nLayers = 3;
nAntennas = 4;
codeBookIdx = 1;
out = ltePUSCHPrecode(eye(nLayers),nAntennas,codeBookIdx)
```

```
out =

   0.5000 + 0.0000i  -0.5000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i   0.5000 + 0.0000i   0.0000 + 0.0000i
   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.5000 + 0.0000i
```

Input Arguments

`in` — Transmission input layers

numeric matrix

Transmission input layers, specified as a numeric matrix of size *N*-by-*NU*. `in` consists of the *N* modulation symbols for transmission upon *NU* layers. The `lteLayerMap` function generates such a matirx.

Example: [1 0 0; 0 1 0; 0 0 1]

Data Types: `double`
Complex Number Support: Yes

`p` — Number of transmission antennas

1 | 2 | 4

Number of transmission antennas, specified as an integer having the values 1, 2, or 4.

Example: 1

Data Types: `double`

`codebook` — Codebook index

scalar integer

`codebook` is a scalar integer specifying the codebook index to be used during precoding. This input is ignored when `p` is 1. The codebook matrix corresponding to a particular index can be found in TS 36.211, Section 5.3.3A [1].

Data Types: `double`

`ue` — UE-specific settings

structure

UE-specific settings, specified as a structure having the following fields.

`NTxAnts` — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as 1, 2, or 4. Optional.

Data Types: `double`

Data Types: `struct`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified a structure. `chs` can contain the following field. The `PMI` parameter field is only required if `ue.NTxAnts` is set to 2 or 4.

`PMI` — Precoder matrix indication

0 (default) | optional | numeric scalar (0...23)

Precoder matrix indication, specified as a numeric scalar between 0 (default) and 23. Only required if `ue.NTxAnts` is set to 2 or 4. Acceptable values for `PMI` depend upon `ue.NTxAnts` and the number of layers, *NU*. The scalar PMI is used during precoding.

Data Types: `double`

Data Types: `struct`

Output Arguments

`out` — Precoded output symbols

M-by-*P* numeric matrix

Precoded output symbols, returned as a numeric matrix of size *M*-by-*P*. Where *M* is the number of symbols per antenna and *P* is the number of transmission antennas.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCH` | `ltePUSCHDecode` | `ltePUSCHDeprecode` | `ltePUSCHDRS` | `ltePUSCHDRSIndices` | `ltePUSCHIndices` | `lteULPMIInfo` | `lteULPrecode`

Introduced in R2013b

lteRIDecode

Rank indication channel decoding

Syntax

```
out = lteRIDecode(chs,in)
```

Description

`out = lteRIDecode(chs,in)` performs the block decoding on soft input data, `in`. The input is assumed to be encoded using the procedure defined for RI in TS 36.212 [1], Section 5.2.2.6 for given channel transmission configuration, `chs`. The function returns the decoded output, `out`, as a vector of length `ORI`, the number of uncoded RI bits transmitted.

The block decoding will be performed separately on each soft input data using a maximum likelihood (ML) approach, assuming that `in` has been demodulated and equalized to best restore the originally transmitted values.

The RI decoder performs different type of block decoding depending upon the number of uncoded RI bits to be recovered. For `ORI` less than 3 bits, the decoder assumed the bits are encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6. For decoding 3 to 11 RI bits, the decoder assumes the bits are block encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6.4. For decoding greater than 11 bits, the decoder performs the inverse procedure described in TS 36.212 [1], Section 5.2.2.6.5.

Examples

Decode RI Bits for 64QAM

Decode coded rank indication (RI) soft input bits for a 64QAM channel transmission configuration.

Generate rank indication bits and initialize the channel transmission configuration structure. Encode logical RI bits and turn logical bits into 'LLR' data. Decode the RI bits.

```
ri = [1;0;1];
chs.Modulation = '64QAM';
chs.QdRI = 1;
chs.ORI = length(ri);
chs.NLayers = 1;

codedRI = lteRIEncode(chs,ri);
codedRI(codedRI == 0) = -1
```

```
codedRI =

  6×1 int8 column vector

    1
   -1
    1
   -1
   -1
    1
```

```
decRI = lteRIDecode(chs,codedRI)
```

```
decRI =

  3×1 logical array

   1
   0
   1
```

Input Arguments

chs — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure. Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field

values apply to both codewords and a scalar `NLayers` is the total number. See "UL-SCH Parameterization" for further details.

`Modulation` — Modulation format

`'QPSK'` | `'16QAM'` | `'64QAM'` | cell array of character vectors

Modulation scheme type, specified as a character vector or cell array of character vectors. If there are two blocks and you provide a cell array with two character vectors, each character vector is associated with a transport block.

Data Types: `char` | `cell`

`ORI` — Number of uncoded RI bits

0 (default) | optional | nonnegative integer

Number of uncoded RI bits, specified as a nonnegative integer. The RI decoder performs different type of block decoding depending upon the number of uncoded RI bits to be recovered.

For `ORI` less than 3 bits, the decoder assumed the bits are encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6.

For decoding 3 to 11 RI bits, the decoder assumes the bits are block encoded using the procedure defined in TS 36.212 [1], Section 5.2.2.6.4. For decoding greater than 11 bits, the decoder performs the inverse procedure described in TS 36.212 [1], Section 5.2.2.6.5.

Data Types: `double`

`NLayers` — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, specified as 1, 2, 3, or 4.

Data Types: `double`

Data Types: `struct`

`in` — RI input bits

numeric vector | cell array of numeric vectors

RI input bits, specified as a numeric vector or a cell array of numeric vectors. The block decoding will be performed separately on each soft input data using a maximum likelihood (ML) approach assuming that `in` has been demodulated and equalized to best restore the originally transmitted values.

Data Types: `double` | `cell`

Output Arguments

`out` — Decoded output

logical column vector

Decoded output, returned as a logical column vector. The vector length is determined by the value of `ORI`.

Data Types: `logical`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteACKDecode` | `lteCQIDecode` | `lteRIEncode` | `lteULSCHDecode` | `lteULSCHDeinterleave`

Introduced in R2014a

lteRIEncode

Rank indication channel encoding

Syntax

```
out = lteRIEncode(chs,in)
```

Description

`out = lteRIEncode(chs,in)` returns the coded rank indication (RI) bits after performing block coding, as defined for RI in TS 36.212 [1], Section 5.2.2.6. `in` should be a vector or cell array containing up to 15 RI bits. `out` contains the encoded bits in the same form.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for further details.

Since the RI bits are carried on all defined codewords, a single input will result in a cell array of encoded outputs if multiple codewords are parameterized. This allows for easy integration with the other functions.

The RI coder performs different types of block coding depending upon the number of RI bits in vector `in`. If `in` consists of one element, it uses TS 36.212 [1], Table 5.2.2.6-3. If `in` consists of two elements, it uses TS 36.212 [1], Table 5.2.2.6-4 for encoding. The placeholder bits, x and y in the tables, are represented by –1 and –2, respectively.

Similarly, for 3 to 11 bits, the RI encoding is performed as per TS 36.212 [1], Section 5.2.2.6.4. For greater than 11 bits, the encoding is performed as described in TS 36.212 [1], Section 5.2.2.6.5.

Examples

Encode RI Bits for One Codeword

Generate the coded rank indication (RI) bits for a single codeword.

```
riBit = 0;
chs.Modulation = '64QAM';
chs.QdRI = 1;
chs.NLayers = 1;

codedRi = lteRIEncode(chs,riBit)
```

```
codedRi =

  6×1 int8 column vector

    0
   -2
   -1
   -1
   -1
   -1
```

Encode RI Bits for Two Codewords

Generate the coded rank indication (RI) bits for a two codewords on 3 layers.

```
riBit = 0;
chs.Modulation = {'64QAM' '64QAM'};
chs.QdRI = 1;
chs.NLayers = 3;

codedRi = lteRIEncode(chs,riBit)
codedRi{:}
```

```
codedRi =

  1×2 cell array

    [6×1 int8]    [12×1 int8]
```

```
ans =

  6×1 int8 column vector

    0
   -2
   -1
   -1
   -1
   -1


ans =

  12×1 int8 column vector

    0
   -2
   -1
   -1
   -1
   -1
    0
   -2
   -1
   -1
   -1
   -1
```

Input Arguments

chs — PUSCH-specific parameter structure

scalar structure | structure array

PUSCH-specific parameter structure, specified as a scalar structure or a structure array. `chs` contains the following fields.

QdRI — Number of coded RI symbols

nonnegative numeric scalar | nonnegative numeric vector

Number of coded RI symbols, specified as a nonnegative numeric scalar or vector (Q'_RI).

Data Types: `double`

`Modulation` — Modulation format

`'QPSK'` | `'16QAM'` | `'64QAM'` | cell array of character vectors

Modulation format, specified as a character vector or cell array of character vectors. If there are 2 blocks, each character vector in the cell array is associated with each transport block.

Data Types: `char` | `cell`

`NLayers` — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, specified as a positive numeric scalar. Optional.

Data Types: `double`

Data Types: `struct`

`in` — RI input bits

logical vector of length 1 to 15 | cell array of logical vectors

RI input bits, specified as a logical vector of length 1 to 15 or a cell array of logical vectors. Each vector can contain up to 15 RI bits apiece.

Data Types: `cell` | `double`

Output Arguments

`out` — Encoded output bits

integer column vector | cell array of integer column vectors

Encoded output bits, returned as a integer column vector or a cell array of integer column vectors, in same form as `in`. If the PUSCH-specific parameter structure `chs` defines multiple codewords, `out` is a cell array.

Data Types: `int8` | `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteACKEncode` | `lteCQIEncode` | `lteRIDecode` | `lteULSCH` | `lteULSCHInterleave`

Introduced in R2014a

lteRMCDL

Downlink reference measurement channel configuration

Syntax

```
rmccfgout = lteRMCDL(rc,duplexmode,totsubframes)
rmccfgout = lteRMCDL(rmccfg,ncodewords)
```

Description

`rmccfgout = lteRMCDL(rc,duplexmode,totsubframes)` returns a configuration structure for the reference channel defined by `rc`. This structure uses a channel-specific default configuration. The structure contains the configuration parameters required to generate a given reference channel waveform using the reference measurement channel (RMC) generator tool, `lteRMCDLTool`. The field names and default values comply with the definition found in TS 36.101 [1], Annex A.3.

`duplexmode` and `totsubframes` are optional input parameters that define the duplexing mode and total number of subframes to generate, respectively.

`rmccfgout = lteRMCDL(rmccfg,ncodewords)` returns a fully configured structure for the reference channel partially, or wholly, defined by the input structure, `rmccfg`. The number of PDSCH codewords to modulate can be specified by the optional input `ncodewords`.

Examples

Generate RMC Configuration Where Allocated Resource Blocks Vary Per SF

Create a configuration structure for reference measurement channel R.44 as specified in TS 36.101.

```
rc = 'R.44';

rmcOut = lteRMCDL(rc);
```

For this RMC, the size of the resource allocation varies per subframe. Evidence of this is seen by viewing the `PRBSet` and observing that the length of resource allocation vectors in the `PRBSet` cell array vary per subframe.

```
rmcOut.PDSCH.PRBSet
```

```
ans =

  1×10 cell array

  Columns 1 through 4

    [41×1 double]    [50×1 double]    [50×1 double]    [50×1 double]

  Columns 5 through 9

    [50×1 double]    []    [50×1 double]    [50×1 double]    [50×1 double]

  Column 10

    [50×1 double]
```

Generate RMC Configuration Where CFI Varies Per Subframe

Create a configuration structure for reference measurement channel R.0 in TDD mode as specified in TS 36.101. For this RMC and duplex mode combination, the value of CFI varies per subframe.

Set input arguments.

```
rc = 'R.0';
duplexmode = 'TDD';
```

Generate the configuration structure.

```
rmcOut = lteRMCDL(rc,duplexmode)
```

```
rmcOut =

  struct with fields:

                RC: 'R.0'
```

```
           NDLRB: 15
         CellRefP: 1
          NCellID: 0
      CyclicPrefix: 'Normal'
               CFI: [3 2 3 3 3 3 2 3 3 3]
       PCFICHPower: 0
                Ng: 'Sixth'
    PHICHDuration: 'Normal'
           HISet: [112×3 double]
      PHICHPower: 0
          NFrame: 0
       NSubframe: 0
     TotSubframes: 10
        Windowing: 0
       DuplexMode: 'TDD'
            PDSCH: [1×1 struct]
  OCNGPDCCHEnable: 'Off'
   OCNGPDCCHPower: 0
  OCNGPDSCHEnable: 'Off'
   OCNGPDSCHPower: 0
        OCNGPDSCH: [1×1 struct]
              SSC: 4
        TDDConfig: 1
```

In TDD mode, looking at the `rmcOut.CFI` vector, we see variation which corresponds to per subframe CFI value adjustment.

```
rmcOut.CFI
```

```
ans =

     3     2     3     3     3     3     2     3     3     3
```

Generate Downlink R.11 RMC Configuration

Create a configuration structure for reference measurement channel R.11 as specified in TS 36.101. View the contents of the configuration sturucture.

```
rmc.RC = 'R.11';
rmc.NCellID = 100;
rmc.PDSCH.TxScheme = 'SpatialMux';
rmcOut = lteRMCDL(rmc,2)
```

```
rmcOut =

  struct with fields:

                RC: 'R.11'
             NDLRB: 50
           CellRefP: 2
            NCellID: 100
       CyclicPrefix: 'Normal'
                CFI: 2
        PCFICHPower: 0
                 Ng: 'Sixth'
      PHICHDuration: 'Normal'
             HISet: [112×3 double]
         PHICHPower: 0
             NFrame: 0
          NSubframe: 0
       TotSubframes: 10
          Windowing: 0
         DuplexMode: 'FDD'
              PDSCH: [1×1 struct]
    OCNGPDCCHEnable: 'Off'
     OCNGPDCCHPower: 0
    OCNGPDSCHEnable: 'Off'
     OCNGPDSCHPower: 0
          OCNGPDSCH: [1×1 struct]
```

Display the contents of the PDSCH substructure.

```
rmcOut.PDSCH
```

```
ans =

  struct with fields:

           TxScheme: 'SpatialMux'
         Modulation: {'16QAM'  '16QAM'}
            NLayers: 2
                Rho: 0
               RNTI: 1
              RVSeq: [2×4 double]
                 RV: [0 0]
```

```
     NHARQProcesses: 8
       NTurboDecIts: 5
             PRBSet: [50×1 double]
     TargetCodeRate: 0.5000
     ActualCodeRate: [2×10 double]
         TrBlkSizes: [2×10 double]
    CodedTrBlkSizes: [2×10 double]
          DCIFormat: 'Format2'
        PDCCHFormat: 2
         PDCCHPower: 0
            CSIMode: 'PUSCH 3-1'
            PMIMode: 'Wideband'
             PMISet: 0
```

Display the contents of the OCNGPDSCH substructure.

```
rmcOut.OCNGPDSCH
```

```
ans =

  struct with fields:

          RNTI: 0
    Modulation: 'QPSK'
      TxScheme: 'TxDiversity'
```

Override Default Downlink R.13 RMC Configuration

Create a new customized parameter set by overriding selected values of an existing preset RMC. To define a single codeword full-band 10MHz PDSCH using 4 CRS port spatial multiplexing and 64QAM modulation, begin by initializing an RMC configuration structure to R.13. Looking at TS 36.101, Table A.3.1.1-1, see the RMC R.13 matches desired configuration except the default QPSK modulation must be adjusted.

Create an R.13 RMC configured structure and display `rmc.PDSCH`.

```
rmcOverride.RC = 'R.13';
rmc = lteRMCDL(rmcOverride,1);
rmc.PDSCH
```

```
ans =
```

```
  struct with fields:

          TxScheme: 'SpatialMux'
        Modulation: {'QPSK'}
           NLayers: 1
               Rho: 0
              RNTI: 1
             RVSeq: [0 1 2 3]
                RV: 0
    NHARQProcesses: 8
      NTurboDecIts: 5
            PRBSet: [50×1 double]
    TargetCodeRate: 0.3333
    ActualCodeRate: [1×10 double]
        TrBlkSizes: [3624 4392 4392 4392 4392 0 4392 4392 4392 4392]
   CodedTrBlkSizes: [12032 12800 12800 12800 12800 0 12800 12800 12800 12800]
         DCIFormat: 'Format2'
        PDCCHFormat: 2
         PDCCHPower: 0
            CSIMode: 'PUSCH 1-2'
            PMIMode: 'Wideband'
             PMISet: 0
```

Override the default modulation, execute `lteRMCDL`. Inspect `rmc.PDSCH`, PDSCH transport block sizes and physical channel capacities are updated to maintain the R=1/3 coding rate when the modulation is overridden.

```
rmcOverride.PDSCH.Modulation = '64QAM';
rmc = lteRMCDL(rmcOverride,1);
rmc.PDSCH
```

```
ans =

  struct with fields:

          TxScheme: 'SpatialMux'
        Modulation: {'64QAM'}
           NLayers: 1
               Rho: 0
              RNTI: 1
             RVSeq: [0 0 1 2]
                RV: 0
```

```
     NHARQProcesses: 8
       NTurboDecIts: 5
             PRBSet: [50×1 double]
     TargetCodeRate: 0.3333
     ActualCodeRate: [1×10 double]
         TrBlkSizes: [15264 15264 15264 15264 15264 0 15264 15264 15264 15264]
    CodedTrBlkSizes: [36096 38400 38400 38400 38400 0 38400 38400 38400 38400]
          DCIFormat: 'Format2'
        PDCCHFormat: 2
         PDCCHPower: 0
            CSIMode: 'PUSCH 1-2'
            PMIMode: 'Wideband'
             PMISet: 0
```

Note the RV sequence is also updated to reflect appropriate values for 64QAM modulation.

Input Arguments

`rc` — Reference measurement channel

`'R.0'` | `'R.1'` | `'R.2'` | `'R.3'` | `'R.4'` | `'R.5'` | `'R.6'` | `'R.7'` | `'R.8'` | `'R.9'` | `'R.10'` | `'R.11'` | `'R.12'` | `'R.13'` | `'R.14'` | `'R.25'` | `'R.26'` | `'R.27'` | `'R.28'` | `'R.31-3A'` | `'R.31-4'` | `'R.43'` | `'R.44'` | `'R.45'` | `'R.45-1'` | `'R.48'` | `'R.50'` | `'R.51'` | `'R.6-27RB'` | `'R.12-9RB'` | `'R.11-45RB'`

Reference measurement channel, specified as a character vector. See "DL Reference Channel Options" on page 1-995 for a list of the default top-level configuration associated with the available downlink reference channels.

Data Types: `char`

`duplexmode` — Duplexing mode

`'FDD'` (default) | `'TDD'` | optional

Duplexing mode frame structure type, specified as `'FDD'` or `'TDD'`.

For `'R.25'`, `'R.26'`, `'R.27'`, and `'R.28'`, the default duplexing mode is `'TDD'`.

Data Types: `char`

`totsubframes` — Total number of subframes

10 (default) | positive integer | optional

Total number of subframes, specified as an integer. `totsubframes` defines the number of subframes that form the resource grid, used by `lteRMCDLTool`, to generate the waveform.

Data Types: `double`

`rmccfg` — Reference channel configuration

structure

Reference channel configuration, specified as a structure. The structure defines any, or all, of the fields or subfields contained in the output structure, `rmccfgout`. Any undefined fields are given appropriate default values.

Parameter Field	Required or Optional	Values	Description
`RC`	Optional	`'R.0'` (default), `'R.1'`, `'R.2'`, `'R.3'`, `'R.4'`, `'R.5'`, `'R.6'`, `'R.7'`, `'R.8'`, `'R.9'`, `'R.10'`, `'R.11'`, `'R.12'`, `'R.13'`, `'R.14'`, `'R.25'`, `'R.26'`, `'R.27'`, `'R.28'`, `'R.31-3A'`, `'R.31-4'`, `'R.43'`, `'R.44'`, `'R.45'`, `'R.45-1'`, `'R.48'`, `'R.50'`, `'R.51'`, `'R.6-27RB'`, `'R.12-9RB'`, `'R.11-45RB'`	Reference measurement channel (RMC) number or type, as specified in TS 36.101, Annex A.3. • `'R.31-3A'` and `'R.31-4'` are sustained data rate RMCs with user data in subframe 5. • `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` are custom RMCs configured for non-standard bandwidths that maintain the same code rate as the standardized versions defined in TS 36.101, Annex A.3.

Data Types: `struct`

`ncodewords` — Number of PDSCH codewords to modulate

optional | 1 | 2

Number of PDSCH codewords to modulate, specified as 1 or 2. The default used is the value defined in TS 36.101, [1] for the RMC configuration given by `RC`.

Data Types: `double`

Output Arguments

`rmccfgout` — RMC configuration output
structure

RMC configuration output structure

RMC configuration, returned as a scalar structure. `rmccfgout` contains RMC-specific configuration parameters. Field definitions and settings align with `rmccfg`.

`rmccfgout` contains these fields:

Parameter Field	Values	Description
`RC`	`'R.0'` (default), `'R.1'`, `'R.2'`, `'R.3'`, `'R.4'`, `'R.5'`, `'R.6'`, `'R.7'`, `'R.8'`, `'R.9'`, `'R.10'`, `'R.11'`, `'R.12'`, `'R.13'`, `'R.14'`, `'R.25'`, `'R.26'`, `'R.27'`, `'R.28'`, `'R.31-3A'`, `'R.31-4'`, `'R.43'`, `'R.44'`, `'R.45'`, `'R.45-1'`, `'R.48'`, `'R.50'`, `'R.51'`, `'R.6-27RB'`, `'R.12-9RB'`, `'R.11-45RB'`	Reference measurement channel (RMC) number or type, as specified in TS 36.101, Annex A.3. • `'R.31-3A'` and `'R.31-4'` are sustained data rate RMCs with user data in subframe 5. • `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` are custom RMCs configured for non-standard bandwidths that maintain the same code rate as the standardized versions defined in TS 36.101, Annex A.3. See footnote 2.
`NDLRB`	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CellRefP`	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports

Parameter Field	Values	Description
NCellID	Integer from 0 to 503	Physical layer cell identity
CyclicPrefi	`'Normal'` (default), `'Extended'`	Cyclic prefix length
CFI	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`) See footnote 1
PCFICHPower	0 (default), scalar	PCFICH symbol power adjustment, in dB
Ng	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
PHICHDurati	`'Normal'`, `'Extended'`	PHICH duration
HISet	Matrix with default size 112-by-3.	Contains the maximum PHICH groups (112) as per TS 36.211, Section 6.9 with the first PHICH sequence of each group set to ACK). For further details, see `ltePHICH`.
PHICHPower	0 (default), numeric scalar	PHICH symbol power in dB.
NFrame	0 (default), nonnegative scalar integer	Frame number
NSubFrame	0 (default), nonnegative scalar integer	Subframe number
TotSubFrame	Nonnegative scalar integer	Total number of subframes to generate
Windowing	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied
DuplexMode	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

Parameter Field	Values	Description
This field is only present and applicable for `'Port7-14'` transmission scheme		
`CSIRSPer`	`'On'` (default), `'Off'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following fields are only present and applicable for `'Port7-14'` transmission scheme (`TxScheme`) and only required in `rmccfg` if `CSIRSPeriod` is not set to `'Off'`.		
`CSIRSCon`	Scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
`CSIRefP`	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
These fields are only present and applicable for `'Port7-14'` transmission scheme (`TxScheme`)		
`ZeroPowe`	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following field is only applicable for `'Port7-14'` transmission scheme (`TxScheme`) and only required in `rmccfg` if `CSIRSPeriod` is not set to `'Off'`.		
`ZeroPowe`	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

Parameter Field	Values	Description
PDSCH	Scalar structure	PDSCH transmission configuration substructure
OCNGPDCCHEna	`'Off'`, `'On'`	Enable PDCCH OCNG See footnote 2
OCNGPDCCHPow	Scalar integer, `0` (default)	PDCCH OCNG power in dB
OCNGPDSCHEna	`'Off'`, `'On'`	Enable PDSCH OCNG
OCNGPDSCHPow	Scalar integer, defaults to `PDSCH.Rho` (default)	PDSCH OCNG power in dB
OCNGPDSCH	Scalar structure	PDSCH OCNG configuration substructure
OCNG	`'Off'`, `'On'`. `'Disable'` and `'Enable'` are also accepted.	OFDMA channel noise generator **Note:** This parameter will be removed in a future release. Use the PDCCH and PDSCH-specific OCNG parameters instead.
These fields are only present and applicable for `'TDD'` duplex mode (`DuplexMode`).		
SSC	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
TDDConfi	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration

Parameter Field	Values	Description
	1 CFI is equal to the number of symbols allocated to: • (PDCCH - 1) for `NDLRB < 10` • PDCCH for `NDLRB ≥ 10` For the RMCs, the number of symbols allocated to PDCCH varies with channel bandwidth setting, • Two symbols for 20 MHz, 15 MHz, and 10 MHz • Three symbols for 5 MHz and 3 MHz • Four symbols for 1.4 MHz • In the TDD mode, only two OFDM symbols are allocated to PDCCH in special subframes irrespective of the channel bandwidth. Therefore, the CFI value varies per subframe for the 5 MHz, 3 MHz, and 1.4 MHz channel bandwidths. Specifically, for bandwidths where PDCCH symbol allocation is not two in other subframes. **2** The PDCCH OCNG fills the unused PDCCH resource elements with QPSK symbols using either single port or transmit diversity depending on the number of cell RS ports.	

PDSCH substructure

The substructure PDSCH relates to the physical channel configuration and contains these fields:

Parameter Field	Values	Description
`TxScheme`	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, `'MultiUser'`, `'Port5'`, `'Por` `'Port8'`, `'Por`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity

<table>
<tr><th>Parameter Field</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table>
</td></tr>
<tr><td>Modulation</td><td>'QPSK', '16QAM', '64QAM', or '256QAM'</td><td>Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.</td></tr>
<tr><td>NLayers</td><td>Integer from 1 to 8</td><td>Number of transmission layers.</td></tr>
<tr><td>NTxAnts</td><td>Nonnegative scalar integer</td><td>Number of transmission antenna ports. This argument is only present for UE-specific demodulation reference symbols.

Note: NTxAnts is provided by lteRMCDL for information only.</td></tr>
<tr><td>Rho</td><td>0 (default), Numeric scalar</td><td>PDSCH resource element power allocation, in dB</td></tr>
<tr><td>RNTI</td><td>0 (default), scalar integer</td><td>Radio network temporary identifier (RNTI) value (16 bits)</td></tr>
</table>

Parameter Field	Values	Description
RVSeq	Integer vector (0,1,2,3), specified as a one or two row matrix (for one or two codewords)	Specifies the sequence of Redundancy Version (RV) indicators for each HARQ process. The number of elements in each row is equal to the number of transmissions in each HARQ process. If `RVSeq` is a row vector in a two codeword transmission, then the same RV sequence is applied to both codewords. See footnote 2.
RV	Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).	Specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is Read-Only.
NHARQProces	1, 2, 3, 4, 5, 6, 7, or 8	Number of HARQ processes per component carrier
NTurboDecit	5 (default), nonnegative scalar integer	Number of turbo decoder iteration cycles

Parameter Field	Values	Description
PRBSet	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`. See footnote 1.
TargetCodeRa	Scalar or one or two row numeric matrix	Target code rates for one or two codewords for each subframe in a frame. Used for calculating the transport block sizes according to TS 36.101 [1], Annex A.3.1. If both `TargetCodeRate` and `TrBlkSizes` are not provided at the input, and the RC does not have a single ratio target code rate in TS 36.101, Table A.3.1.1-1, `TargetCodeRate` == `ActualCodeRate`.
ActualCodeRa	One or two row numeric matrix	Actual code rates for one or two codewords for each subframe in a frame, calculated according to TS 36.101 [1], Annex A.3.1. The maximum actual code rate is 0.93. This parameter field is only for informational purposes and is read-only.

Parameter Field	Values	Description
TrBlkSizes	One or two row numeric matrix	Transport block sizes for each subframe in a frame See footnote 2.
CodedTrBlkS	One or two row numeric matrix	Coded transport block sizes for one or two codewords. This parameter field is only for informational purposes. See footnote 2.
DCIFormat	`'Format0'`, `'Format1'`, `'Format1A'`, `'Format1B'`, `'Format1C'`, `'Format1D'`, `'Format2'`, `'Format2A'`, `'Format2B'`, `'Format2C'`, `'Format2D'`, `'Format3'`, `'Format3A'`, `'Format4'`, `'Format5'`	Downlink control information (DCI) format type of the PDCCH associated with the PDSCH. See `lteDCI`.
PDCCHFormat	0, 1, 2, 3	Aggregation level of PDCCH associated with PDSCH
PDCCHPower	Numeric scalar	PDCCH power in dB
CSIMode	`'PUCCH 1-0'`, `'PUCCH 1-1'`, `'PUSCH 1-2'`, `'PUSCH 3-0'`, `'PUSCH 3-1'`	CSI reporting mode
PMIMode	`'Wideband'` (default), `'Subband'`	PMI reporting mode. `PMIMode='Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and `PMIMode='Subband'` corresponds to PUSCH reporting Mode 3-1.

Parameter Field	Values	Description
The following field is only present for `TxScheme = 'SpatialMux'`.		
`PMISet`	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.
The following field is only present for `TxScheme` = `'Port7-8'`, `'Port8'`, or `'Port7-14'`.		
`NSCID`	0 (default), 1	Scrambling identity (*ID*)
The following field is only present for UE-specific beamforming (`'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`).		
`W`	Numeric matrix	`NLayers`-by-*P* precoding matrix, chosen according to TS 36.101 Annex B.4. *P* is the number of transmit antennas. The resulting precoding matrix with index zero is selected from: • The set defined in TS 36.211, Section 6.3.4 for `'Port5', 'Port7-8', and 'Port8'` transmission schemes • or from the set associated with CSI reporting as defined in TS 36.213, Section 7.2.4 for the `'Port7-14'` transmission scheme. `W` is present only for wideband UE-specific beamforming (`'Port5', 'Port7-8', 'Port8', 'Port7-14'`).

Parameter Field	Values	Description
1	The function returns valid `TrBlkSizes` and `CodedTrBlkSizes` set to 0 when `PRBSet` is empty, indicating there is no PDSCH allocation in this frame.	
2	Any parameters missing at the input are initialized based on the `RC` field if present or `'R.0'` otherwise. • When the `RC` field is specified, the RMC specified defines the subframe scheduling. • If the `RC` field is absent or set to empty, all downlink subframes and special subframes (if TDD mode) are assumed to be scheduled. `TrBlkSizes` and `CodedTrBlkSizes` are set according to the target code rate, the modulation scheme and the allocated resources. • The value of `RVSeq` is set according to the modulation scheme.	

OCNGPDSCH substructure

The substructure, `OCNGPDSCH`, defines the OCNG patterns in associated RMCs and tests according to TS 36.101, Section A.5. `OCNGPDSCH` contains these fields which can also be customized with the full range of PDSCH-specific values.

Parameter Field	Values	Description
`Modulation`	OCNG `Modulation` has same setting options as `rmccfgout.PDSCH.Modul`	See `rmccfgout.PDSCH.Modulation`
`TxScheme`	OCNG `TxScheme` has same setting options as `rmccfgout.PDSCH.TxSch`	See `rmccfgout.PDSCH.TxScheme`
`RNTI`	0 (default), scalar integer	OCNG radio network temporary identifier (RNTI) value. (16 bits)

Definitions

DL Reference Channel Options

The output configuration structure is initialized in accordance with the reference channels defined in TS 36.101, Annex A.3. Initialization choices available for the downlink reference channel and associated top-level configuration defaults include:

Reference channels	Reference channels (continued)
R.0 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)	R.31-3A FDD (CDD, 50 RB, 64QAM, CellRefP=2, R=0.85-0.90)
R.1 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)	R.31-3A TDD (CDD, 68 RB, 64QAM, CellRefP=2, R=0.87-0.90)
R.2 (Port0, 50 RB, QPSK, CellRefP=1, R=1/3)	R.31-4 (CDD, 100 RB, 64QAM, CellRefP=2, R=0.87-0.90)
R.3 (Port0, 50 RB, 16QAM, CellRefP=1, R=1/2)	R.43 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.4 (Port0, 6 RB, QPSK, CellRefP=1, R=1/3)	R.43 TDD (SpatialMux, 100 RB, 16QAM, CellRefP=4, R=1/2)
R.5 (Port0, 15 RB, 64QAM, CellRefP=1, R=3/4)	R.44 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.6 (Port0, 25 RB, 64QAM, CellRefP=1, R=3/4)	R.44 TDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)
R.7 (Port0, 50 RB, 64QAM, CellRefP=1, R=3/4)	R.45 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)
R.8 (Port0, 75 RB, 64QAM, CellRefP=1, R=3/4)	R.45-1 (Port7-14, 39 RB, 16QAM, CellRefP=2, R=1/2)
R.9 (Port0, 100 RB, 64QAM, CellRefP=1, R=3/4)	R.48 (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/2)

Reference channels	Reference channels (continued)
`R.10 (TxDiversity|SpatialMux, 50 RB, QPSK, CellRefP=2, R=1/3)`	`R.50 FDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)`
`R.11 (TxDiversity|SpatialMux|CDD, 50 RB, 16QAM, CellRefP=2, R=1/2)`	`R.50 TDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)`
`R.12 (TxDiversity, 6 RB, QPSK, CellRefP=4, R=1/3)`	`R.51 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)`
`R.13 (SpatialMux, 50 RB, QPSK, CellRefP=4, R=1/3)`	`R.6-27RB (Port0, 27 RB, 64QAM, CellRefP=1, R=3/4)`
`R.14 (SpatialMux|CDD, 50 RB, 16QAM, CellRefP=4, R=1/2)`	`R.12-9RB (TxDiversity, 9 RB, QPSK, CellRefP=4, R=1/3)`
`R.25 (Port5, 50 RB, QPSK, CellRefP=1, R=1/3)`	`R.11-45RB (CDD, 45 RB, 16QAM, CellRefP=2, R=1/2)`
`R.26 (Port5, 50 RB, 16QAM, CellRefP=1, R=1/2)`	
`R.27 (Port5, 50 RB, 64QAM, CellRefP=1, R=3/4)`	
`R.28 (Port5, 1 RB, 16QAM, CellRefP=1, R=1/2)`	

Note: Reference channels `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` maintain the same code rate as the standard versions but are custom RMCs configured for nonstandard bandwidths.

References

[1] 3GPP TS 36.101. "User Equipment (UE) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical channels and modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[4] 3GPP TS 36.321. "Medium Access Control (MAC) protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteRMCDLTool` | `lteRMCUL` | `lteTestModel`

Introduced in R2014a

lteRISelect

PDSCH rank indication calculation

Syntax

```
[ri,pmiset] = lteRISelect(enb,chs,hest,noiseest)
```

Description

`[ri,pmiset] = lteRISelect(enb,chs,hest,noiseest)` calculates PDSCH rank indication (RI), given cell-wide settings,`enb`, channel configuration settings, `chs`, channel estimate resource array `hest`, and receiver noise variance `noiseest`. For more information, see “RI Selection” on page 1-1005.

Examples

Rank Indication example

This example shows how to populate an empty resource grid for RMC R.13 with cell-specific reference signal symbols. The signal is passed through a channel and OFDM demodulated. Estimates of the channel and noise power spectral density are used for RI and PMI calculation. A CodebookSubset bitmap of all ones means that no codebook subset restriction is applied, allowing any PMI/RI combination applicable for the configured transmission scheme to be selected during RI selection.

Create empty resource grid and populate with cell specific reference symbols. Set `enb.PDSCH.CodebookSubset` to all ones so the PMI selection is unconstrained

```
enb = lteRMCDL('R.13');
enb.PDSCH.CodebookSubset = '111111111111111';
reGrid = lteResourceGrid(enb);
reGrid(lteCellRSIndices(enb)) = lteCellRS(enb);
[txWaveform,txInfo] = lteOFDMModulate(enb,reGrid);
```

Initialize the channel configuration structure (`chcfg`), filter the signal through a channel and demodulate the signal.

```
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 4;
chcfg.DopplerFreq = 5;
chcfg.MIMOCorrelation = 'Low';
chcfg.SamplingRate = txInfo.SamplingRate;
chcfg.Seed = 1;
chcfg.InitPhase = 'Random';
chcfg.ModelType = 'GMEDS';
chcfg.NTerms = 16;
chcfg.NormalizeTxAnts = 'On';
chcfg.NormalizePathGains = 'On';
chcfg.InitTime = 0;

rxWaveform = lteFadingChannel(chcfg,txWaveform);
rxSubframe = lteOFDMDemodulate(enb,rxWaveform);
```

Estimate corresponding channel, including noise spectral density and reference signal subcarriers. Use `lteRISelect` to calculate RI & PMI

```
cec.FreqWindow = 1;
cec.TimeWindow = 15;
cec.InterpType = 'cubic';
cec.PilotAverage = 'UserDefined';
cec.InterpWinSize = 1;
cec.InterpWindow = 'Centered';
[hest,noiseEst] = lteDLChannelEstimate(enb,cec,rxSubframe);
[ri,pmi] = lteRISelect(enb,enb.PDSCH,hest,noiseEst)
```

```
ri =

     3


pmi =

    13
```

Input Arguments

enb — eNodeB cell-wide settings

structure

eNodeB cell-wide settings, specified as a structure containing the following parameter fields:

Parameter Field	Required or Optiona	Values	Description
NDLRB	Require	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
NCellID	Require	Integer from 0 to 503	Physical layer cell identity
CellRefP	Require	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefi	Optiona	`'Normal'` (default), `'Extended'`	Cyclic prefix length
DuplexMode	Optiona	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
The following parameters apply when `DuplexMode` is set to, `TDD`.			
TDDConf	Optiona	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SSC	Optiona	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
NSubfra	Require	0 (default), nonnegative scalar integer	Subframe number
The following parameters apply when `chs.TxScheme` is set to `'Port7–14'`.			
CSIRefP	Require	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
CSIRSCo	Require	Scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRSPe	Optiona	`'On'` (default), `'Off'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or

Parameter Field	Required or Optional	Values	Description
		also specify values in a cell array of configurations for each resource.	from a cell array of configurations for each resource.
`NFrame`	Optional	0 (default), nonnegative scalar integer	Frame number

`chs` — Channel-specific transmission configuration

structure | structure array

Channel specific transmission configuration, specified as scalar structure, or structure array containing the following parameter fields:

Parameter Field	Required or Optional	Values	Description
`PMIMode`	Optional	`'Wideband'` (default), `'Subband'`	PMI reporting mode. `PMIMode='Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and `PMIMode='Subband'` corresponds to PUSCH reporting Mode 3-1.
`TxScheme`	Optional	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMu` `'MultiUser` `'Port5'`, `'Port7-8'`, `'Port8'`, `'Port7-14'`	PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td>
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td><code>'MultiUser'</code></td><td>Multi-user MIMO</td></tr>
<tr><td><code>'Port5'</code></td><td>Single-antenna port, port 5</td></tr>
<tr><td><code>'Port7-8'</code></td><td>Single-antenna port, port 7, when <code>NLayers</code> = 1. Dual layer transmission, ports 7 and 8, when <code>NLayers</code> = 2.</td></tr>
<tr><td><code>'Port8'</code></td><td>Single-antenna port, port 8</td></tr>
<tr><td><code>'Port7-14'</code></td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table>
</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
CodebookSub	Optional	Character vector or integer vector, all ones (default)	Codebook subset restriction, specified as a character vector bitmap. The default values are all ones, permitting all PMI values. This parameter is configured by higher layers and indicates the values of PMI that can be reported. The bitmap, defined in TS 36.213, Section 7.2, is arranged a_A-1,a_A-2,...a_0. For example, the element CodebookSubset(1) corresponds to a_A-1 and the element CodebookSubset(end) corresponds to a_0. The length of the bitmap is given by the info.CodebookSubsetSize field returned by `ltePMIInfo`. You can also specify the bitmap in a hexadecimal form by prefixing the character vector with `'0x'`. Alternatively, you can specify a numeric array identical to the `pmiset` output, indicating to restrict the selection to only those `pmiset` values. Specifying the parameter in this way enables you to obtain SINR estimates against an existing reported PMI for RI and CQI selection. If this parameter field is defined but is empty, no codebook subset restriction is applied. `(codebookSubsetRestriction)`
The following parameter applies for `'Port7–14'` transmission scheme with `CSIRefP` equal to 4, or for `'Port7-8'` or `'Port8'` transmission scheme with `CellRefP` equal to 4.			
AltCodeb	Optional	`'Off'` (default), `'On'`	If set to `'On'`, enables the alternative codebook for CSI reporting with four antennas defined in TS 36.213, Tables 7.2.4-0A to 7.2.4-0D. The default is `'Off'`. (*alternativeCodebookEnabledFor4TX-r12*)

`hest` — Channel estimate

multidimensional array

Channel estimate, specified as a *K*-by-*L*-by-*NRxAnts*-by-*P* array where:

- *K* is the number of subcarriers.
- *L* is the number of OFDM symbols.
- *NRxAnts* is the number of receive antennas.
- *P* is the number of transmit antennas.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Receiver noise variance

numeric scalar

Receiver noise variance, specified as numeric scalar. It is an estimate of the received noise power spectral density.

Data Types: `double`

Output Arguments

`ri` — Rank indication

scalar

Rank indication, returned as a scalar, indicates the optimal number of layers to use for transmission to maximize SINR.

`pmiset` — Precoder matrix indications

scalar | column vector

Precoder matrix indications, returned as a scalar, or a column vector.

- For wideband reporting (`NSubbands`=1), `pmiset` is a scalar specifying the selected wideband codebook index,*i2*.
- For the `'Port7-14'` transmission scheme with eight CSI-RS ports, or for CSI reporting with the alternative codebook for four antennas, `pmiset` has `NSubbands` `+1` rows. The first row indicates wideband codebook index, *i1*, and the subsequent `NSubbands` rows indicate the subband codebook indices, *i2*.

- For other numbers of CSI-RS ports in the `'Port7-14'` transmission scheme, and for other transmission schemes, `pmiset` has `NSubbands` rows, each row returns the subband codebook index for that subband.

The number of subbands, `NSubbands`, is a field in the `info` structure output by `ltePMIInfo` and `ltePMISelect`.

Definitions

RI Selection

The PDSCH rank indication (RI) selection process determines the optimal number of layers (*NLayers*) to use for transmission to maximize SINR. The range of *NLayers* to consider is calculated based on the transmission scheme and the configured reference signal ports.

1. For v = 1,...,*NLayers*,
   a. Use `ltePMISelect`, with `chs.NLayers` = v, to perform PMI selection.
   b. Record the selected PMI and total SINR across all layers, excluding layers with SINR below the threshold of 0 dB.
2. Select the number of transmission layers, v, that maximizes the SINR of the transmission and return as the rank indication, `ri` and corresponding PMI set, `pmiset`.

RI selection corresponds to:

- Report Type 3 (for reporting Mode 1-0 or Mode 1-1) on the PUCCH.
- Reporting Mode 1-2 or Mode 3-1 on the PUSCH.

For more information on RI selection, see TS 36.213 Section 7.2.

PMI Selection

PDSCH precoder matrix indication (PMI) selection calculates a PMI set, `pmiset`. Functions, such as `lteRMCDLTool` or `ltePDSCH`, can use the returned `pmiset` to configure the PMI for downlink transmissions they generate. PMI selection is performed using the PMI definitions specified in TS 36.213, Section 7.2.4.

- The CSI reporting codebook is used for:
  - `'Port7-14'` transmission scheme with eight CSI-RS ports
  - CSI reporting with the alternative codebook for four antennas (*alternativeCodeBookEnabledFor4TX -r12* = true).
- The codebook for closed-loop spatial multiplexing, defined in TS 36.211 Tables 6.3.4.2.3-1 and 6.3.4.2.3-2, is used for other cases.

ThePMI feedback type associated with the PMI selection process can be wideband or subband:

- `PMIMode = 'Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2).
- `PMIMode = 'Subband'` corresponds to PUSCH reporting Mode 3-1.

PMI selection is based on the rank indicated by `chs.NLayers`, except for `'TxDiversity'` transmission scheme, where the rank is 1. In PUCCH reporting Mode 1-1, you can achieve codebook subsampling for submode 2, as specified in TS 36.213, Table 7.2.2-1D, with an appropriate `chs.CodebookSubset`.

References

[1] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. “Physical channels and modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCQISelect` | `ltePMIInfo` | `ltePMISelect`

Introduced in R2014b

lteRMCDLTool

Downlink RMC waveform generation

Syntax

```
[waveform,grid,rmccfgout] = lteRMCDLTool
[waveform,grid,rmccfgout] = lteRMCDLTool(rmccfg,trdata)
[waveform,grid,rmccfgout] = lteRMCDLTool(rc,trdata,duplexmode,
totsubframes)
```

Description

`[waveform,grid,rmccfgout] = lteRMCDLTool` starts a user interface for the parameterization and generation of the reference measurement channel (RMC) `waveform`, the resource element `grid`, and an RMC configuration structure. See "DL Reference Channel Options" on page 1-1032 for a list of the default top-level configuration associated with the available downlink reference channels.

`[waveform,grid,rmccfgout] = lteRMCDLTool(rmccfg,trdata)` where `rmccfg` specifies a user-defined reference channel structure. The reference configuration structure with default parameters can easily be created using `lteRMCDL` then modified if desired.

Note: SIB1 messages and the associated PDSCH and PDCCH can be added to the output `waveform` by adding the substructure `rmccfg.SIB`.

`[waveform,grid,rmccfgout] = lteRMCDLTool(rc,trdata,duplexmode, totsubframes)` specifies the default reference measurement channel, `rc`, and information bits `trdata`. `duplexmode` and `totsubframes` are optional input arguments, that define the duplex mode of the generated waveform and total number of subframes that make up the `grid`.

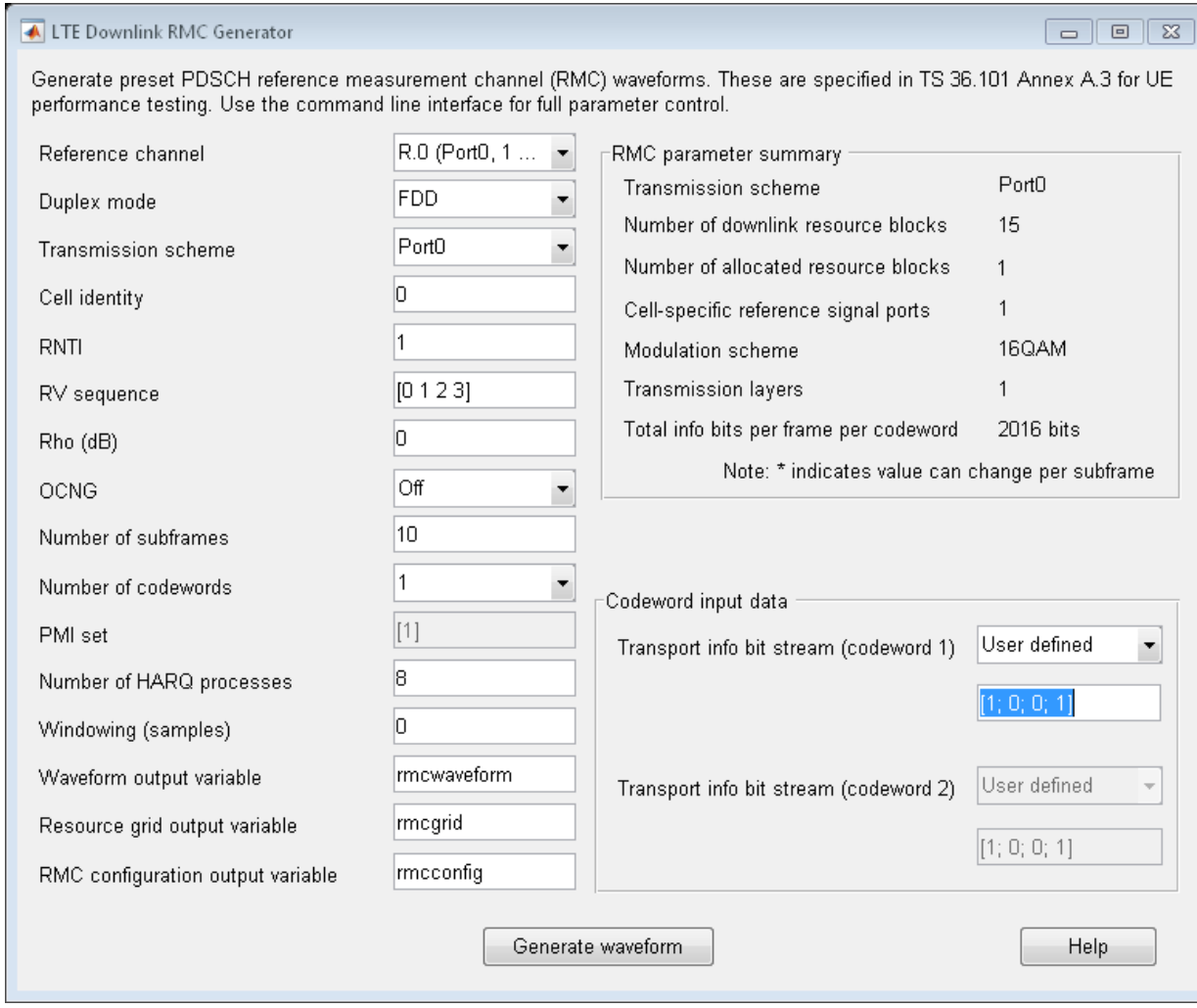
Examples

Open LTE Downlink RMC Generator User Interface

Open the LTE user interface to generate a downlink reference measurement channel waveform.

The LTE Downlink RMC Generator dialog box appears when you execute the `lteRMCDLTool` function with no input arguments.

```
lteRMCDLTool
```


LTE Downlink RMC Generator
Generate preset PDSCH reference measurement channel (RMC) waveforms. These are specified in TS 36.101 Annex A.3 for UE performance testing. Use the command line interface for full parameter control.
Reference channel
R.0 (Port0, 1 ...
Duplex mode
FDD
Transmission scheme
Port0
Cell identity
0
RNTI
1
RV sequence
[0 1 2 3]
Rho (dB)
0
OCNG
Off
Number of subframes
10
Number of codewords
1
PMI set
[1]
Number of HARQ processes
8
Windowing (samples)
0
Waveform output variable
rmcwaveform
Resource grid output variable
rmcgrid
RMC configuration output variable
rmcconfig
RMC parameter summary
Transmission scheme
Port0
Number of downlink resource blocks
15
Number of allocated resource blocks
1
Cell-specific reference signal ports
1
Modulation scheme
16QAM
Transmission layers
1
Total info bits per frame per codeword
2016 bits
Note: * indicates value can change per subframe
Codeword input data
Transport info bit stream (codeword 1)
User defined
[1; 0; 0; 1]
Transport info bit stream (codeword 2)
User defined
[1; 0; 0; 1]
Generate waveform
Help

You can use the user interface to generate the default waveform or adjust default settings prior to waveform generation.

Generate LTE DL RMC R.31-4

Generate a time domain signal and a 3-dimensional array of the resource elements for R.31-4 FDD as specified in TS 36.101 Annex A.3.9.1-1. R.31-4 FDD is 20MHz, 64QAM, variable code rate and has user data scheduled in subframe 5.

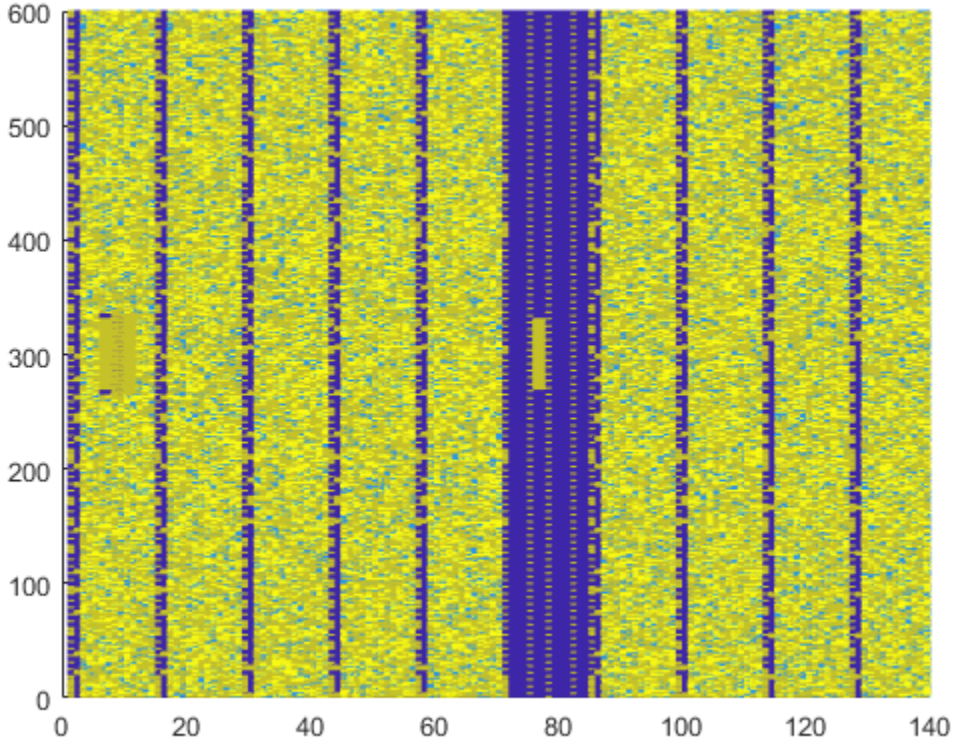
```
[txWaveform,txGrid,rmcCfgOut] = lteRMCDLTool('R.31-4',{[1;0] [1;0]});
```

Generate RMC R.3 with SIB

This example shows use of `lteRMCDLTool` to generate a tx waveform with SIB transmission enabled using DCIFormat1A and localized allocation.

Specify desired RMC, initialize configuration structure and define `txData`. Generate `txGrid` and plot it.

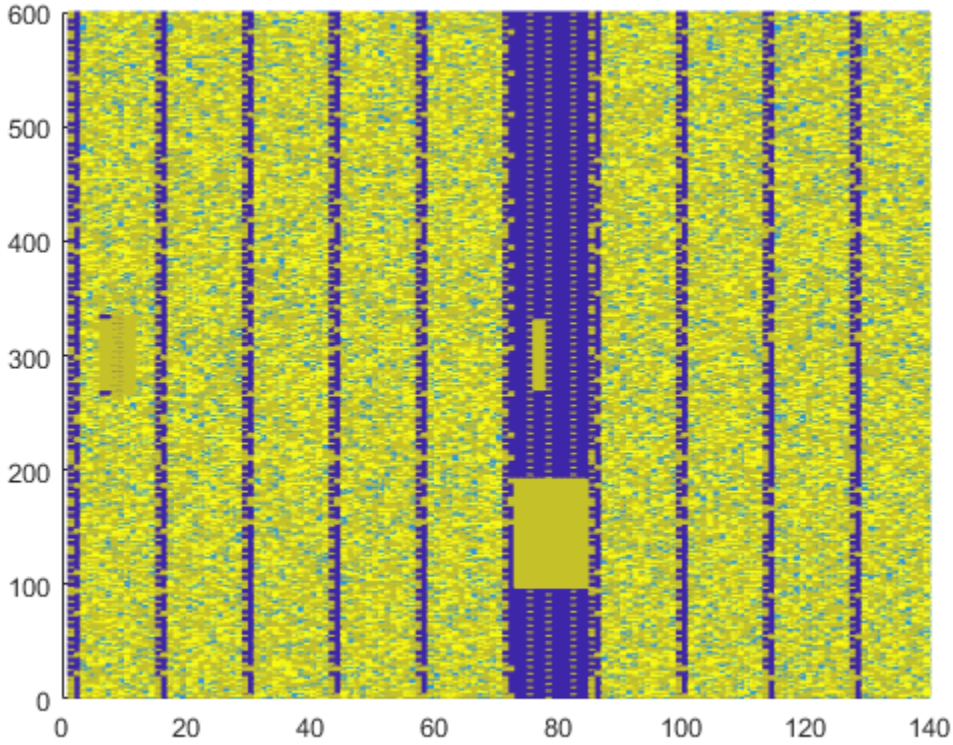
```
rc = 'R.3';
rmc = lteRMCDL(rc);

txData = [1;0;0;1];
[~,txGrid,~] = lteRMCDLTool(rmc, txData);
mesh(abs(txGrid))
view(2)
```



To insert SIB1 message into the output waveform, initialize `SIB` substructure, enable SIB transmission, adjust other defaults, and regenerate txGrid. Plot `txGrid` to illustrate the presence of SIB1 message in subframe 5

```
rmc.SIB.Enable = 'On';
rmc.SIB.DCIFormat = 'Format1A';
rmc.SIB.AllocationType = 0;
rmc.SIB.VRBStart = 8;
rmc.SIB.VRBLength = 8;
rmc.SIB.Data = randi([0 1],144,1);

[txWaveform,txGrid,rmcCfgOut] = lteRMCDLTool(rmc, txData);
figure
mesh(abs(txGrid))
```

```
view(2)
```



Generate LTE DL RMC R.12 With 16QAM Modulation

Generate a time domain waveform, and a 3D array of the resource elements for RMC R.12 as specified in TS 36.101. Modify the standard R.12 RMC to use 16QAM modulation scheme instead of the default QPSK.

Create an RMC setting structure specifying R.12 for `RC` and 16QAM for `Modulation`.

```
rmc.RC = 'R.12';
rmc.PDSCH.Modulation = '16QAM';
```

Generate the tx waveform, RE grid and also output the RMC configuration structure.

```
txData = [1;0;0;1];
[txWaveform, txGrid, rmcCfgOut] = lteRMCDLTool(rmc, txData);
```

Review the `rmcCgfOut` structure and `PDSCH` substructure.

```
rmcCfgOut
rmcCfgOut.PDSCH
```

```
rmcCfgOut =

  struct with fields:

                RC: 'R.12'
             NDLRB: 6
           CellRefP: 4
            NCellID: 0
       CyclicPrefix: 'Normal'
                CFI: 3
        PCFICHPower: 0
                 Ng: 'Sixth'
      PHICHDuration: 'Normal'
              HISet: [112×3 double]
         PHICHPower: 0
             NFrame: 0
          NSubframe: 0
       TotSubframes: 10
          Windowing: 0
         DuplexMode: 'FDD'
              PDSCH: [1×1 struct]
    OCNGPDCCHEnable: 'Off'
     OCNGPDCCHPower: 0
    OCNGPDSCHEnable: 'Off'
     OCNGPDSCHPower: 0
          OCNGPDSCH: [1×1 struct]
          SerialCat: 1
       SamplingRate: 1920000
               Nfft: 128


ans =

  struct with fields:

              TxScheme: 'TxDiversity'
```

```
            Modulation: {'16QAM'}
               NLayers: 4
                   Rho: 0
                  RNTI: 1
                 RVSeq: [0 1 2 3]
                    RV: 0
        NHARQProcesses: 8
          NTurboDecIts: 5
                PRBSet: [6×1 double]
        TargetCodeRate: 0.3333
        ActualCodeRate: [1×10 double]
            TrBlkSizes: [0 936 936 936 936 0 936 936 936 936]
       CodedTrBlkSizes: [0 2496 2496 2496 2496 0 2496 2496 2496 2496]
             DCIFormat: 'Format1'
          PDCCHFormat: 2
           PDCCHPower: 0
              CSIMode: 'PUCCH 1-1'
              PMIMode: 'Wideband'
    HARQProcessSequence: [0 1 2 3 4 0 5 6 7 8]
```

Display Uplink PRB Allocation Type 1

Display the PRB allocations associated with the sequence of subframes in a frame for DCI Format 0 and uplink resource allocation type 1.

Configure a type 1 uplink resource allocation (multi-cluster). TS 36.213, Section 8.1.2 describes the resourse indication value (RIV) determination.

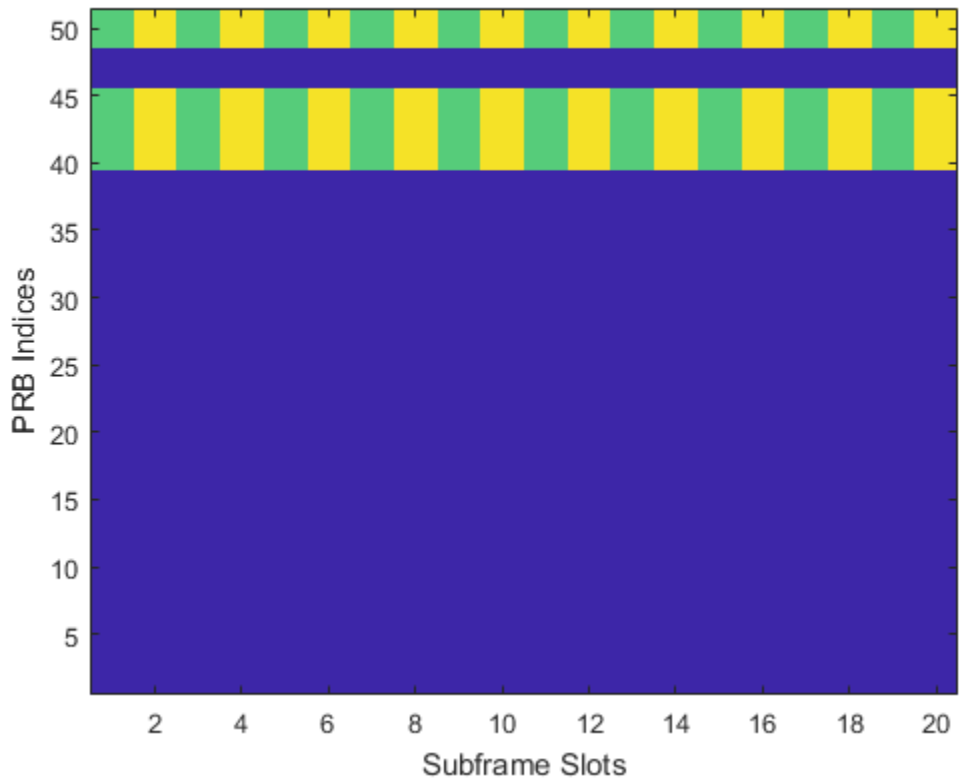
```
enb = struct('NDLRB',50);
dci = lteDCI(enb,struct('DCIFormat','Format0','AllocationType',1));
dci.Allocation.RIV = 1;
```

Display an image of the PRBs used in each slot of each subframe in a frame.

- Create a `subframeslots` matrix full of zeros. There are 20 slots per frame, specifically two slots per subframe and ten subframes per frame.
- Loop through assigning a PRB set of indices for each subframe. Also assign a value in `subframeslots` for each occupied PRB index.

```
subframeslots = zeros(enb.NDLRB,20);
for i = 0:9
    enb.NSubframe = i;
```

```
        prbSet = lteDCIResourceAllocation(enb,dci);
        prbSet = repmat(prbSet,1,2/size(prbSet,2));
        for s = 1:2
            subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
        end
    end
    image(subframeslots);
    axis xy;
    xlabel('Subframe Slots');
    ylabel('PRB Indices');
```



Observe from the image that the same set of PRB indices is used in each slot.

Display Uplink Hopping PRB Allocation

Display the PRB allocations associated with the sequence of subframes in a frame for an uplink resource allocation with hopping.

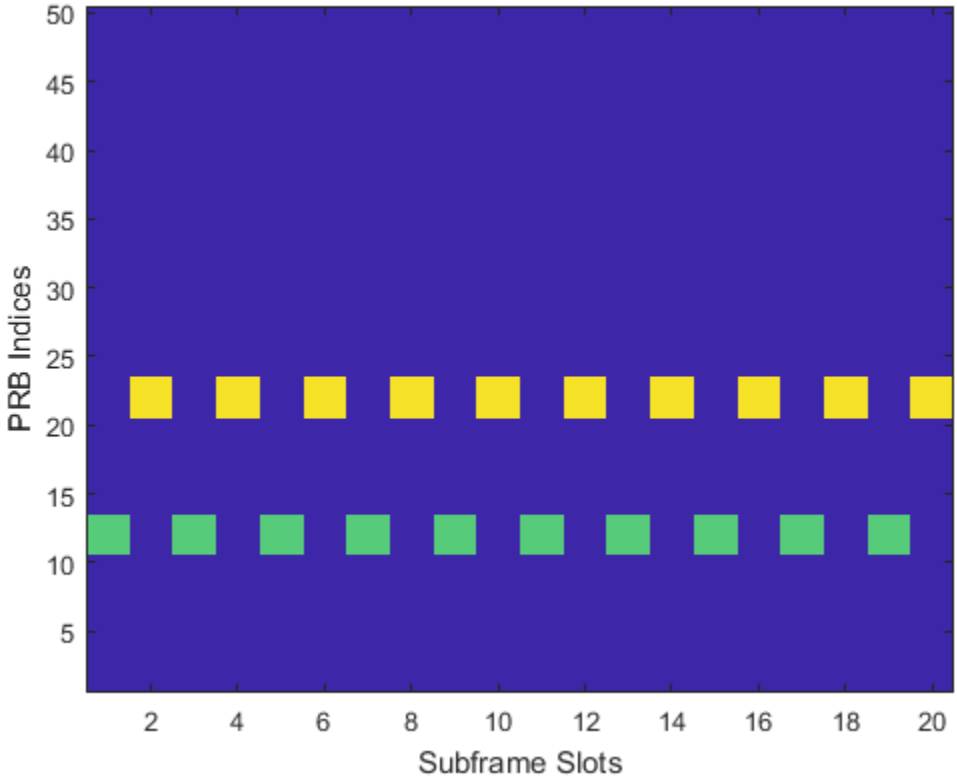
Configure a type 1 uplink resource allocation that has type 0 hopping and slot and subframe hopping.

```
enb = struct('NDLRB',50,'NCellID',0);
dci = lteDCI(enb,struct('DCIFormat','Format0','AllocationType',0,...
    'FreqHopping',1));
dci.Allocation.HoppingBits = 0;
dci.Allocation.RIV = 110;
enb.PUSCHHopping = 'InterAndIntra';
enb.MacTxNumber = 0;
enb.NSubbands = 1;
enb.PUSCHHoppingOffset = 10;
```

Display an image of the PRBs used in each slot of each subframe in a frame.

- Create a `subframeslots` matrix full of zeros. There are 20 slots per frame, specifically two slots per subframe and ten subframes per frame.
- Loop through assigning a PRB set of indices for each subframe. Also assign a value in `subframeslots` for each occupied PRB index.

```
subframeslots = zeros(enb.NDLRB,20);
for i = 0:9
    enb.NSubframe = i;
    prbSet = lteDCIResourceAllocation(enb,dci);
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots)
axis xy
xlabel('Subframe Slots')
ylabel('PRB Indices')
```



Observe from the image that the occupied PRB indices hops in odd and even slots.

- "Generate LTE Downlink RMC Waveforms"

Input Arguments

rc — Reference channel

'R.0' | 'R.1' | 'R.2' | 'R.3' | 'R.4' | 'R.5' | 'R.6' | 'R.7' | 'R.8' | 'R.9' | 'R.10' | 'R.11' | 'R.12' | 'R.13' | 'R.14' | 'R.25' | 'R.26' | 'R.27' | 'R.28' | 'R.31.3A' | 'R.31.4' | 'R.43' | 'R.44' | 'R.45' | 'R.45-1' | 'R.48' | 'R.50' | 'R.51' | 'R.6-27RB' | 'R.12-9RB' | 'R.11-45RB'

Reference channel, specified as a character vector. This argument identifies the reference measurement channel (RMC) number, as specified in TS 36.101, [1]. See "DL Reference Channel Options" on page 1-1032 for a list of the default top-level configuration associated with the available downlink reference channels.

Data Types: `char`

`trdata` — Information bits

vector | cell array containing one or two vectors

Information bits, specified as a vector or cell array containing one or two vectors of bit values. Each vector contains the information bits stream to be coded across the duration of the generation, which represents multiple concatenated transport blocks. If the number of bits required across all subframes of the generation exceeds the length of the vectors provided, the `txdata` vector is looped internally. This feature allows you to enter a short pattern, such as `[1;0;0;1]`, which is repeated as the input to the transport coding. In each subframe of generation, the number of data bits taken from this stream comes from the elements of the `rmccfgout.PDSCH.TrBlkSizes` matrix.

When the `trdata` input contains empty vectors, there is no transport data. The transmission of PDSCH and its corresponding PDCCH are skipped in the `waveform` when the `trdata` contains empty vectors. The other physical channels and signals are transmitted as normal in generated `waveform`.

Example: `[1;0;0;1]`

Data Types: `double | cell`
Complex Number Support: Yes

`duplexmode` — Duplexing mode

`'FDD'` (default) | optional | `'TDD'`

Duplexing mode, specified as `'FDD'` or `'TDD'` to indicate the frame structure type of the generated waveform.

Data Types: `char`

`totsubframes` — Total number of subframes

10 (default) | optional | positive numeric scalar

Total number of subframes, specified as a numeric scalar. Optional. This argument specifies the total number of subframes that form the resource grid.

Data Types: `double`

`rmccfg` — Reference channel configuration

scalar structure

Reference channel configuration, specified as a structure. The structure defines any (or all) of the fields or subfields. The reference configuration structure with default parameters can easily be created using the `lteRMCDL` function. `lteRMCDL` generates the various RMC configuration structures, as defined in TS 36.101 [1], Annex A.3.

You can use the `lteRMCDL` output configuration structure without change or modify it to align with your simulation requirements to generate the output `waveform`. SIB1 messages and the associated PDSCH and PDCCH can be added to the output `waveform` by adding the substructure `rmccfg.SIB`. `rmccfg` may include fields contained in the output structure, `rmccfgout`.

Data Types: `struct`

Output Arguments

`waveform` — Generated RMC time-domain waveform

numeric matrix

Generated RMC time-domain waveform, returned as a N_S-by-N_T numeric matrix. N_S is the number of time-domain samples and N_T is the number of transmit antennas.

Data Types: `double`
Complex Number Support: Yes

`grid` — Populated resource grid

numeric 3-D array

Populated resource grid, returned as a numeric 3-D array of resource elements for several subframes across all configured antenna ports, as described in “Data Structures”.

`grid` represents the populated resource grid for all the physical channels specified in TS 36.101 [1], Annex A.3.

Data Types: `double`
Complex Number Support: Yes

`rmccfgout` — RMC configuration

structure

RMC configuration output structure

RMC configuration, returned as a scalar structure. `rmccfgout` contains information about the OFDM-modulated waveform and RMC-specific configuration parameters. Field definitions and settings align with `rmccfg`.

For more information about the OFDM modulated waveform, see `lteOFDMInfo`. For more information about the RMC-specific configuration parameters, see `lteRMCDL`.

Parameter Field	Values	Description
`RC`	`'R.0'` (default), `'R.1'`, `'R.2'`, `'R.3'`, `'R.4'`, `'R.5'`, `'R.6'`, `'R.7'`, `'R.8'`, `'R.9'`, `'R.10'`, `'R.11'`, `'R.12'`, `'R.13'`, `'R.14'`, `'R.25'`, `'R.26'`, `'R.27'`, `'R.28'`, `'R.31-3A'`, `'R.31-4'`, `'R.43'`, `'R.44'`, `'R.45'`, `'R.45-1'`, `'R.48'`, `'R.50'`, `'R.51'`, `'R.6-27RB'`, `'R.12-9RB'`, `'R.11-45RB'`	Reference measurement channel (RMC) number or type, as specified in TS 36.101, Annex A.3. • `'R.31-3A'` and `'R.31-4'` are sustained data rate RMCs with user data in subframe 5. • `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` are custom RMCs configured for non-standard bandwidths that maintain the same code rate as the standardized versions defined in TS 36.101, Annex A.3.
`NDLRB`	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CellRefP`	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`NCellD`	Integer from 0 to 503	Physical layer cell identity
`CyclicPrefi`	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CFI`	1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)

Parameter Field	Values	Description
	(corresponding to a frame).	See footnote 1.
PCFICHPower	0 (default), numeric scalar	PCFICH symbol power adjustment, in dB
Ng	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
PHICHDurati	`'Normal'`, `'Extended'`	PHICH duration
HISet	Matrix with default size 112-by-3.	Contains the maximum PHICH groups (112) as per TS 36.211, Section 6.9 with the first PHICH sequence of each group set to ACK). For further details, see `ltePHICH`.
PHICHPower	0 (default), numeric scalar	PHICH symbol power in dB.
NFrame	0 (default), nonnegative scalar integer	Frame number
NSubFrame	0 (default), nonnegative scalar integer	Subframe number
TotSubFrame	Nonnegative scalar integer	Total number of subframes to generate
Windowing	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied
DuplexMode	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
This field is only present and applicable for `'Port7-14'` transmission scheme (`TxScheme`)		

Parameter Field	Values	Description
CSIRSPer	`'On'` (default), `'Off'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
The following fields are only present and applicable for `'Port7-14'` transmission scheme (`TxScheme`) and only required in `rmccfg` if `CSIRSPeriod` is not set to `'Off'`.		
CSIRSCon	Scalar integer	Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.
CSIRefP	1 (default), 2, 4, 8	Array of number of CSI-RS antenna ports
These fields are only present and applicable for `'Port7-14'` transmission scheme (`TxScheme`)		
ZeroPowe	`'Off'` (default), `'On'`, `Icsi-rs` (0,...,154), `[Tcsi-rs Dcsi-rs]`. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS subframe configurations for one or more zero power CSI-RS resource configuration index lists. Multiple zero power CSI-RS resource lists can be configured from a single common subframe configuration or from a cell array of configurations for each resource list.
The following field is only applicable for `'Port7-14'` transmission scheme (`TxScheme`) and only required in `rmccfg` if `CSIRSPeriod` is not set to `'Off'`.		
ZeroPowe	16-bit bitmap character vector (truncated if not 16 bits or `'0'` MSB extended), or a numeric list of CSI-RS configuration indices. You can also specify values in a cell array of configurations for each resource.	Zero power CSI-RS resource configuration index lists (TS 36.211 Section 6.10.5.2). Specify each list as a 16-bit bitmap character vector (if less than 16 bits, then `'0'` MSB extended). or as a numeric list of CSI-RS configuration indices from TS 36.211 Table 6.10.5.2-1 in the `'4'` CSI reference signal column. Multiple lists can be defined using a cell array of bitmap character vectors or numerical lists.

Parameter Field	Values	Description
PDSCH	Scalar structure	PDSCH transmission configuration substructure
SIB	Scalar structure	Include a SIB message by adding the `SIB` substructure to the `lteRMCDL` function configuration output structure, `rmccfgout`, after it is generated and before using the `rmccfgout` structure as input to `lteRMCDLTool`.
OCNGPDCCHEna	`'Off'`, `'On'`	Enable PDCCH OFDMA channel noise generator (OCNG). See footnote 2.
OCNGPDCCHPo	Scalar integer, `0` (default)	PDCCH OCNG power in dB
OCNGPDSCHEna	`'Off'`, `'On'`	Enable PDSCH OCNG
OCNGPDSCHPo	Scalar integer, defaults to `PDSCH.Rho` (default)	PDSCH OCNG power in dB
OCNGPDSCH	Scalar structure	PDSCH OCNG configuration substructure
OCNG	`'Off'`, `'On'`. `'Disable'` and `'Enable'` are also accepted.	OFDMA channel noise generator **Note:** This parameter will be removed in a future release. Use the PDCCH and PDSCH-specific OCNG parameters instead.
The following fields are only present and applicable for `'TDD'` duplex mode (`DuplexMode`).		
SSC	0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
TDDConfi	0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
SamplingRat	Numeric scalar	Carrier sampling rate in Hz, $(N_{SC}/N_{SYM}) \times 3.84e6$, where N_{SC} is the number of subcarriers and N_{SYM} is the number of OFDM symbols in a subframe.

Parameter Field	Values	Description
`Nfft`	Scalar integer, typically one of {128, 256, 512, 1024, 1536, 2048} for standard channel bandwidths {`'1.4MHz'`, `'3MHz'`, `'5MHz'`, `'10MHz'`, `'15MHz'`, `'20MHz'`}, respectively.	Number of FFT frequency bins

1 CFI is equal to the number of symbols allocated to:

- PDCCH - 1 for `NDLRB < 10`
- PDCCH for `NDLRB >= 10`

For the RMCs, the number of symbols allocated to PDCCH varies with channel bandwidth setting,

- 2 symbols for 20 MHz, 15 MHz, and 10 MHz
- 3 symbols for 5 MHz and 3 MHz
- 4 symbols for 1.4 MHz

In the TDD mode, only two OFDM symbols are allocated to PDCCH in subframes 1 and 6 irrespective of the channel bandwidth. Therefore, the CFI value varies per subframe for the 5 MHz and 3 MHz and 1.4 MHz channel bandwidths, that is for bandwidths where PDCCH symbol allocation is not two for other subframes.

2 The PDCCH ONCG fills the unused PDCCH resource elements with QPSK symbols using either single port or transmit diversity depending on the number of cell RS ports.

PDSCH substructure

The substructure PDSCH relates to the physical channel configuration and contains these fields:

<table>
<tr><th>Parameter Field</th><th>Values</th><th>Description</th></tr>
<tr><td>TxScheme</td><td>'Port0', 'TxDiversity', 'CDD', 'SpatialMux', 'MultiUser', 'Port7-8', 'Port7-14'.</td><td>PDSCH transmission scheme, specified as one of the following options.
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td>Modulation</td><td>'QPSK', '16QAM', '64QAM', or '256QAM'</td><td>Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.</td></tr>
<tr><td>NLayers</td><td>Integer from 1 to 8</td><td>Number of transmission layers.</td></tr>
<tr><td>Rho</td><td>0 (default), Numeric scalar</td><td>PDSCH resource element power allocation, in dB</td></tr>
<tr><td>RNTI</td><td>0 (default), scalar integer</td><td>Radio network temporary identifier (RNTI) value (16 bits)</td></tr>
</table>

Parameter Field	Values	Description
RVSeq	Integer vector (0,1,2,3), specified as a one or two row matrix (for one or two codewords)	Specifies the sequence of Redundancy Version (RV) indicators for each HARQ process. The number of elements in each row is equal to the number of transmissions in each HARQ process. If `RVSeq` is a row vector in a two codeword transmission, then the same RV sequence is applied to both codewords.
RV	Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).	Specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is Read-Only.
NHARQProces	1, 2, 3, 4, 5, 6, 7, or 8	Number of HARQ processes per component carrier
NTurboDecit	5 (default), nonnegative scalar integer	Number of turbo decoder iteration cycles
PRBSet	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.

Parameter Field	Values	Description
TargetCodeRa	Numeric scalar or one or two row numeric matrix	Target code rates for one or two codewords for each subframe in a frame. Used for calculating the transport block sizes according to TS 36.101 [1], Annex A.3.1. If both `TargetCodeRate` and `TrBlkSizes` are not provided at the input, and the RC does not have a single ratio target code rate in TS 36.101, Table A.3.1.1-1, `TargetCodeRate` == `ActualCodeRate`.
ActualCodeRa	One or two row numeric matrix	Actual code ratesfor one or two codewords for each subframe in a frame, calculated according to TS 36.101 [1], Annex A.3.1. The maximum actual code rate is 0.93. This parameter field is only for informational purposes and is read-only.
TrBlkSizes	One or two row numeric matrix	Transport block sizes for each subframe in a frame
CodedTrBlkS	One or two row numeric matrix	Coded transport block sizes for one or two codewords. This parameter field is only for informational purposes.
DCIFormat	`'Format0'`, `'Format1'`, `'Format1A'`, `'Format1B'`, `'Format1C'`, `'Format1D'`, `'Format2'`, `'Format2A'`, `'Format2B'`, `'Format2C'`, `'Format2D'`, `'Format3'`, `'Format3A'`, `'Format4'`, `'Format5'`	Downlink control information (DCI) format type of the PDCCH associated with the PDSCH. See `lteDCI`.

Parameter Field	Values	Description
PDCCHFormat	0, 1, 2, 3	Aggregation level of PDCCH associated with PDSCH
PDCCHPower	Numeric scalar	PDCCH power in dB
CSIMode	'PUCCH 1-0', 'PUCCH 1-1', 'PUSCH 1-2', 'PUSCH 3-0', 'PUSCH 3-1'	CSI reporting mode
PMIMode	'Wideband' (default), 'Subband'	PMI reporting mode. PMIMode='Wideband' corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and PMIMode='Subband' corresponds to PUSCH reporting Mode 3-1.
The following field is only present for 'SpatialMux' transmission scheme (TxScheme).		
PMISet	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see ltePMIInfo.
The following field is only present for 'Port7-8', 'Port8', or 'Port7-14' transmission schemes (TxScheme).		
NSCID	0 (default), 1	Scrambling identity (*ID*)
The following fields are only present for UE-specific beamforming ('Port5', 'Port7-8', 'Port8', or 'Port7-14').		
W	Numeric matrix	NLayers-by-*P* precoding matrix for the wideband UE-specific beamforming of the PDSCH symbols. *P* is the number of transmit antennas. An empty matrix, [], signifies no precoding.
NTxAnts	Nonnegative scalar integer	Number of transmission antennas.

Parameter Field	Values	Description
HARQProcess	1-by-L_{HARQ_Seq} integer vector.	One-based HARQ process indices for the internal HARQ scheduling sequence. The sequence of length L_{HARQ_Seq} is optimized according to transport block sizes, number of HARQ processes, duplex mode, and when in TDD mode the UL/DL configuration. See footnote 2.

1 The function returns valid `TrBlkSizes` and `CodedTrBlkSizes` set to 0 when `PRBSet` is empty, indicating there is no PDSCH allocation in this frame.

2 The HARQ process sequence table is calculated according to the procedure detailed in 3GPP Tdoc R5-095777 ("Scheduling of retransmissions and number of active HARQ processes for DL performance RMC-s")

- For the case when `NHARQProcesses` = 1, the `HARQProcessSequence` is `[1 0 0 0 0 0 0 0 0 0]`. Using this HARQ process sequence, only the `TrBlkSize` corresponding to subframe 0 gets transmitted. There is no transmission in other subframes, even if the transport block sizes in other subframes are nonzero.

SIB substructure

If the substructure `SIB` has been added to `rmccfg`, SIB1 messages and the associated PDSCH and PDCCH can be generated. The `SIB` substructure includes these fields:

Parameter Field	Values	Description
Data	(0,1), bit array	SIB1 transport block information bits See footnote 1.
VRBStart	variable, see rules in TS 36.213 Section 7.1.6.3	Virtual RB allocation starting resource block, RB_{start}.
VRBLength	variable, see rules in TS 36.213 Section 7.1.6.3	Length in terms of virtualy contiguously allocated resource blocks, L_{CRBs}.
Enable	`'On'` (default), `'Off'`	Enable/Disable SIB generation

Parameter Field	Values	Description
DCIFormat	'Format1A' (default) or 'Format1C'	Downlink control information (DCI) format
AllocationTy	0 (default) or 1, single bit flag	Localized (0) or distributed (1) allocation of virtual resource blocks for Resource allocation type 2
The following parameter is only applicable when DCIFormat = 'Format1A'.		
N1APRB	2 or 3	Transport block set selection parameter, N_{PRB}^{1A} Indicates the column in TS 36.213, Table 7.1.7.2.1-1 for transport block size selection. The default is the smallest transport block size, in either column 2 or 3, that provides a valid transport block size bigger than or equal to the length of the Data field. Also see TS 36.212 Section 5.3.3.1.3 and TS 36.213 Section 7.1.7.
The following parameter is only applicable when using distributed allocation (AllocationType = 1).		
Gap	0 or 1	Distributed allocation gap, '0' for $N_{\text{gap},1}$ or '1' for $N_{\text{gap},2}$

Parameter Field	Values	Description
	1 The set of valid transport block sizes is specified in TS 36.213 [4], Table 7.1.7.2.1-1. Only columns 2 and 3 apply to the SIB DL-SCH. The `Data` field is padded with zeros to the closest valid size from this table.	

Note:

- Per TS 36.321 [5], Section 6.1.1, the lowest order information bit of the `SIB.Data` field is mapped to the most significant bit of the SIB1 transport block.
- For subframe 5, per TS 36.101 [1], Annex A.3, reference PDSCH transmissions are not scheduled in subframe 5 except for the SIB1 associated PDSCH.
- Setting the `OCNG` parameter field `'On'` fills all unused, unscheduled PDSCH resource elements with QPSK modulated random data.
- The values for CFI and PRBSet can vary per subframe. If these parameters are arrays, then the function cyclically steps through the elements of the array starting with the index given by mod(*NSubframe*,length(*parameter*)). When *parameter* is `PRBSet`, the parameter must be a cell array of column vectors or slot-wise matrices.
- The PHICH symbols carry a single ACK on the first PHICH instance in each PHICH group.

OCNGPDSCH substructure

The substructure, `OCNGPDSCH`, defines the OCNG patterns in associated RMCs and tests according to TS 36.101 [1], Section A.5. `OCNGPDSCH` contains these fields which can also be customized with the full range of PDSCH-specific values.

Parameter Field	Values	Description
`Modulation`	OCNG `Modulation` has same setting options as `rmccfgout.PDSCH.Modul`	See `rmccfgout.PDSCH.Modulation`
`TxScheme`	OCNG `TxScheme` has same setting options as `rmccfgout.PDSCH.TxSch`	See `rmccfgout.PDSCH.TxScheme`

Parameter Field	Values	Description
RNTI	0 (default), scalar integer	OCNG radio network temporary identifier (RNTI) value. (16 bits)

Data Types: `struct`

Definitions

DL Reference Channel Options

The output configuration structure is initialized in accordance with the reference channels defined in TS 36.101, Annex A.3. Initialization choices available for the downlink reference channel and associated top-level configuration defaults include:

Reference channels	Reference channels (continued)
`R.0 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)`	`R.31-3A FDD (CDD, 50 RB, 64QAM, CellRefP=2, R=0.85-0.90)`
`R.1 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)`	`R.31-3A TDD (CDD, 68 RB, 64QAM, CellRefP=2, R=0.87-0.90)`
`R.2 (Port0, 50 RB, QPSK, CellRefP=1, R=1/3)`	`R.31-4 (CDD, 100 RB, 64QAM, CellRefP=2, R=0.87-0.90)`
`R.3 (Port0, 50 RB, 16QAM, CellRefP=1, R=1/2)`	`R.43 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)`
`R.4 (Port0, 6 RB, QPSK, CellRefP=1, R=1/3)`	`R.43 TDD (SpatialMux, 100 RB, 16QAM, CellRefP=4, R=1/2)`
`R.5 (Port0, 15 RB, 64QAM, CellRefP=1, R=3/4)`	`R.44 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)`
`R.6 (Port0, 25 RB, 64QAM, CellRefP=1, R=3/4)`	`R.44 TDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)`
`R.7 (Port0, 50 RB, 64QAM, CellRefP=1, R=3/4)`	`R.45 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)`

Reference channels	Reference channels (continued)
R.8 (Port0, 75 RB, 64QAM, CellRefP=1, R=3/4)	R.45-1 (Port7-14, 39 RB, 16QAM, CellRefP=2, R=1/2)
R.9 (Port0, 100 RB, 64QAM, CellRefP=1, R=3/4)	R.48 (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/2)
R.10 (TxDiversity|SpatialMux, 50 RB, QPSK, CellRefP=2, R=1/3)	R.50 FDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)
R.11 (TxDiversity|SpatialMux|CDD, 50 RB, 16QAM, CellRefP=2, R=1/2)	R.50 TDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.12 (TxDiversity, 6 RB, QPSK, CellRefP=4, R=1/3)	R.51 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)
R.13 (SpatialMux, 50 RB, QPSK, CellRefP=4, R=1/3)	R.6-27RB (Port0, 27 RB, 64QAM, CellRefP=1, R=3/4)
R.14 (SpatialMux|CDD, 50 RB, 16QAM, CellRefP=4, R=1/2)	R.12-9RB (TxDiversity, 9 RB, QPSK, CellRefP=4, R=1/3)
R.25 (Port5, 50 RB, QPSK, CellRefP=1, R=1/3)	R.11-45RB (CDD, 45 RB, 16QAM, CellRefP=2, R=1/2)
R.26 (Port5, 50 RB, 16QAM, CellRefP=1, R=1/2)	
R.27 (Port5, 50 RB, 64QAM, CellRefP=1, R=3/4)	
R.28 (Port5, 1 RB, 16QAM, CellRefP=1, R=1/2)	

Note: Reference channels `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` maintain the same code rate as the standard versions but are custom RMCs configured for nonstandard bandwidths.

References

[1] 3GPP TS 36.101. "User Equipment (UE) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical channels and modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[4] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[5] 3GPP TS 36.321. "Medium Access Control (MAC) protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

Apps

LTE Downlink RMC Generator

Functions

`lteRMCDL` | `lteRMCULTool` | `lteTestModelTool`

Topics

"Generate LTE Downlink RMC Waveforms"

Introduced in R2014a

lteRMCUL

Uplink reference measurement channel or FRC configuration

Syntax

```
rmccfgout = lteRMCUL(rc,duplexmode,totsubframes)
rmccfgout = lteRMCUL(rmccfg)
```

Description

`rmccfgout = lteRMCUL(rc,duplexmode,totsubframes)` returns a configuration structure for the reference channel defined by `rc` using a channel-specific default configuration. `duplexmode` and `totsubframes` are optional input parameters which define the duplexing mode and total number of subframes to be generated.

Use `rmccfgout` to generate a waveform with the fixed reference channel (FRC) generator tool, `lteRMCULTool`. The field names and default values of FRCs are in accordance with TS 36.104 [2], Annex A.

`rmccfgout = lteRMCUL(rmccfg)` returns a fully configured structure for the reference channel partially, or wholly, defined by the input structure, `rmccfg`. Any parameters missing at the input will be initialized based on the `rc` field, if present in `rmccfg`, or the reference channel `'A1-1'` otherwise.

`rmccfg` can include the field `SRS` to enable SRS related configuration parameters.

Examples

Create Uplink RMC

Using the reference measurement channel designation, create an uplink RMC configuration for RC 'A7-4'.

```
rmc = lteRMCUL('A7-4')
```

```
rmc =
```

```
  struct with fields:

              RC: 'A7-4'
           NULRB: 25
         NCellID: 0
          NFrame: 0
       NSubframe: 0
    CyclicPrefixUL: 'Normal'
       CyclicShift: 0
         Shortened: 0
           Hopping: 'Off'
          SeqGroup: 0
     TotSubframes: 10
             RNTI: 1
          NTxAnts: 1
        Windowing: 0
       DuplexMode: 'FDD'
            PUSCH: [1×1 struct]
```

Create Uplink RMC Configuration

Create a configuration structure for RC A1-1 as specified in TS 36.104.

```
rmc.RC = 'A1-1';
rmc.NCellID = 100;
rmcOut = lteRMCUL(rmc)
rmcOut.PUSCH
```

```
rmcOut =

  struct with fields:

              RC: 'A1-1'
           NULRB: 6
         NCellID: 100
          NFrame: 0
       NSubframe: 0
    CyclicPrefixUL: 'Normal'
       CyclicShift: 0
         Shortened: 0
           Hopping: 'Off'
          SeqGroup: 0
```

```
      TotSubframes: 10
              RNTI: 1
           NTxAnts: 1
         Windowing: 0
        DuplexMode: 'FDD'
             PUSCH: [1×1 struct]


ans =

  struct with fields:

          Modulation: 'QPSK'
             NLayers: 1
       DynCyclicShift: 0
            NBundled: 0
             BetaACK: 2
             BetaCQI: 2
              BetaRI: 2
       NHARQProcesses: 8
               RVSeq: [0 2 3 1]
                  RV: 0
        NTurboDecIts: 5
           OrthCover: 'On'
                 PMI: 0
              PRBSet: [6×1 double]
       TargetCodeRate: 0.3333
       ActualCodeRate: [1×10 double]
           TrBlkSizes: [600 600 600 600 600 600 600 600 600 600]
      CodedTrBlkSizes: [1728 1728 1728 1728 1728 1728 1728 1728 1728 1728]
```

Customize Uplink RMC

Create a new customized parameter set by overriding selected values of an existing preset RMC. Define a full-band 5MHz PUSCH using 64QAM modulation and 1/3 rate.

Looking at TS 36.104 Annex A reference measurement channels, A1-3 matches this criteria but with QPSK modulation.

Create a configuration structure for RC A1-3 as specified in TS 36.104.

```
rmc.RC = 'A1-3';
rmcout = lteRMCUL(rmc,1);
rmcout.PUSCH
```

```
ans =

  struct with fields:

         Modulation: 'QPSK'
            NLayers: 1
       DynCyclicShift: 0
             NBundled: 0
              BetaACK: 2
              BetaCQI: 2
               BetaRI: 2
       NHARQProcesses: 8
                RVSeq: [0 2 3 1]
                   RV: 0
         NTurboDecIts: 5
            OrthCover: 'On'
                  PMI: 0
               PRBSet: [25×1 double]
       TargetCodeRate: 0.3333
       ActualCodeRate: [1×10 double]
           TrBlkSizes: [2216 2216 2216 2216 2216 2216 2216 2216 2216 2216]
      CodedTrBlkSizes: [7200 7200 7200 7200 7200 7200 7200 7200 7200 7200]
```

Override the PUSCH modulation, setting it to 64QAM. Create a new configuration structure. Inspect `rmcout` to see the modulation is 64QAM and the PUSCH transport block sizes and physical channel capacities have been updated to maintain the same 1/3 code rate.

```
rmc.PUSCH.Modulation = '64QAM';
rmcOverrideOut = lteRMCUL(rmc,1);
rmcOverrideOut
rmcOverrideOut.PUSCH
```

```
rmcOverrideOut =

  struct with fields:

                  RC: 'A1-3'
               NULRB: 25
             NCellID: 0
              NFrame: 0
           NSubframe: 0
```

```
    CyclicPrefixUL: 'Normal'
       CyclicShift: 0
         Shortened: 0
           Hopping: 'Off'
          SeqGroup: 0
      TotSubframes: 10
              RNTI: 1
           NTxAnts: 1
         Windowing: 0
        DuplexMode: 'FDD'
             PUSCH: [1×1 struct]


ans =

  struct with fields:

         Modulation: '64QAM'
            NLayers: 1
     DynCyclicShift: 0
           NBundled: 0
            BetaACK: 2
            BetaCQI: 2
             BetaRI: 2
     NHARQProcesses: 8
              RVSeq: [0 2 3 1]
                 RV: 0
       NTurboDecIts: 5
          OrthCover: 'On'
                PMI: 0
             PRBSet: [25×1 double]
     TargetCodeRate: 0.3333
     ActualCodeRate: [1×10 double]
         TrBlkSizes: [7224 7224 7224 7224 7224 7224 7224 7224 7224 7224]
    CodedTrBlkSizes: [1×10 double]
```

Input Arguments

rc — Reference channel number

```
'A1-1' | 'A1-2' | 'A1-3' | 'A1-4' | 'A1-5' | 'A2-1' | 'A2-2' | 'A2-3' |
'A3-1' | 'A3-2' | 'A3-3' | 'A3-4' | 'A3-5' | 'A3-6' | 'A3-7' | 'A4-1' |
```

```
'A4-2' | 'A4-3' | 'A4-4' | 'A4-5' | 'A4-6' | 'A4-7' | 'A4-8' | 'A5-1' |
'A5-2' | 'A5-3' | 'A5-4' | 'A5-5' | 'A5-6' | 'A5-7' | 'A7-1' | 'A7-2' |
'A7-3' | 'A7-4' | 'A7-5' | 'A7-6' | 'A8-1' | 'A8-2' | 'A8-3' | 'A8-4' |
'A8-5' | 'A8-6' | 'A11-1' | 'A3-2-9RB' | 'A4-3-9RB'
```

Reference channel number, specified as a character vector. This argument represents the reference measurement channel (RMC) number, or fixed reference channel (FRC), as described in TS 36.104[2]. See "UL Reference Channel Options" on page 1-1047 for a list of the default top-level configuration associated with the available uplink reference channels.

Data Types: `char`

`duplexmode` — Duplexing mode

`'FDD'` (default) | optional | `'TDD'`

Duplexing mode, specified as `'FDD'` or `'TDD'`. It represents the frame structure type.

Data Types: `char`

`totsubframes` — Total number of subframes

10 (default) | optional | positive numeric scalar

Total number of subframes, specified as a numeric scalar. This argument specifies the total number of subframes that form the resource grid.

Data Types: `double`

`rmccfg` — Reference channel configuration

structure

Reference channel configuration, specified as a structure. The structure defines any, or all, of the fields or subfields contained in the output structure, `rmccfgout`. Any undefined fields are given appropriate default values.

Parameter Field	Required or Optional	Values	Description
RC	Optional	`'A1-1'` (default), `'A1-2'`, `'A1-3'`, `'A1-4'`, `'A1-5'`,	Reference measurement channel (RMC) number or type, as specified in TS 36.104 Annex A.

Parameter Field	Required or Optional	Values	Description
		`'A2-1'`, `'A2-2'`, `'A2-3'`, `'A3-1'`, `'A3-2'`, `'A3-3'`, `'A3-4'`, `'A3-5'`, `'A3-6'`, `'A3-7'`, `'A4-1'`, `'A4-2'`, `'A4-3'`, `'A4-4'`, `'A4-5'`, `'A4-6'`, `'A4-7'`, `'A4-8'`, `'A5-1'`, `'A5-2'`, `'A5-3'`, `'A5-4'`, `'A5-5'`, `'A5-6'`, `'A5-7'`, `'A7-1'`, `'A7-2'`, `'A7-3'`, `'A7-4'`, `'A7-5'`, `'A7-6'`, `'A8-1'`, `'A8-2'`, `'A8-3'`, `'A8-4'`, `'A8-5'`, `'A8-6'`, `'A11-1'`, `'A3-2-9RB'`, `'A4-3-9RB'`	[2].
SRS	Optional	`'off'` (default), `'on'`	Enable SRS related configuration parameters (set SRS to `'on'`) for RMCs which optionally support SRS, or a complete or part SRS structure. If absent, no SRS configuration is created.

Data Types: `struct`

Output Arguments

`rmccfgout` — Configuration parameters

structure

Configuration parameters structure

Configuration parameters, returned as a structure. `rmccfgout` contains the following fields.

Parameter Field	Values	Description
`RC`	`'A1-1'` (default), `'A1-2'`, `'A1-3'`, `'A1-4'`, `'A1-5'`, `'A2-1'`, `'A2-2'`, `'A2-3'`, `'A3-1'`, `'A3-2'`, `'A3-3'`, `'A3-4'`, `'A3-5'`, `'A3-6'`, `'A3-7'`, `'A4-1'`, `'A4-2'`, `'A4-3'`, `'A4-4'`, `'A4-5'`, `'A4-6'`, `'A4-7'`, `'A4-8'`, `'A5-1'`, `'A5-2'`, `'A5-3'`, `'A5-4'`, `'A5-5'`, `'A5-6'`, `'A5-7'`, `'A7-1'`, `'A7-2'`, `'A7-3'`, `'A7-4'`, `'A7-5'`, `'A7-6'`, `'A8-1'`, `'A8-2'`, `'A8-3'`, `'A8-4'`, `'A8-5'`, `'A8-6'`, `'A11-1'`, `'A3-2-9RB'`, `'A4-3-9RB'`	Reference channel number
`NULRB`	Scalar integer from 6 to 110	Number of uplink resource blocks. ($N_{\mathrm{RB}}^{\mathrm{UL}}$)
`NCellD`	Integer from 0 to 503	Physical layer cell identity
`NFrame`	0 (default), nonnegative scalar integer	Frame number
`NSubFrame`	0 (default), nonnegative scalar integer	Initial subframe number
`CyclicPrefi`	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CyclicShift`	0, 1, 2, 3, 4, 5, 6, 7	Cyclic shift. This argument yields $n_{\mathrm{DMRS}}^{(1)}$.
`Shortened`	0 (default), 1	Subframe shortened flag. If the function sets the flag to `1`, the last symbol of the

Parameter Field	Values	Description
		subframe is not used. Subframes with possible SRS transmission require this flag to be set.
Hopping	`'Off'` (default), `'Group'`, or `'Sequence'`	Hopping type
SeqGroup	0 (default), integer from 0 to 29	PUSCH sequence group assignment (Δ_{SS}).
TotSubFrames	`10` (default) Positive scalar integer	Total number of subframes to generate This argument specifies the total number of subframes that form the resource grid.
RNTI	`1` (default) Scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
NTxAnts	1, 2, 4	Number of transmission antennas.
Windowing	Nonnegative scalar integer	The number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied
DuplexMode	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex It represents the frame structure type.
PUSCH	Structure	PUSCH transmission configuration
SRS	Structure	Sounding Reference Signal (SRS) configuration

PUSCH substructure

The substructure `PUSCH` relates to the physical channel configuration and contains these fields:

Parameter Field	Values	Description
Modulation	'QPSK', '16QAM', '64QAM'	Modulation format
NLayers	1, 2, 3, 4	Number of transmission layers.
DynCyclicSh	0, 1, 2, 3, 4, 5, 6, 7	Cyclic shift for DM-RS (yields $n_{\mathrm{DMRS}}^{(2)}$).
NBundled	0, 1, 2, 3, 4, 5, 6, 7, 8, 9	HARQ-ACK bundling scrambling sequence index
BetaACK	Scalar integer	Modulation and coding scheme (MCS) offset for HARQ-ACK bits, returned as a scalar integer.
BetaCQI	Scalar integer	Modulation and coding scheme (MCS) offset for CQI and PMI bits
BetaRI	Scalar integer	Modulation and coding scheme (MCS) offset for RI bits
NHARQProces	1, 2, 3, 4, 5, 6, 7, 8	Number of HARQ processes per component carrier
RVSeq	Numeric matrix	Redundancy version (RV) indicator, returned as a numeric matrix. This argument is a 1- or 2-row matrix that specifies the redundancy version (RV) indicator for one or two codewords. The RV indicator specified in each column is applied to the transmission in a HARQ process. The number of transmissions in a HARQ process equals the number of columns in `RVSeq`, where the row defines the RV indicator for one or two codewords. In a two-codeword transmission, if `RVSeq` is a row vector, the same RV indicator is applied to both codewords. See footnote 1.

Parameter Field	Values	Description
RV	Numeric matrix	Redundancy version (RV) indicator in initial subframe, returned as a numeric matrix. This argument is a 1- or 2-column vector that specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is read-only.
NTurboDecIt	Positive scalar integer	Number of turbo decoder iteration cycles
OrthCover	`'Off'` (default), `'On'`	Orthogonal cover sequence flag. Applies (`'On'`), or does not apply (`'Off'`), orthogonal cover sequence *w* (*Activate-DMRS-with OCC*).
PMI	Integer from 0 to 23	Scalar precoder matrix indication (PMI) to be used during precoding
PRBSet	Integer matrix	Physical resource block set of indices, returned as a integer matrix. This argument is a 1- or 2-column matrix that contains the 0-based physical resource block indices (PRBs) corresponding to the resource allocations for this PUSCH.
TargetCodeR	Scalar or vector	Target code rates for each subframe in a frame. Used for calculating the transport block sizes according to TS 36.101[1], Annex A.2.1.2. If `TargetCodeRate` is not provided and `TrBlkSizes` is provided at the input, `TargetCodeRate` == `ActualCodeRate`.
ActualCodeR	Numeric vector	Actual code rates for each subframe in a frame. The maximum actual code rates is 0.93. This parameter field is only for informational purposes and is read-only.

Parameter Field	Values	Description
TrBlkSizes	Numeric vector	Transport block sizes for each subframe in a frame See footnote 1.
CodedTrBlkS	Numeric vector	Coded transport block sizes for each a subframe in a frame, returned as a numeric vector. This parameter field is only for informational purposes and is read-only. See footnote 1.
1 The values of RVSeq, TrBlkSizes, and CodedTrBlkSizes are set according to the modulation scheme and TargetCodeRate.		

SRS substructure

The substructure SRS contains these fields:

Parameter Field	Values	Description
NTxAnts	1 (default), 2, 4	Number of transmission antennas.
BWConfig	0, 1, 2, 3, 4, 5, 6, 7	Cell-specific SRS Bandwidth Configuration value (C_{SRS})
BW	0, 1, 2, 3	UE-specific SRS Bandwidth value (B_{SRS})
ConfigIdx	Integer from 0 to 644	Configuration index (I_{SRS}) for UE-specific periodicity (T_{SRS}) and subframe offset (T_{offset}).
TxComb	0 or 1	Transmission comb. Controls SRS positions; SRS is transmitted in 6 carriers per resource block on odd (1) and even (0) resource indices.
HoppingBW	0, 1, 2, 3	SRS Frequency hopping configuration index (b_{hop})
FreqPositio	Integer from 0 to 23	Frequency domain position (n_{RRC})

Parameter Field	Values	Description
`CyclicShift`	0 (default), integer from 0 to 7	UE-specific cyclic shift ($n_{\mathrm{SRS}}^{\mathrm{cs}}$)
`SeqGroup`	0 (default), integer from 0 to 29	SRS sequence group number (u)
`SeqIdx`	0 or 1	Base sequence number (v)
`SubframeCon`	Integer from 0 to 15	Sounding reference signal (SRS) subframe configuration
The following fields are present only when `DuplexMode` is set to `'TDD'`.		
`NF4RachPre`	0, 1, 2, 3, 4, 5, 6	Number of RACH preamble frequency resources of Format 4 in *UpPTS*
`OffsetIdx`	0 or 1	Choice of SRS Subframe Offset in the case of 2 ms SRS periodicity. This parameter indexes the two SRS Subframe Offset entries in the row specified by the `ConfigIdx` parameter in table 8.2-2 of TS 36.213 for the SRS Configuration Index.

Definitions

UL Reference Channel Options

Initialization choices available for the uplink reference channel and associated top-level configuration defaults include:

Reference channels	Reference channels (continued)	Reference channels (continued)
`A1-1 (6 RB, QPSK, R=1/3)`	`A4-1 (1 RB, 16QAM, R=3/4)`	`A7-1 (3 RB, 16QAM, R=3/4)`
`A1-2 (15 RB, QPSK, R=1/3)`	`A4-2 (1 RB, 16QAM, R=3/4)`	`A7-2 (6 RB, 16QAM, R=3/4)`
`A1-3 (25 RB, QPSK, R=1/3)`	`A4-3 (6 RB, 16QAM, R=3/4)`	`A7-3 (12 RB, 16QAM, R=3/4)`

Reference channels	Reference channels (continued)	Reference channels (continued)
A1-4 (3 RB, QPSK, R=1/3)	A4-4 (15 RB, 16QAM, R=3/4)	A7-4 (25 RB, 16QAM, R=3/4)
A1-5 (9 RB, QPSK, R=1/3)	A4-5 (25 RB, 16QAM, R=3/4)	A7-5 (25 RB, 16QAM, R=3/4)
A2-1 (6 RB, 16QAM, R=2/3)	A4-6 (50 RB, 16QAM, R=3/4)	A7-6 (25 RB, 16QAM, R=3/4)
A2-2 (15 RB, 16QAM, R=2/3)	A4-7 (75 RB, 16QAM, R=3/4)	A8-1 (3 RB, QPSK, R=1/3)
A2-3 (25 RB, 16QAM, R=2/3)	A4-8 (100 RB, 16QAM, R=3/4)	A8-2 (6 RB, QPSK, R=1/3)
A3-1 (1 RB, QPSK, R=1/3)	A5-1 (1 RB, 64QAM, R=5/6)	A8-3 (12 RB, QPSK, R=1/3)
A3-2 (6 RB, QPSK, R=1/3)	A5-2 (6 RB, 64QAM, R=5/6)	A8-4 (25 RB, QPSK, R=1/3)
A3-3 (15 RB, QPSK, R=1/3)	A5-3 (15RB, 64QAM, R=5/6)	A8-5 (25 RB, QPSK, R=1/3)
A3-4 (25 RB, QPSK, R=1/3)	A5-4 (25 RB, 64QAM, R=5/6)	A8-6 (25 RB, QPSK, R=1/3)
A3-5 (50 RB, QPSK, R=1/3)	A5-5 (50 RB, 64QAM, R=5/6)	A11-1 (3RB, QPSK, R=11/27)
A3-6 (75 RB, QPSK, R=1/3)	A5-6 (75 RB, 64QAM, R=5/6)	A3-2-9RB (6 RB, QPSK, R=1/3)
A3-7 (100 RB, QPSK, R=1/3)	A5-7 (100 RB, 64QAM, R=5/6)	

The fields in the output configuration structure, `rmccfgout`, are initialized in accordance with the reference channels defined in TS 36.104, Annex A.

- `'A3-2-9RB'`, and `'A4-3-9RB'` are custom RMC configured for non-standard bandwidths but with the same code rate as the standardized versions.
- `'A11-1'` enables TTI bundling and the corresponding HARQ pattern (enhanced HARQ pattern for FDD).

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteRMCDL` | `lteRMCULTool` | `lteTestModel`

Introduced in R2014a

lteRMCULTool

Uplink RMC or FRC waveform generation

Syntax

```
[waveform,grid,rmccfgout] = lteRMCULTool
[waveform,grid,rmccfgout] = lteRMCULTool(rc,trdata)
[waveform,grid,rmccfgout] = lteRMCULTool(rc,trdata,duplexmode,
totsubframes)
[waveform,grid,rmccfgout] = lteRMCULTool(rmccfg,trdata)
[waveform,grid,rmccfgout] = lteRMCULTool(rmccfg,trdata,cqi,ri,ack)
```

Description

`[waveform,grid,rmccfgout] = lteRMCULTool` starts a user interface for the parameterization and generation of the reference measurement channel (RMC) `waveform`, the resource element `grid`, and an RMC configuration structure, `rmccfgout`. The main function outputs are specified in the GUI but can also be assigned to variables. See "UL Reference Channel Options" on page 1-1066 for a list of the default top-level configuration associated with the available uplink reference channels.

`[waveform,grid,rmccfgout] = lteRMCULTool(rc,trdata)` specifies the reference channel, `rc`, and information bits, `trdata`.

`[waveform,grid,rmccfgout] = lteRMCULTool(rc,trdata,duplexmode, totsubframes)` also accepts optional input arguments to define the duplex mode of the generated waveform and total number of subframes that make up the `grid`.

`[waveform,grid,rmccfgout] = lteRMCULTool(rmccfg,trdata)` where `rmccfg` specifies a reference channel structure. The reference channel structure with default parameters can easily be created with the function `lteRMCUL` then modified as desired.

`[waveform,grid,rmccfgout] = lteRMCULTool(rmccfg,trdata,cqi,ri,ack)` where support for control information transmission on PUSCH is specified in vectors `cqi`, `ri`, and `ack`. Together, these three fields form an uplink control information (UCI)

message. If these particular control information bits are not present in this transmission, `cqi`, `ri`, and `ack` can be empty vectors. The UCI is encoded for PUSCH transmission using the processing defined in TS 36.212 [3], Section 5.2.4, consisting of UCI coding and channel interleaving. The vectors `cqi`, `ri`, and `ack` are not treated as data streams. Thus, each subframe contains the same CQI, RI, and ACK information bits.

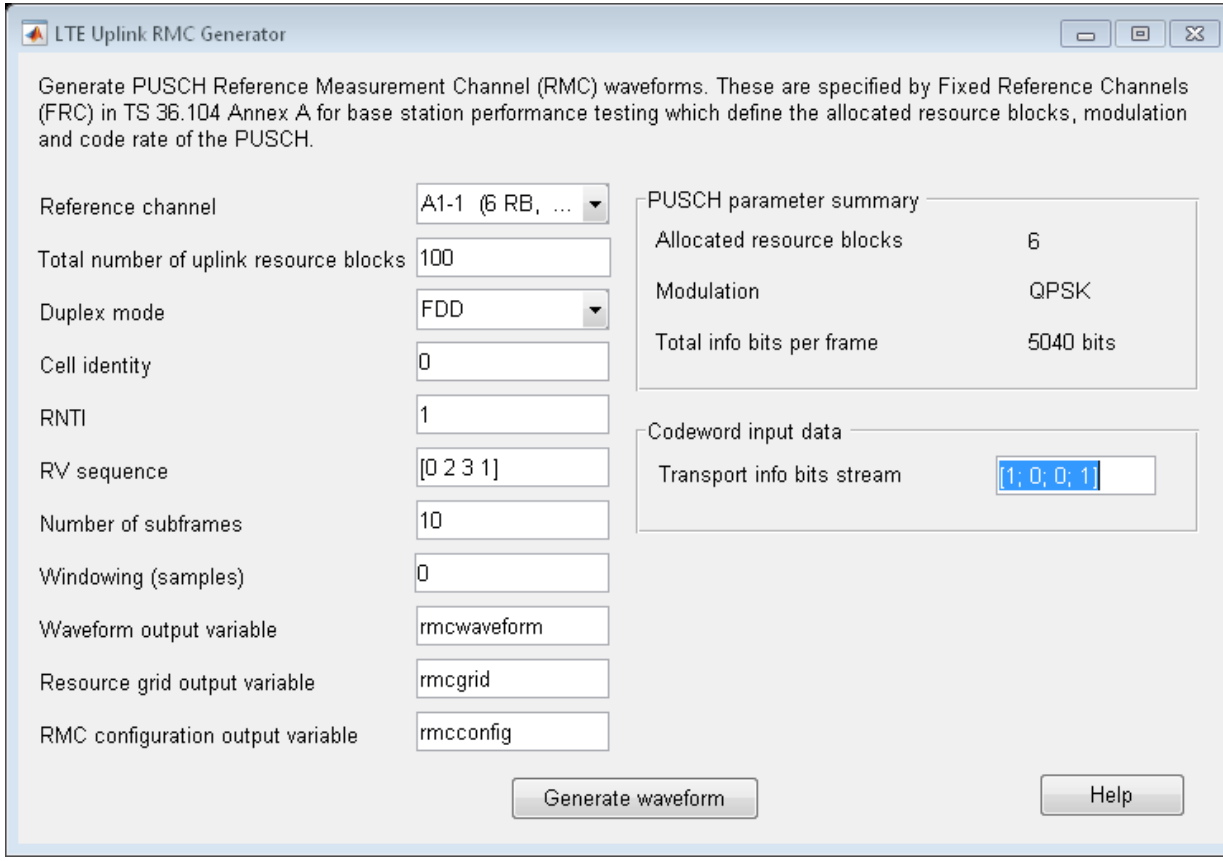
Examples

Open LTE Uplink RMC Generator User Interface

Open the LTE user interface to generate an upink reference measurement channel waveform.

The LTE Uplink RMC Generator dialog box appears when you execute the `lteRMCULTool` function with no input arguments.

```
lteRMCULTool;
```



Use the user interface to generate the default waveform or adjust default settings prior to waveform generation.

Generate Uplink LTE FRC A3-2

Generate a time domain signal and a 3-dimensional array of the resource elements for A3-2 as specified in TS 36.104 Annex A. The A3-2 fixed reference channel (FRC) settings include: FDD, 1.4MHz, QPSK, and 1/3 code rate.

```
rmc = lteRMCUL('A3-2');
[waveform,grid,rmccfgout] = lteRMCULTool(rmc,1);
```

Inspect the FRC configuration settings.

```
rmccfgout
rmccfgout.PUSCH
rmccfgout.PUSCH.ActualCodeRate


rmccfgout =

  struct with fields:

                RC: 'A3-2'
             NULRB: 6
           NCellID: 0
            NFrame: 0
         NSubframe: 0
    CyclicPrefixUL: 'Normal'
       CyclicShift: 0
         Shortened: 0
           Hopping: 'Off'
          SeqGroup: 0
      TotSubframes: 10
              RNTI: 1
           NTxAnts: 1
         Windowing: 0
        DuplexMode: 'FDD'
             PUSCH: [1×1 struct]
      SamplingRate: 1920000
              Nfft: 128


ans =

  struct with fields:

            Modulation: 'QPSK'
               NLayers: 1
         DynCyclicShift: 0
              NBundled: 0
               BetaACK: 2
               BetaCQI: 2
                BetaRI: 2
         NHARQProcesses: 8
                  RVSeq: [0 2 3 1]
                     RV: 0
           NTurboDecIts: 5
              OrthCover: 'On'
```

```
                    PMI: 0
                 PRBSet: [6×1 double]
         TargetCodeRate: 0.3333
         ActualCodeRate: [1×10 double]
             TrBlkSizes: [600 600 600 600 600 600 600 600 600 600]
        CodedTrBlkSizes: [1728 1728 1728 1728 1728 1728 1728 1728 1728 1728]
    HARQProcessSequence: [1×40 double]


ans =

  Columns 1 through 7

    0.3611    0.3611    0.3611    0.3611    0.3611    0.3611    0.3611

  Columns 8 through 10

    0.3611    0.3611    0.3611
```

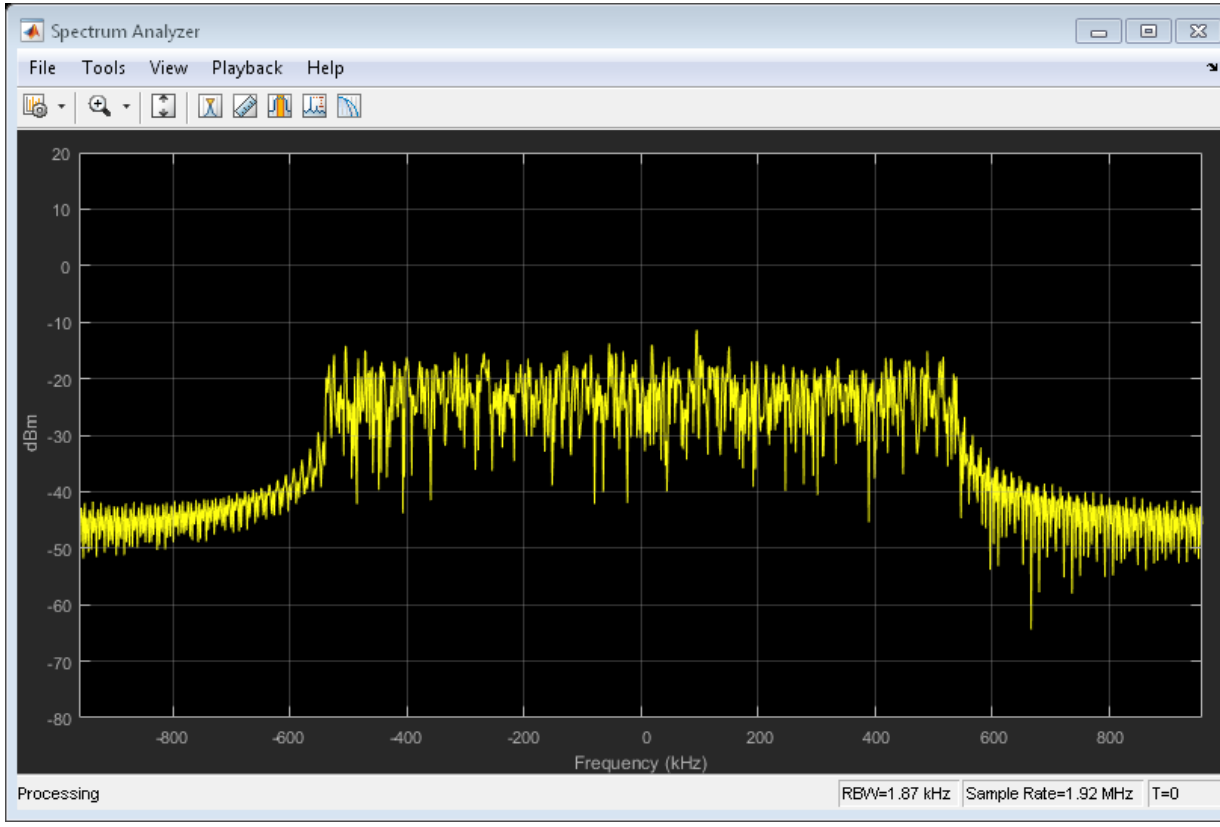
The actual code rate of 0.3611 is slightly higher then the target code rate of 1/3.

Generate Uplink RMC Waveform

Generate a time-domain signal and a 2-D array of the resource elements for a modified A1-1 fixed reference channel.

Initialize the `frc` configuration structure and change the modulation scheme to `'16QAM'`. Generate the `txWaveform`, `txGrid`, and output the configuration structure. Create a spectrum analyzer object, setting the sampling rate. Plot the waveform.

```
frc = lteRMCUL('A1-1');
frc.PUSCH.Modulation = '16QAM';

[txWaveform,txGrid,rmcCfgOut] = lteRMCULTool(frc,[1;0;0;1]);

saScope = dsp.SpectrumAnalyzer('SampleRate', rmcCfgOut.SamplingRate);
saScope(txWaveform)
```



Customized Uplink RMC configuration

Create a new customized parameter set by overriding selected values of an existing preset RMC to define a full-band, 5MHz, PUSCH using 64QAM modulation, and 1/3 coding rate.

Begin with TS 36.104 Annex A, RMC A1-3, which matches this criteria but with QPSK modulation.

```
rmcOverride.RC = 'A1-3';
rmc = lteRMCUL(rmcOverride,1);
rmc.PUSCH
```

```
ans =
```

```
  struct with fields:

        Modulation: 'QPSK'
           NLayers: 1
     DynCyclicShift: 0
         NBundled: 0
          BetaACK: 2
          BetaCQI: 2
           BetaRI: 2
     NHARQProcesses: 8
            RVSeq: [0 2 3 1]
               RV: 0
       NTurboDecIts: 5
          OrthCover: 'On'
                PMI: 0
           PRBSet: [25×1 double]
     TargetCodeRate: 0.3333
     ActualCodeRate: [1×10 double]
         TrBlkSizes: [2216 2216 2216 2216 2216 2216 2216 2216 2216 2216]
    CodedTrBlkSizes: [7200 7200 7200 7200 7200 7200 7200 7200 7200 7200]
```

Override the PUSCH modulation. `lteRMCUL` returns recomputed PUSCH transport block sizes and physical channel capacities to maintain the coding rate of R=1/3.

```
rmcOverride.PUSCH.Modulation = '64QAM';
rmc = lteRMCUL(rmcOverride,1);
rmc.PUSCH
```

```
ans =

  struct with fields:

        Modulation: '64QAM'
           NLayers: 1
     DynCyclicShift: 0
         NBundled: 0
          BetaACK: 2
          BetaCQI: 2
           BetaRI: 2
     NHARQProcesses: 8
            RVSeq: [0 2 3 1]
               RV: 0
```

```
      NTurboDecIts: 5
         OrthCover: 'On'
               PMI: 0
            PRBSet: [25×1 double]
    TargetCodeRate: 0.3333
    ActualCodeRate: [1×10 double]
        TrBlkSizes: [7224 7224 7224 7224 7224 7224 7224 7224 7224 7224]
   CodedTrBlkSizes: [1×10 double]
```

- “Generate LTE Uplink RMC Waveforms”

Input Arguments

`rc` — Reference measurement channel

`'A1-1' | 'A1-2' | 'A1-3' | 'A1-4' | 'A1-5' | 'A2-1' | 'A2-2' | 'A2-3' | 'A3-1' | 'A3-2' | 'A3-3' | 'A3-4' | 'A3-5' | 'A3-6' | 'A3-7' | 'A4-1' | 'A4-2' | 'A4-3' | 'A4-4' | 'A4-5' | 'A4-6' | 'A4-7' | 'A4-8' | 'A5-1' | 'A5-2' | 'A5-3' | 'A5-4' | 'A5-5' | 'A5-6' | 'A5-7' | 'A7-1' | 'A7-2' | 'A7-3' | 'A7-4' | 'A7-5' | 'A7-6' | 'A8-1' | 'A8-2' | 'A8-3' | 'A8-4' | 'A8-5' | 'A8-6' | 'A11-1' | 'A3-2-9RB' | 'A4-3-9RB'`

Reference channel, specified as a character vector. This argument identifies the reference measurement channel (RMC) number, as specified in TS 36.104 [2]. See “UL Reference Channel Options” on page 1-1066 for a list of the default top-level configuration associated with the available uplink reference channels.

Data Types: `char`

`trdata` — Information bits

column vector | cell array of one or two column vectors

Information bits, specified as a column vector or a cell array containing one or two column vectors of bit values. Each vector contains the information bits stream to be coded across the duration of the generation, which represents multiple concatenated transport blocks. Internally these vectors are looped if the number of bits required across all subframes of the generation exceeds the length of the vectors provided. Looping on the information bits allows you to enter a short pattern, such as `[1;0;0;1]`, that is repeated as the input to the transport coding. The `TrBlkSizes` matrix field of `rmccfgout.PUSCH` defines the number of data bits taken from the information bit stream for each subframe of generation.

Data Types: `double` | `cell`

`duplexmode` — Duplexing mode

`'FDD'` (default) | optional | `'TDD'`

Duplexing mode, specified as `'FDD'` or `'TDD'` to indicate the frame structure type of the generated waveform.

Data Types: `char`

`totsubframes` — Total number of subframes

10 (default) | optional | positive numeric scalar

Total number of subframes, specified as a numeric scalar. Optional. This argument specifies the total number of subframes that form the resource grid.

Data Types: `double`

`rmccfg` — Reference channel configuration

structure

Reference channel configuration, specified as a structure. The structure defines any (or all) of the fields or subfields. The reference configuration structure with default parameters can easily be created using the `lteRMCUL` function. `lteRMCUL` generates the various FRC configuration structures, as defined in TS 36.104 [2], Annex A.

`rmccfg` may include fields contained in the output structure, `rmccfgout`.

Data Types: `struct`

`cqi` — CQI information bits

numeric vector

CQI information bits, specified as a numeric vector. CQI stands for channel quality information. `cqi` can be empty if these particular control information bits are not present in the transmission. `cqi` is not treated as a data stream, and thus each subframe contains the same CQI information bits.

Data Types: `double`

`ri` — RI information bits

numeric vector

RI information bits, specified as a numeric vector. RI stands for rank indication. `ri` can be empty if these particular control information bits are not present in the transmission.

`ri` is not treated as a data stream, and thus each subframe contains the same RI information bits.

Data Types: `double`

`ack` — ACK information bits

numeric vector

ACK information bits, specified as a numeric vector. ACK stands for acknowledgment in automatic repeat request (ARQ) protocols. `ack` can be empty if these particular control information bits are not present in the transmission. `ack` is not treated as a data stream, and thus each subframe contains the same ACK information bits.

Data Types: `double`

Output Arguments

`waveform` — Generated RMC time-domain waveform

numeric matrix

Generated RMC time-domain waveform, returned as a T-by-P numeric matrix. T is the number of time-domain samples and P is the number of antennas.

`grid` is a 3-D array of resource elements for the generated subframes across all configured antenna ports, as described in “Data Structures”. `rmccfgout` is a structure containing information about the SC-FDMA modulated waveform and RMC configuration parameters.

Data Types: `double`
Complex Number Support: Yes

`grid` — Populated resource grid

numeric 3-D array

Populated resource grid, returned as a numeric 3-D array of resource elements for several subframes across all configured antenna ports, as described in “Data Structures”.

`grid` represents the populated resource grid for all the physical channels specified in TS 36.104 [2], Annex A

Data Types: `double`
Complex Number Support: Yes

`rmccfgout` — Configuration parameters
structure

Configuration parameters structure

Configuration parameters, returned as a structure. `rmccfgout` contains the following fields.

Parameter Field	Values	Description
`RC`	`'A1-1'` (default), `'A1-2'`, `'A1-3'`, `'A1-4'`, `'A1-5'`, `'A2-1'`, `'A2-2'`, `'A2-3'`, `'A3-1'`, `'A3-2'`, `'A3-3'`, `'A3-4'`, `'A3-5'`, `'A3-6'`, `'A3-7'`, `'A4-1'`, `'A4-2'`, `'A4-3'`, `'A4-4'`, `'A4-5'`, `'A4-6'`, `'A4-7'`, `'A4-8'`, `'A5-1'`, `'A5-2'`, `'A5-3'`, `'A5-4'`, `'A5-5'`, `'A5-6'`, `'A5-7'`, `'A7-1'`, `'A7-2'`, `'A7-3'`, `'A7-4'`, `'A7-5'`, `'A7-6'`, `'A8-1'`, `'A8-2'`, `'A8-3'`, `'A8-4'`, `'A8-5'`, `'A8-6'`, `'A11-1'`, `'A3-2-9RB'`, `'A4-3-9RB'`	Reference channel number
`NULRB`	Scalar integer from 6 to 110	Number of uplink resource blocks. ($N_{\mathrm{RB}}^{\mathrm{UL}}$)
`NCellD`	Integer from 0 to 503	Physical layer cell identity
`NFrame`	0 (default), nonnegative scalar integer	Frame number
`NSubFrame`	0 (default), nonnegative scalar integer	Initial subframe number
`CyclicPrefi`	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`CyclicShift`	0, 1, 2, 3, 4, 5, 6, 7	Cyclic shift. This argument yields $n_{\mathrm{DMRS}}^{(1)}$.

Parameter Field	Values	Description
`Shortened`	0 (default), 1	Subframe shortened flag. If the function sets the flag to `1`, the last symbol of the subframe is not used. Subframes with possible SRS transmission require this flag to be set.
`Hopping`	`'Off'` (default), `'Group'`, or `'Sequence'`	Hopping type
`SeqGroup`	0 (default), integer from 0 to 29	PUSCH sequence group assignment (Δ_{SS}).
`TotSubFrames`	`10` (default) Positive scalar integer	Total number of subframes to generate This argument specifies the total number of subframes that form the resource grid.
`RNTI`	`1` (default) Scalar integer	Radio network temporary identifier (RNTI) value (16 bits)
`NTxAnts`	1, 2, 4	Number of transmission antennas.
`Windowing`	Nonnegative scalar integer	The number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied
`DuplexMode`	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex It represents the frame structure type.
`PUSCH`	Structure	PUSCH transmission configuration
`SRS`	Structure	Sounding Reference Signal (SRS) configuration

Parameter Field	Values	Description
SamplingRat	Numeric scalar	Carrier sampling rate in Hz, N_{SC} / N_{SYM} × 3.84e6, where N_{SC} is the number of subcarriers and N_{SYM} is the number of SC-FDMA symbols in a subframe.
Nfft	Scalar integer, typically one of {128, 256, 512, 1024, 1536, 2048} for standard channel bandwidths {'1.4MHz', '3MHz', '5MHz', '10MHz', '15MHz', '20MHz'}, respectively.	Number of FFT frequency bins

PUSCH substructure

The substructure PUSCH relates to the physical channel configuration and contains these fields:

Parameter Field	Values	Description
Modulation	'QPSK', '16QAM', '64QAM'	Modulation format
NLayers	1, 2, 3, 4	Number of transmission layers.
DynCyclicSh	0, 1, 2, 3, 4, 5, 6, 7	Cyclic shift for DM-RS (yields $n_{DMRS}^{(2)}$).
NBundled	0, 1, 2, 3, 4, 5, 6, 7, 8, 9	HARQ-ACK bundling scrambling sequence index
BetaACK	Scalar integer	Modulation and coding scheme (MCS) offset for HARQ-ACK bits
BetaCQI	Scalar integer	Modulation and coding scheme (MCS) offset for CQI and PMI bits
BetaRI	Scalar integer	Modulation and coding scheme (MCS) offset for RI bits

Parameter Field	Values	Description
NHARQProces	1, 2, 3, 4, 5, 6, 7, 8	Number of HARQ processes per component carrier
RVSeq	Numeric matrix	Redundancy version (RV) indicator, returned as a numeric matrix. This argument is a 1- or 2-row matrix that specifies the redundancy version (RV) indicator for one or two codewords. The RV indicator specified in each column is applied to the transmission in a HARQ process. The number of transmissions in a HARQ process equals the number of columns in `RVSeq`, where the row defines the RV indicator for one or two codewords. In a two-codeword transmission, if `RVSeq` is a row vector, the same RV indicator is applied to both codewords.
RV	Numeric matrix	Redundancy version (RV) indicator in initial subframe, returned as a numeric matrix. This argument is a 1- or 2-column vector that specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is read-only.
NTurboDecIt	Positive scalar integer	Number of turbo decoder iteration cycles
OrthCover	`'Off'` (default), `'On'`	Orthogonal cover sequence flag. Applies (`'On'`), or does not apply (`'Off'`), orthogonal cover sequence *w* (*Activate-DMRS-with OCC*).
PMI	Integer from 0 to 23	Scalar precoder matrix indication (PMI) to be used during precoding

Parameter Field	Values	Description
PRBSet	Integer matrix	Physical resource block set of indices, returned as an integer matrix. This argument is a 1- or 2-column matrix that contains the 0-based physical resource block indices (PRBs) corresponding to the resource allocations for this PUSCH.
TargetCodeRa	Numeric scalar or vector	Target code rates for each subframe in a frame. Used for calculating the transport block sizes according to TS 36.101 [1], Annex A.2.1.2. If `TargetCodeRate` is not provided and `TrBlkSizes` is provided at the input, `TargetCodeRate` == `ActualCodeRate`.
ActualCodeRa	Numeric vector	Actual code rates for each subframe in a frame. The maximum actual code rate is 0.93. This parameter field is only for informational purposes and is read-only.
TrBlkSizes	Numeric vector	Transport block sizes for each subframe in a frame
CodedTrBlkS	Numeric vector	Coded transport block sizes for each a subframe in a frame, returned as a numeric vector. This parameter field is only for informational purposes and is read-only.
HARQProcessS	1-by-$L_{\text{HARQ\_Seq}}$ integer vector.	One-based HARQ process indices for the internal HARQ scheduling sequence, based on same transport block size in all active subframes. See footnote 1

Parameter Field	Values	Description
1		When creating the HARQ process sequence, TTI bundling is considered. The length of the HARQ process sequence, L_{HARQ_Seq} = 10 × `lcm`(`NHARQProcesses` × *ttiPerBundle*,`sum`(*activesfs*)) / `sum`(*activesfs*). The number of TTI per bundle, *ttiPerBundle* = 4. The `sum`(*activesfs*) is the number of active subframes. For FDD, all subframes are active and for TDD, all uplink subframes are active. The uplink supports `NHARQProcesses` allowed by the standard and also the transport block sizes are the same for all the active subframes.

SRS substructure

The substructure `SRS` contains these fields:

Parameter Field	Values	Description
`NTxAnts`	1 (default), 2, 4	Number of transmission antennas.
`BWConfig`	0, 1, 2, 3, 4, 5, 6, 7	Cell-specific SRS Bandwidth Configuration value (C_{SRS})
`BW`	0, 1, 2, 3	UE-specific SRS Bandwidth value (B_{SRS})
`ConfigIdx`	Integer from 0 to 644	Configuration index (I_{SRS}) for UE-specific periodicity (T_{SRS}) and subframe offset (T_{offset}).
`TxComb`	0 or 1	Transmission comb. Controls SRS positions; SRS is transmitted in 6 carriers per resource block on odd (1) and even (0) resource indices.
`HoppingBW`	0, 1, 2, 3	SRS Frequency hopping configuration index (b_{hop})
`FreqPositio`	Integer from 0 to 23	Frequency domain position (n_{RRC})
`CyclicShift`	0 (default), integer from 0 to 7	UE-specific cyclic shift (n_{SRS}^{cs})

Parameter Field	Values	Description
SeqGroup	0 (default), integer from 0 to 29	SRS sequence group number (u)
SeqIdx	0 or 1	Base sequence number (v)
SubframeCon	Integer from 0 to 15	Sounding reference signal (SRS) subframe configuration
The following fields are present only when `DuplexMode` is set to `'TDD'`.		
NF4RachPre	0, 1, 2, 3, 4, 5, 6	Number of RACH preamble frequency resources of Format 4 in *UpPTS*
OffsetIdx	0 or 1	Choice of SRS Subframe Offset in the case of 2 ms SRS periodicity. This parameter indexes the two SRS Subframe Offset entries in the row specified by the `ConfigIdx` parameter in table 8.2-2 of TS 36.213 for the SRS Configuration Index.

Definitions

UL Reference Channel Options

Initialization choices available for the uplink reference channel and associated top-level configuration defaults include:

Reference channels	Reference channels (continued)	Reference channels (continued)
`A1-1 (6 RB, QPSK, R=1/3)`	`A4-1 (1 RB, 16QAM, R=3/4)`	`A7-1 (3 RB, 16QAM, R=3/4)`
`A1-2 (15 RB, QPSK, R=1/3)`	`A4-2 (1 RB, 16QAM, R=3/4)`	`A7-2 (6 RB, 16QAM, R=3/4)`
`A1-3 (25 RB, QPSK, R=1/3)`	`A4-3 (6 RB, 16QAM, R=3/4)`	`A7-3 (12 RB, 16QAM, R=3/4)`

Reference channels	Reference channels (continued)	Reference channels (continued)
A1-4 (3 RB, QPSK, R=1/3)	A4-4 (15 RB, 16QAM, R=3/4)	A7-4 (25 RB, 16QAM, R=3/4)
A1-5 (9 RB, QPSK, R=1/3)	A4-5 (25 RB, 16QAM, R=3/4)	A7-5 (25 RB, 16QAM, R=3/4)
A2-1 (6 RB, 16QAM, R=2/3)	A4-6 (50 RB, 16QAM, R=3/4)	A7-6 (25 RB, 16QAM, R=3/4)
A2-2 (15 RB, 16QAM, R=2/3)	A4-7 (75 RB, 16QAM, R=3/4)	A8-1 (3 RB, QPSK, R=1/3)
A2-3 (25 RB, 16QAM, R=2/3)	A4-8 (100 RB, 16QAM, R=3/4)	A8-2 (6 RB, QPSK, R=1/3)
A3-1 (1 RB, QPSK, R=1/3)	A5-1 (1 RB, 64QAM, R=5/6)	A8-3 (12 RB, QPSK, R=1/3)
A3-2 (6 RB, QPSK, R=1/3)	A5-2 (6 RB, 64QAM, R=5/6)	A8-4 (25 RB, QPSK, R=1/3)
A3-3 (15 RB, QPSK, R=1/3)	A5-3 (15RB, 64QAM, R=5/6)	A8-5 (25 RB, QPSK, R=1/3)
A3-4 (25 RB, QPSK, R=1/3)	A5-4 (25 RB, 64QAM, R=5/6)	A8-6 (25 RB, QPSK, R=1/3)
A3-5 (50 RB, QPSK, R=1/3)	A5-5 (50 RB, 64QAM, R=5/6)	A11-1 (3RB, QPSK, R=11/27)
A3-6 (75 RB, QPSK, R=1/3)	A5-6 (75 RB, 64QAM, R=5/6)	A3-2-9RB (6 RB, QPSK, R=1/3)
A3-7 (100 RB, QPSK, R=1/3)	A5-7 (100 RB, 64QAM, R=5/6)	

The fields in the output configuration structure, `rmccfgout`, are initialized in accordance with the reference channels defined in TS 36.104, Annex A.

- `'A3-2-9RB'` is a custom RMC configured for non-standard bandwidth but with the same code rate as the standardized version.
- `'A11-1'` enables TTI bundling and the corresponding HARQ pattern (enhanced HARQ pattern for FDD).

References

[1] 3GPP TS 36.101. "User Equipment (UE) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

Apps

LTE Uplink RMC Generator

Functions

`lteRMCDLTool` | `lteRMCUL` | `lteTestModelTool`

Topics

"Generate LTE Uplink RMC Waveforms"

Introduced in R2014a

lteRateMatchConvolutional

Convolutional rate matching

Syntax

```
out = lteRateMatchConvolutional(in,outlen)
```

Description

`out = lteRateMatchConvolutional(in,outlen)` rate matches the input data vector, `in`, to create an output vector, `out`, of length `outlen`. This function includes the stages of subblock interleaving, bit collection and bit selection, and pruning defined for convolutionally encoded data. For more information, see TS 36.212 [1], Section 5.1.4.2. The input data is assumed to comprise a concatenation of 3 subblocks, each of which is then interleaved prior to virtual circular buffer creation. No special processing is given to input filler bits.

Examples

Perform Convolutional Rate Matching

Perform convolutional rate matching of a coded block vector of length 132, with the output length set to 50.

```
rateMatched = lteRateMatchConvolutional(ones(132,1),50);
size(rateMatched)
```

```
ans =

    50     1
```

Input Arguments

`in` — Input data

numeric column vector

Input data, specified as a column vector. Input data is assumed to comprise a concatenation of 3 subblocks each of which is then interleaved prior to virtual circular buffer creation. No special processing is given to input filler bits.

Example: `ones(5,1)`

Data Types: `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`
Complex Number Support: Yes

`outlen` — Output vector length

nonnegative scalar integer

Output vector length, specified as a nonnegative scalar integer.

Data Types: `double`

Output Arguments

`out` — Rate matched output

numeric column vector

Rate matched output, returned as numeric column vector.

Data Types: `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCH` | `lteConvolutionalEncode` | `lteDCIEncode` | `lteRateMatchTurbo` | `lteRateRecoverConvolutional`

Introduced in R2014a

lteRateMatchTurbo

Turbo rate matching

Syntax

```
out = lteRateMatchTurbo(in,outlen,rv)
out = lteRateMatchTurbo(in,outlen,rv,chs)
```

Description

`out = lteRateMatchTurbo(in,outlen,rv)` performs rate matching of the input data, `in`, to create the output vector, `out`, of length `outlen`. The input data could be a vector or a cell array. This function includes the stages of subblock interleaving, bit collection and bit selection, and pruning defined for turbo encoded data. For more information, see TS 36.212 [1], Section 5.1.4.1.

The input data can be a single vector or a cell array of vectors assumed to be code blocks. In the cell array case, each vector is rate matched separately and the results are concatenated into the single output vector, `out`. The length of each nonempty input vector must be an integer multiple of 3. The parameter `rv` controls the redundancy version of the output. The bit selection stage assumes a QPSK transmission mapped onto a single layer. It also assumes no restriction on the number of soft bits, as in an uplink UL-SCH transport channel.

`out = lteRateMatchTurbo(in,outlen,rv,chs)` allows additional control of the bit selection stage through selection of parameters for the soft buffer size and physical channel configuration in the `chs` input structure.

Examples

Perform Turbo Rate Matching

Rate match an input vector of 132 bits to a length of 100 with the RV parameter set to 0.

```
codedBlklen = 132;
```

```
invec = ones(codedBlklen,1);
outlen = 100;
rv = 0;

rmatched = lteRateMatchTurbo(invec,outlen,rv);
size(rmatched)


ans =

   100     1
```

Input Arguments

`in` — Input data

vector | cell array of vectors

Input data, specified as a single vector or a cell array of vectors, assumed to be code blocks. In the cell array case, each vector is rate matched separately and the results are concatenated into the single output vector, `out`. The length of each nonempty input vector must be an integer multiple of 3.

Example: `ones(132,1)`

Data Types: `double | cell`

`outlen` — Output vector length

nonnegative integer

Output vector length, specified as a nonnegative integer.

Example: 3

Data Types: `double`

`rv` — Redundancy version control

0 | 1 | 2 | 3

Redundancy version control, specified as 0, 1, 2, or 3.

Example: 1

Data Types: `double`

chs — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure. It allows additional control of the bit selection stage through parameters for the soft buffer size and physical channel configuration.

For downlink turbo coded transport channels, you can control the soft buffer dimensions by including either `NIR` or the combined set of `NSoftbits`, `TxScheme`, and `DuplexMode`. If `DuplexMode` is `'TDD'`, also specify `TDDConfig`. If included, `NIR`, takes precedence for controlling the soft buffer dimensions. When neither of these optional `chs` fields (`NIR` or the set including `NSoftbits`) are present, the function assumes an uplink turbo coded transport channel and places no limit on the number of soft bits.

`chs` can contain the following fields.

Modulation — Modulation scheme

`'QPSK' | '16QAM' | '64QAM' | '256QAM'`

Modulation scheme, specified as `'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`.

Data Types: `char`

NLayers — Number of transmission layers for transport block

1 (default) | 2 | 3 | 4

Number of transmission layers for transport block, specified as 1 (default), 2, 3, or 4. Not necessary if `TxScheme` is set to `'Port0'`, `'TxDiversity'`, or `'Port5'`.

Data Types: `double`

TxScheme — Transmission scheme

`'Port0'` (default) | `'TxDiversity'` | `'CDD'` | `'SpatialMux'` | `'MultiUser'` | `'Port5'` | `'Port7-8'` | `'Port8'` | `'Port7-14'` | optional

PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme

Transmission scheme	Description
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

Data Types: `char`

`NIR` — Soft buffer size for entire input transport block

nonnegative integer

Soft buffer size for entire input transport block, specified as a nonnegative integer.

Data Types: `double`

`NSoftbits` — Total number of soft channel bits

nonnegative integer

Total number of soft channel bits, specified as a nonnegative integer.

Data Types: `double`

`DuplexMode` — Duplex mode

`'FDD'` (default) | optional | `'TDD'`

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration

0 (default) | optional | nonnegative scalar integer from 0 to 6

Uplink or downlink configuration, specified as a nonnegative scalar integer from 0 through 6. Optional. Only required if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

Data Types: `struct`

Output Arguments

`out` — Turbo rate matched output

numeric column vector

Turbo rate matched output, returned as a numeric column vector.

Data Types: `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCH` | `lteRateMatchConvolutional` | `lteRateRecoverTurbo` | `lteTurboEncode` | `lteULSCH`

Introduced in R2013b

lteRateRecoverConvolutional

Convolutional rate matching recovery

Syntax

```
out = lteRateRecoverConvolutional(in,outlen)
```

Description

`out = lteRateRecoverConvolutional(in,outlen)` performs rate recovery of the input data vector, `in`, to create an output vector, `out`, of length `outlen`. This function is the inverse of the rate matching operation for convolutionally encoded data. For more information, see `lteRateMatchConvolutional`. This function includes the inverses of the subblock interleaving, bit collection and bit selection, and pruning stages. This function also implements additive soft combining of the input data elements in the case where repetition occurred during the original rate matching.

Examples

Perform Convolutional Rate Recovery

Perform rate recovery after rate matching. The returned vector has the same length as the input to rate matching.

```
codedBlklen = 132;
rateMatched = lteRateMatchConvolutional(ones(codedBlklen ,1),50);
rateRecovered = lteRateRecoverConvolutional(rateMatched,codedBlklen);
size(rateRecovered)
```

```
ans =

   132     1
```

The output variable, `rateRecovered`, is a vector of the same length as the input to rate matching.

Input Arguments

`in` — Input data

numeric column vector

Input data, specified as a numeric column vector.

Data Types: `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

`outlen` — Output vector length

nonnegative scalar integer

Output vector length, specified as a nonnegative scalar integer.

Example: 50

Data Types: `double`

Output Arguments

`out` — Rate recovered output

numeric column vector

Rate recovered output, returned as a numeric column vector.

Data Types: `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

See Also

See Also

`lteBCHDecode` | `lteConvolutionalDecode` | `lteDCIDecode` | `lteRateMatchConvolutional` | `lteRateRecoverTurbo`

Introduced in R2014a

lteRateRecoverTurbo

Turbo rate recovery

Syntax

```
out = lteRateRecoverTurbo(in,trblklen,rv)
out = lteRateRecoverTurbo(in,trblklen,rv,chs,cbsbuffers)
```

Description

`out = lteRateRecoverTurbo(in,trblklen,rv)` performs rate recovery of the input vector, `in`, creating a cell array of vectors, `out`. `out` represents the turbo encoded code blocks before concatenation. This function is the inverse of the rate matching operation for turbo encoded data. For more information, see `lteRateMatchTurbo` and TS 36.212, Section 5.1.4.1 [1]. This function includes the inverses of the subblock interleaving, bit collection, and bit selection and pruning stages. The dimensions of `out` are deduced from `trblklen`, which represents the length of the original encoded transport block. This parameterization is required to recover the original number of code blocks, their encoded lengths, and the locations of any filler bits. The parameter `rv` controls the redundancy version of the output. The bit selection recovery assumes a QPSK transmission mapped onto a single layer. It also assumes no restriction on the number of soft bits, as in an uplink UL-SCH transport channel.

`out = lteRateRecoverTurbo(in,trblklen,rv,chs,cbsbuffers)` specifies two additional inputs. The `chs` input structure allows additional control of the bit selection recovery stage through parameters for the soft buffer size and physical channel configuration. The `cbsbuffers` input allows combining with pre-existing soft information for the HARQ process.

Examples

Perform Turbo Rate Recovery

Create a codeword from a transport block then rate recover the codeword back into a set of coded code blocks. The transport block is originally segmented into a single code block

so the `rateRecovered` output variable is a cell array containing a single turbo coded code block.

Define the transport block length prior to CRC and turbo coding, code word length, redundancy version, and CRC polynomial. Use these parameters to perform coding operations.

```
trBlkLen = 135;
codewordLen = 450;
rv = 0;
crcPoly = '24A';

trblockwithcrc = lteCRCEncode(zeros(trBlkLen,1),crcPoly);
codeblocks = lteCodeBlockSegment(trblockwithcrc);
turbocodedblocks = lteTurboEncode(codeblocks);
codeword = lteRateMatchTurbo(turbocodedblocks,codewordLen,rv);
rateRecovered = lteRateRecoverTurbo(codeword,trBlkLen,rv)
```

```
rateRecovered =

  cell

    [492×1 int8]
```

`rateRecovered` is a cell array with a single coded code block of size indicated above.

Further turbo decoding, desegmentation and CRC decoding of `rateRecovered` would result in a decoded transport block of length equal to the original transport block. Note that the `trBlkLen` parameter of the `lteRateRecoverTurbo` function is the transport block length before CRC and turbo coding, not the length after turbo coding or rate matching.

Input Arguments

`in` — Input data

numeric vector

Input data, specified as a numeric vector.

Data Types: `double`

`trblklen` — Length of original encoded transport block before encoding

numeric value

Length of the original encoded transport block before encoding, specified as a numeric value.

Data Types: `double`

`rv` — Redundancy version used to recover data

0 | 1 | 2 | 3

Redundancy version used to recover data, specified as 0, 1, 2, or 3.

Data Types: `double`

`chs` — Channel transmission configuration

structure

Channel transmission configuration, specified as a structure. It allows additional control of the bit selection stage through parameters for the soft buffer size and physical channel configuration.

For downlink turbo coded transport channels, you can control the soft buffer dimensions by including either `NIR` or the combined set of `NSoftbits`, `TxScheme`, and `DuplexMode`. If `DuplexMode` is `'TDD'`, also specify `TDDConfig`. If included, `NIR`, takes precedence for controlling the soft buffer dimensions. When neither of these optional `chs` fields (`NIR` or the set including `NSoftbits`) are present, the function assumes an uplink turbo coded transport channel and places no limit on the number of soft bits.

`chs` can contain the following fields.

`Modulation` — Modulation scheme

`'QPSK' | '16QAM' | '64QAM' | '256QAM'`

Modulation scheme, specified as `'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`.

Data Types: `char`

`NLayers` — Number of transmission layers for transport block

1 (default) | 2 | 3 | 4

Number of transmission layers for transport block, specified as 1 (default), 2, 3, or 4. Not necessary if `TxScheme` is set to `'Port0'`, `'TxDiversity'`, or `'Port5'`.

Data Types: `double`

`TxScheme` — Transmission scheme

`'Port0'` (default) | optional | `'TxDiversity'` | `'CDD'` | `'SpatialMux'` | `'MultiUser'` | `'Port5'` | `'Port7-8'` | `'Port8'` | `'Port7-14'`

PDSCH transmission scheme, specified as one of the following options.

Transmission scheme	Description
`'Port0'`	Single antenna port, port 0
`'TxDiversity'`	Transmit diversity
`'CDD'`	Large delay cyclic delay diversity scheme
`'SpatialMux'`	Closed loop spatial multiplexing
`'MultiUser'`	Multi-user MIMO
`'Port5'`	Single-antenna port, port 5
`'Port7-8'`	Single-antenna port, port 7, when **`NLayers`** = 1. Dual layer transmission, ports 7 and 8, when **`NLayers`** = 2.
`'Port8'`	Single-antenna port, port 8
`'Port7-14'`	Up to eight layer transmission, ports 7–14

Data Types: `char`

`NIR` — Soft buffer size for entire input transport block

nonnegative integer

Soft buffer size for entire input transport block, specified as a nonnegative integer.

Data Types: `double`

`NSoftbits` — Total number of soft channel bits

nonnegative integer

Total number of soft channel bits, specified as a nonnegative integer.

Data Types: `double`

`DuplexMode` — Duplex mode

`'FDD'` (default) | optional | `'TDD'`

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration

0 (default) | optional | nonnegative scalar integer (0...6)

Uplink or downlink configuration, specified as a nonnegative scalar integer from 0 through 6. Optional. Only required if `DuplexMode` is set to `'TDD'`.

Data Types: `double`

Data Types: `struct`

`cbsbuffers` — Code block soft information buffers

cell array of numeric vectors | empty cell array | cell array of numeric scalar elements

Code block soft information buffers, specified as a cell array. This input argument represents any pre-existing code block-oriented soft information to be additively combined with the recovered turbo encoded code blocks. It allows the direct soft combining of consecutive HARQ retransmissions and is typically returned by a previous call to the function to recover an earlier transmission of the same transport block. The `cbsbuffers` cell array either:

- dimensionally matches the output code blocks, `out`
- can be empty to represent the processing of an initial HARQ transmission
- or can be scalar to add a constant offset to all the deinterleaved soft data in a code block.

Data Types: `cell`

Output Arguments

`out` — Turbo encoded code blocks before concatenation

cell array of numeric column vectors

Turbo encoded code blocks before concatenation, returned as a cell array of numeric column vectors. The dimensions of `out` are deduced from `trblklen`, which represents the length of the original encoded transport block.

Data Types: `cell`

References

[1] 3GPP TS 36.212. “Multiplexing and channel coding.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCHDecode` | `lteDLSCHInfo` | `lteRateMatchTurbo` | `lteRateRecoverConvolutional` | `lteTurboDecode` | `lteULSCHDecode` | `lteULSCHInfo`

Introduced in R2013b

lteResourceGrid

Subframe resource array

Syntax

```
grid = lteResourceGrid(cfg)
grid = lteResourceGrid(cfg,p)
```

Description

`grid = lteResourceGrid(cfg)` returns an empty resource array generated from the configuration settings structure, `cfg`. To create a resource array specifically for downlink or uplink, use `lteDLResourceGrid` or `lteULResourceGrid`, respectively.

For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see "Data Structures".

`grid = lteResourceGrid(cfg,p)` returns a resource array, where `p` directly specifies the number of antenna planes in the array.

Examples

Create Downlink Subframe Resource Array

Create an empty resource array that represents the downlink resource elements for 10MHz bandwidth, one subframe, and two antennas.

```
griddl = lteResourceGrid(struct('NDLRB',50,'CellRefP',2,'CyclicPrefix','Normal'));
size(griddl)
```

```
ans =

   600    14     2
```

Create Uplink Subframe Resource Array

Create an empty resource array that represents the uplink resource elements for 10MHz bandwidth, one subframe, and two antennas.

```
gridul = lteResourceGrid(struct('NULRB',50,'NTxAnts',2,'CyclicPrefixUL','Normal'));
size(gridul)
```

```
ans =

   600    14     2
```

Create Downlink Subframe Resource Array Using Optional Antenna Plane Input

Create an empty resource array that represents the downlink resource elements for 20 MHz bandwidth, one subframe, extended cyclic prefix, and four antennas planes.

```
cfg = struct('NDLRB',100,'CyclicPrefix','Extended');
p = 4;
griddl = lteResourceGrid(cfg,p);
size(griddl)
```

```
ans =

        1200          12           4
```

Input Arguments

`cfg` — Configuration settings

scalar structure

Configuration settings, specified as a scalar structure. To create a downlink resource array, `cfg` must contain the `NDLRB` and `CellRefP` fields. To create an uplink resource array, `cfg` must contain the `NULRB` field. The presence of field `NDLRB` takes precedence over the field `NULRB`.

For the downlink, these fields are applicable.

Parameter Field	Required or Optional	Values	Description
NDLRB	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
CellRefP	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
CyclicPrefix	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

For the uplink, these fields are applicable.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
CyclicPrefixUL	Optional	`'Normal'` (default), `'Extended'`	Current cyclic prefix length
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.

p — Number of antenna planes in the output array

nonnegative scalar integer

Number of antenna planes in the output array, specified as a nonnegative scalar integer.

Data Types: `double`

Output Arguments

grid — Empty multidimensional resource grid

3-D numeric array

Empty multidimensional resource grid, returned as an *N*-by-*M*-by-*P* numeric array. *N* is the number of subcarriers (12×NULRB). *M* is the number of OFDM or SC-FDMA symbols in a subframe, 14 for normal cyclic prefix and 12 for extended cyclic prefix. *P* is the

number of transmit antenna ports, `cfg.CellRefP` in the downlink and `cfg.NTxAnts` in the uplink.

Data Types: `double`

See Also

See Also

`lteDLResourceGrid` | `lteOFDMModulate` | `lteResourceGridSize` | `lteSCFDMAModulate` | `lteSLResourceGrid` | `lteULResourceGrid`

Introduced in R2014a

lteResourceGridSize

Size of subframe resource array

Syntax

```
d = lteResourceGridSize(cfg)
d = lteResourceGridSize(cfg,p)
```

Description

`d = lteResourceGridSize(cfg)` returns a three-element row vector of dimension lengths for the resource array generated from the settings structure, `cfg`. To get the dimension lengths specifically for a downlink or uplink resource array, use the function `lteDLResourceGridSize` or `lteULResourceGridSize` respectively. For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see "Data Structures".

`d = lteResourceGridSize(cfg,p)` returns a three-element row vector, where `p` directly specifies the number of antenna planes in the array.

Examples

Get Downlink Subframe Resource Array Size

Get the downlink subframe resource array size from a downlink configuration structure. Then, use the returned vector to directly create a MATLAB™ array.

```
cfgdl = struct('NDLRB',6,'CellRefP',2,'CyclicPrefix','Normal');
griddl = zeros(lteResourceGridSize(cfgdl));
size(griddl)
```

```
ans =
```

```
    72     14      2
```

The output grid, `griddl`, is a resource array. This resource array could be obtained in a similar manner using the `lteResourceGrid` function.

Get Uplink Subframe Resource Array Size

Get the uplink subframe resource array size from an uplink configuration structure. Then, use the returned vector to directly create a MATLAB™ array.

```
cfgul = struct('NULRB',6,'NTxAnts',2,'CyclicPrefixUL','Normal');
gridul = zeros(lteResourceGridSize(cfgul));
size(gridul)
```

```
ans =

    72     14      2
```

The output grid, `gridul`, is a resource array. This resource array could be obtained in a similar manner using the `lteResourceGrid` function.

Get Uplink Subframe Resource Array Size Using Optional Antenna Plane Input

Get the uplink subframe resource array size from an uplink configuration structure and antenna plane input. Then, use the returned vector to directly create a MATLAB™ array.

```
cfgul = struct('NULRB',25,'CyclicPrefixUL','Normal');
p = 4;
gridul = zeros(lteResourceGridSize(cfgul,p));
size(gridul)
```

```
ans =

   300     14      4
```

The output grid, `gridul`, is a resource array. This resource array could be obtained in a similar manner using the `lteResourceGrid` function.

Input Arguments

`cfg` — Configuration settings

scalar structure

Configuration settings, specified as a scalar structure. To create a downlink resource array, `cfg` must contain the `NDLRB` and `CellRefP` fields. To create an uplink resource array, `cfg` must contain the `NULRB` field. If both `NDLRB` and `NULRB` fields are defined, the presence of the field `NDLRB` takes precedence over the field `NULRB`.

For the downlink, these fields are applicable.

Parameter Field	Required or Optional	Values	Description
`NDLRB`	Required	Scalar integer from 6 to 110	Number of downlink resource blocks. (N_{RB}^{DL})
`CellRefP`	Required	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`CyclicPrefix`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

For the uplink, these fields are applicable.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Current cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.

p — Number of antenna planes

positive scalar integer

Number of antenna planes, specified as a positive scalar integer.

Data Types: `double`

Output Arguments

d — Dimension lengths of resource grid

numeric vector

Dimension lengths, returned as a three-element row vector [*N M P*]. *N* is the number of subcarriers (12×`NULRB`). *M* is the number of OFDM or SC-FDMA symbols in a subframe, 14 for normal cyclic prefix and 12 for extended cyclic prefix. *P* is the number of transmit antenna ports, `cfg.CellRefP` in the downlink and `cfg.NTxAnts` in the uplink.

Data Types: `double`

See Also

See Also

`lteDLResourceGridSize` | `lteResourceGrid` | `lteULResourceGridSize`

Introduced in R2014a

lteSCFDMADemodulate

SC-FDMA demodulation

Syntax

```
grid = lteSCFDMADemodulate(ue,waveform)
grid = lteSCFDMADemodulate(ue,waveform,cpfraction)
```

Description

`grid = lteSCFDMADemodulate(ue,waveform)` performs SC-FDMA demodulation of the time-domain waveform, `waveform`, given UE-specific settings structure, `ue`.

The demodulation performs one FFT operation per received SC-FDMA symbol. It recovers the received subcarrier values, which are then used to construct each column of the output resource array, `grid`. The FFT is positioned partway through the cyclic prefix, to allow for a certain degree of channel delay spread while avoiding the overlap between adjacent OFDM symbols. The input FFT is also shifted by half of one subcarrier. The particular position of the FFT chosen here avoids the SC-FDMA symbol overlapping used in the `lteSCFDMAModulate` function. Since the FFT is performed away from the original zero phase point on the transmitted subcarriers, a phase correction is applied to each subcarrier after the FFT.

`grid = lteSCFDMADemodulate(ue,waveform,cpfraction)` allows the specification of the position of the demodulation through the cyclic prefix.

Examples

Perform SC-FDMA Demodulation

Perform SC-FDMA demodulation of uplink fixed reference channel (FRC) A3-2.

```
frc = lteRMCUL('A3-2');
waveform = lteRMCULTool(frc,randi([0,1],frc.PUSCH.TrBlkSizes(1),1));
```

```
rgrid = lteSCFDMADemodulate(frc,waveform);
```

Input Arguments

ue — UE-specific settings
structure

UE-specific settings, specified as a structure. `ue` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length

Data Types: `struct`

waveform — Time-domain waveform
numeric matrix

Time-domain waveform, specified as a numeric matrix. The sampling rate of the time domain waveform `waveform` must be the same as used in the `lteSCFDMAModulate` modulator function for the specified number of resource blocks NULRB. `waveform` must also be time-aligned such that the first sample is the first sample of the cyclic prefix of the first SC-FDMA symbol in a subframe.

Data Types: `double`
Complex Number Support: Yes

cpfraction — Cyclic prefix fraction
`0.55` (default) | positive numeric scalar

Cyclic prefix fraction, specified as a positive numeric scalar between `0` and `1`. This argument specifies the position of the demodulation through the cyclic prefix. A value of `0` represents the start of the cyclic prefix. A value of `1` represents the end of the cyclic prefix. The default value of `0.55` allows for the default level of windowing in the `lteSCFDMAModulate` function.

Data Types: `double`

Output Arguments

`grid` — Output resource array
numeric matrix

Output resource array, returned as a numeric matrix.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`lteSCFDMAInfo` | `lteSCFDMAModulate` | `lteULChannelEstimate` | `lteULChannelEstimatePUCCH1` | `lteULChannelEstimatePUCCH2` | `lteULChannelEstimatePUCCH3` | `lteULFrameOffset` | `lteULFrameOffsetPUCCH1` | `lteULFrameOffsetPUCCH2` | `lteULFrameOffsetPUCCH3` | `lteULPerfectChannelEstimate`

Introduced in R2014a

lteSCFDMAModulate

SC-FDMA modulation

Syntax

```
[waveform,info] = lteSCFDMAModulate(ue,grid)
[waveform,info] = lteSCFDMAModulate(ue,grid,windowing)
```

Description

`[waveform,info] = lteSCFDMAModulate(ue,grid)` performs IFFT calculation, half-subcarrier shifting, and cyclic prefix insertions. It optionally performs raised-cosine windowing and overlapping of adjacent SC-FDMA symbols of the complex symbols in the resource array, `grid`.

For a block diagram that illustrates the steps in SC-FDMA modulation, see “Algorithms” on page 1-1102.

`[waveform,info] = lteSCFDMAModulate(ue,grid,windowing)` allows control of the number of windowed and overlapped samples used in the time-domain windowing. If the value in `ue.Windowing` is present, it is ignored and the output, `info.Windowing`, equals `windowing`.

Examples

Perform SC-FDMA Modulation

Perform SC-FDMA modulation of one subframe of random uniformly-distributed noise, using a 10MHz configuration.

```
ue = struct('NULRB',50);
dims = lteULResourceGridSize(ue);
reGrid = reshape(lteSymbolModulate(randi([0,1],prod(dims)*2,1), ...
    'QPSK'),dims);
```

```
waveform = lteSCFDMAModulate(ue,reGrid);
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure. `ue` contains the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Windowing`	Optional	Nonnegative scalar integer Default value is absent.	The number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied See Note:

Note: If `ue.Windowing` is absent, `info.Windowing` returns a default value chosen as a function of `ue.NULRB` to compromise between the effective duration of cyclic prefix (and therefore the channel delay spread tolerance) and the spectral characteristics of the transmitted signal (not considering any additional FIR filtering). `ue.Windowing` must be even. With a value of zero, issues identified in the description of output, `grid`, concerning concatenation of subframes before SC-FDMA, modulation do not apply.

The number of samples used for windowing depends on the cyclic prefix length (normal or extended) and the number of resource blocks, and is chosen in accordance with the maximum values implied in TS 36.104, Tables E.5.1-1 and E.5.1-2 [1]. The number of windowing samples is a compromise between the effective duration of cyclic prefix (and therefore the channel delay spread tolerance) and the spectral characteristics of the transmitted signal (not considering any additional FIR filtering). For a larger amount of windowing, the effective duration of the cyclic prefix is reduced but the transmitted signal spectrum has smaller out of band emissions.

Number of resource blocks `NULRB`	Windowing samples for normal cyclic prefix	Windowing samples for extended cyclic prefix
6	4	4
15	6	6
25	4	4
50	6	6
75	8	8
100	8	8

Data Types: `struct`

`grid` — Resource grid

M-by-*N*-by-*P* numeric array

Resource grid, specified as an *M*-by-*N*-by-*P* numeric array array. The grid input contains *M* number of subcarriers, *N* number of SC-FDMA symbols, and *P* number of transmission antennas. The array contains resource elements (REs) for a number of subframes across all configured antenna ports, as described in "Data Structures". Alternatively, it contains multiple such matrices concatenated to give multiple subframes (concatenation across the columns or 2nd dimension). The antenna planes in `grid` are each OFDM modulated to give the columns of `waveform`.

Dimension *M* must be 12 ×`NULRB`, where `NULRB` must be an integer from 6 to 110. Dimension *N* must be a multiple number of symbols in a subframe *L*, where *L*=14 for normal cyclic prefix and *L*=12 for extended cyclic prefix. Dimension *P* must be (`1,2,4`).

The `grid` can span multiple subframes and windowing and overlapping is applied between all adjacent SC-FDMA symbols, including the last of one subframe and the first of the next. Therefore a different result is obtained than if `lteSCFDMAModulate` is called on individual subframes and then those time-domain waveforms concatenated. The resulting waveform in that case would have discontinuities at the start/end of each subframe. Therefore it is recommended that all subframes for SC-FDMA modulation first be concatenated before calling `lteSCFDMAModulate` on the resulting multi-subframe array. However, individual subframes can be OFDM modulated and the resulting multi-subframe time-domain waveform created by manually overlapping.

Data Types: `double`

Complex Number Support: Yes

`windowing` — Number of windowed and overlapped samples

positive scalar integer

Number of windowed and overlapped samples, specified as a positive scalar integer. This argument controls the number of windowed and overlapped samples used in time-domain windowing. If present, it is used for the SC-FMDA modulation (instead of `ue.Windowing`) and it is the value output for `info.Windowing`.

Data Types: `double`

Output Arguments

`waveform` — SC-FDMA modulated waveform

numeric matrix

SC-FDMA modulated waveform, returned as a numeric matrix of size T-by-P, where T is the number of time-domain samples and P is the number of transmission antennas. $T = K \times 30720 / 2048 \times N_{fft}$ where N_{fft} is the IFFT size and K is the number of subframes in the input `grid`. N_{fft} is a function of the Number of Resource Blocks (NRB).

NRB	N_{fft}
6	128
15	256
25	512
50	1024
75	2048
100	2048

In general, N_{fft} is the smallest power of 2 greater than or equal to `12×NRB/0.85`. It is the smallest FFT that spans all subcarriers and results in a bandwidth occupancy ($12\times\text{NRB}/N_{\text{fft}}$) of no more than 85%.

Data Types: `double`
Complex Number Support: Yes

`info` — Information about SC-FDMA modulated waveform

scalar structure

Information about SC-FDMA modulated waveform, returned as a scalar structure. `info` contains the following fields.

`SamplingRate` — Sampling rate of time-domain waveform

positive numeric scalar

Sampling rate of time-domain waveform, `waveform`, returned as a positive numeric scalar. The sampling rate of the waveform is given by the equation: *SamplingRate* = 30.72 MHz / 2048 × N_{FFT}.

Data Types: `double`

`Nfft` — Number of FFT points

positive scalar integer

Number of FFT points, returned as a positive scalar integer.

Data Types: `double`

`Windowing` — Number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied

positive scalar integer

Number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied, returned as a positive scalar integer.

Data Types: `double`

`CyclicPrefixLengths` — Cyclic prefix length

even integer scalar

Cyclic prefix length (in samples) of each OFDM symbol in a subframe.

info.Nfft	CyclicPrefixLengths	
	for `CyclicPrefix = 'Normal'`	for `CyclicPrefix = 'Extended'`
2048	[160 144 144 144 144 144 144 160 144 144 144 144 144 144]	[512 512 512 512 512 512 512 512 512 512 512 512]

info.Nfft	CyclicPrefixLengths	
	for `CyclicPrefix = 'Normal'`	for `CyclicPrefix = 'Extended'`
1024	[80 72 72 72 72 72 72 80 72 72 72 72 72 72]	[256 256 256 256 256 256 256 256 256 256 256 256 256 256]
512	[40 36 36 36 36 36 36 40 36 36 36 36 36 36]	[128 128 128 128 128 128 128 128 128 128 128 128 128 128]
256	[20 18 18 18 18 18 18 20 18 18 18 18 18 18]	[64 64 64 64 64 64 64 64 64 64 64 64 64 64]
128	[10 9 9 9 9 9 9 10 9 9 9 9 9 9]	[32 32 32 32 32 32 32 32 32 32 32 32 32 32]

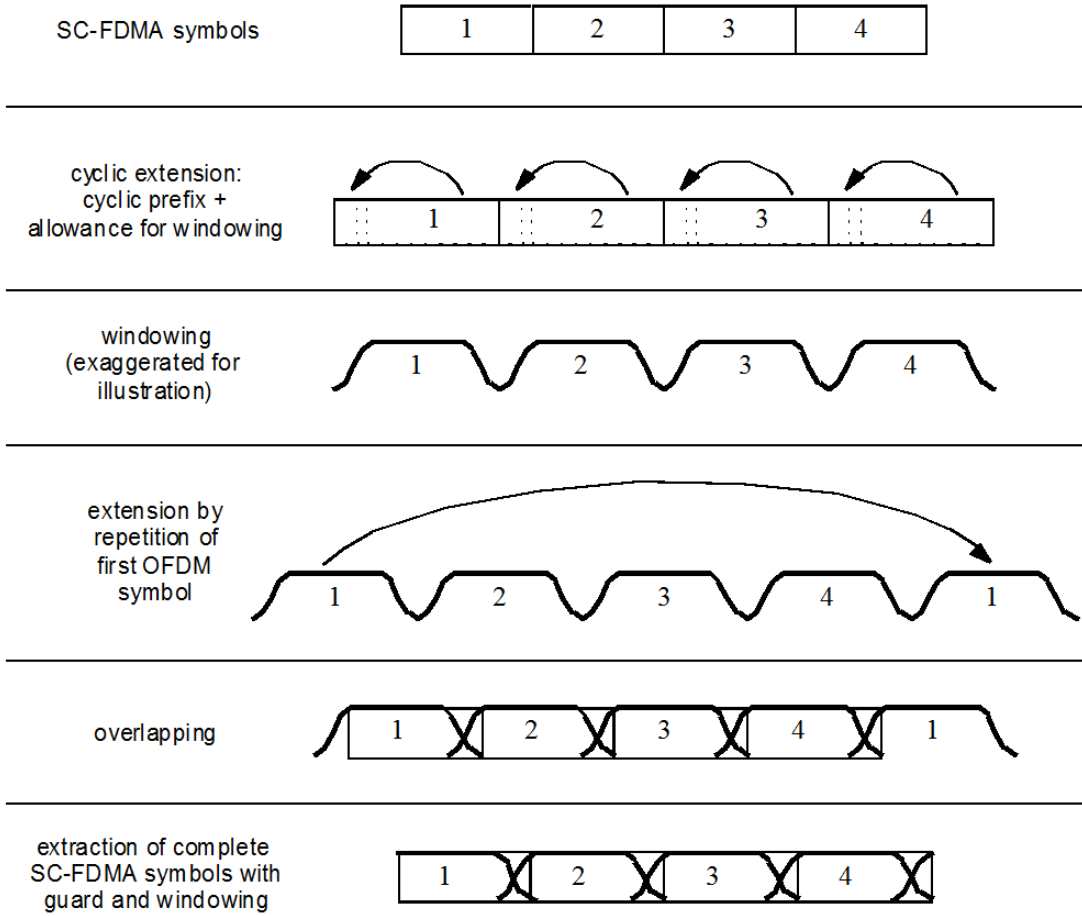
Note: As shown in this table, for `info.Nfft` < 2048, `info.CyclicPrefixLengths` are the `CyclicPrefixLengths` for `info.Nfft` = 2048 scaled by `info.Nfft` / 2048.

Data Types: `int32`

Data Types: `struct`

Algorithms

The following diagram illustrates the processing performed by SC-FDMA modulation.



References

[1] 3GPP TS 36.104. “Base Station (BS) radio transmission and reception.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteFadingChannel` | `lteHSTChannel` | `lteMovingChannel` | `lteSCFDMADemodulate` | `lteSCFDMAInfo` | `lteULResourceGrid` | `lteULResourceGridSize`

Introduced in R2014a

lteSCFDMAInfo

SC-FDMA modulation information

Syntax

```
info = lteSCFDMAInfo(ue)
```

Description

`info = lteSCFDMAInfo(ue)` provides information related to the SC-FDMA modulation performed by `lteSCFDMAModulate`, given the UE-specific settings structure, `ue`.

Examples

Get SC-FDMA Modulation Information

Using lteSCFDMAInfo to get Get SC-FDMA modulation information

Initialize ue configuration structure with bandwidth specified in resource blocks.

```
ue = struct('NULRB',50);
info = lteSCFDMAInfo(ue);
info.SamplingRate
```

```
ans =

    15360000
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure. `ue` is a structure having these fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`Windowing`	Optional	Nonnegative scalar integer	The number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied See Note:

Note: If the `ue.Windowing` field is absent, `info.Windowing` returns a default value chosen as a function of the `ue.NULRB` field. This mechanism acts as a compromise between the effective duration of cyclic prefix (and therefore the channel delay spread tolerance) and the spectral characteristics of the transmitted signal (not considering any additional FIR filtering). See `lteSCFDMAModulate` for details.

Data Types: `struct`

Output Arguments

`info` — Information related to SC-FDMA modulation

structure array

Information related to SC-FDMA modulation, returned as a structure array. The structure contains these fields.

`SamplingRate` — Sampling rate

numeric scalar

Sampling rate, returned as a numeric scalar. The function computes the sampling rate of the time domain waveform using the following equation: `SamplingRate` = 30720000 ÷ 2048 ×N_{fft}

Data Types: `double`

`Nfft` — Number of FFT points

numeric scalar

Number of FFT points used in the SC-FDMA modulator, returned as a numeric scalar.

Data Types: `double`

`Windowing` — Number of time-domain windowing samples

scalar integer

Number of time-domain windowing samples, returned as a scalar integer. This field represents the number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied.

Data Types: `double`

`CyclicPrefixLengths` — Cyclic prefix length

even integer scalar

Cyclic prefix length (in samples) of each OFDM symbol in a subframe.

info.Nfft	CyclicPrefixLengths	
	for `CyclicPrefix = 'Normal'`	for `CyclicPrefix = 'Extended'`
2048	[160 144 144 144 144 144 144 160 144 144 144 144 144 144]	[512 512 512 512 512 512 512 512 512 512 512 512]
1024	[80 72 72 72 72 72 72 80 72 72 72 72 72 72]	[256 256 256 256 256 256 256 256 256 256 256 256]
512	[40 36 36 36 36 36 36 40 36 36 36 36 36 36]	[128 128 128 128 128 128 128 128 128 128 128 128]
256	[20 18 18 18 18 18 18 20 18 18 18 18 18 18]	[64 64 64 64 64 64 64 64 64 64 64 64]
128	[10 9 9 9 9 9 9 10 9 9 9 9 9 9]	[32 32 32 32 32 32 32 32 32 32 32 32]

Note: As shown in table above, for `info.Nfft` < 2048, `info.CyclicPrefixLengths` are the `CyclicPrefixLengths` for `info.Nfft` = 2048 scaled by `info.Nfft` / 2048.

Data Types: `uint32`

Data Types: `struct`

See Also

See Also

`lteOFDMInfo` | `lteSCFDMADemodulate` | `lteSCFDMAModulate` | `lteULResourceGridSize`

Introduced in R2014a

lteSCI

Sidelink control information format structure and bit payload

Syntax

```
[sciout,bitsout] = lteSCI(ue)
[sciout,bitsout] = lteSCI(ue,sciin)
[sciout,bitsout] = lteSCI(ue,bitsin)
[sciout,bitsout] = lteSCI(___,opts)
```

Description

`[sciout,bitsout] = lteSCI(ue)` returns a sidelink control information (SCI) message structure, `sciout`, and the SCI message bit vector, `bitsout`, for the settings specified in the user equipment structure.

This function creates and manipulates SCI format 0 messages, defined in TS 36.212 [1], Section 5.4.3. You can use `lteSCI` to create a default SCI message, to blindly decode SCI format types, and to determine the sizes of the bit fields.

By default, all returned fields are set to zero.

`[sciout,bitsout] = lteSCI(ue,sciin)` returns the SCI structure fields and bit vector using settings specified in SCI input structure `sciin`. Fields not defined in `sciin` are set to defaults specified by `ue`. You can use this syntax to initialize SCI field values, in particular the frequency hopping bit, which affects the fields that the format uses.

`[sciout,bitsout] = lteSCI(ue,bitsin)` returns the SCI structure fields and bit vector using settings specified in bit input vector `bitsin`. The input bit vector is returned as the SCI information bit payload, where `bitsout` == `bitsin`.

`[sciout,bitsout] = lteSCI(___,opts)` formats the `sciout` structure using options specified in `opts`.

Examples

Create SCI Message

Create a format 0 SCI message structure.

Create a UE settings structure.

```
ue = struct('NSLRB','15MHz');
```

Generate an SCI message and view the returned SCI message structure contents.

```
[sci0,bits] = lteSCI(ue);
sci0
allocfields = sci0.Allocation
```

```
sci0 =

  struct with fields:

              SCIFormat: 'Format0'
            FreqHopping: 0
             Allocation: [1×1 struct]
    TimeResourcePattern: 0
              ModCoding: 0
            TimeAdvance: 0
                  NSAID: 0


allocfields =

  struct with fields:

    RIV: 0
```

Create SCI Message with Distributed VRB Allocation Type

Create a format 0 SCI message structure with the distributed VRB allocation type. The allocation message fields are contained in the `Allocation` substructure. To create the appropriate set of fields at the output, the `FreqHopping` field is initialized at the input to the function.

Create a UE settings structure and define `FreqHopping` using an input SCI message structure.

```
ue = struct('NSLRB',50);
sciin = struct('FreqHopping',1);
```

Generate an SCI message and view the returned SCI message structure contents.

```
[sci0,bits] = lteSCI(ue,sciin);
sci0
allocfields = sci0.Allocation
```

```
sci0 =

  struct with fields:

             SCIFormat: 'Format0'
           FreqHopping: 1
            Allocation: [1×1 struct]
    TimeResourcePattern: 0
              ModCoding: 0
           TimeAdvance: 0
                 NSAID: 0


allocfields =

  struct with fields:

    HoppingBits: 0
            RIV: 0
```

Recover SCI Message from Bit Vector

Recover the contents of a format 0 SCI message bit vector.

Create a UE settings structure.

```
ue = struct('NSLRB',50);
```

Generate an SCI message structure.

```
[sci0,bits] = lteSCI(ue);
```

```
sci0
```

```
sci0 =

  struct with fields:

             SCIFormat: 'Format0'
           FreqHopping: 0
            Allocation: [1×1 struct]
    TimeResourcePattern: 0
             ModCoding: 0
           TimeAdvance: 0
                 NSAID: 0
```

Change the `ModCoding` setting to 22 and generate an SCI bits vector.

```
sci0.ModCoding = 22;
[~,bits_new] = lteSCI(ue,sci0);
```

Use the new bits to recover the new SCI message. View the new SCI message structure and confirm that the `ModCoding` setting is now 22.

```
[sci0_new,~] = lteSCI(ue,bits_new)
```

```
sci0_new =

  struct with fields:

             SCIFormat: 'Format0'
           FreqHopping: 0
            Allocation: [1×1 struct]
    TimeResourcePattern: 0
             ModCoding: 22
           TimeAdvance: 0
                 NSAID: 0
```

View SCI Message Field Sizes

Create a format 0 SCI message structure. Use the `opts` input to view the message field sizes and to exclude fields with zero length.

Create a UE settings structure.

```
ue = struct('NSLRB','5MHz');
opts = {'fieldsizes','excludeunusedfields'}
```

```
opts =

  1×2 cell array

    'fieldsizes'    'excludeunusedfields'
```

Generate an SCI message and view the field sizes of the returned SCI message structure contents.

```
[sci0,bits] = lteSCI(ue,opts);
sci0
allocfields = sci0.Allocation
```

```
sci0 =

  struct with fields:

              SCIFormat: 'Format0'
            FreqHopping: 1
             Allocation: [1×1 struct]
    TimeResourcePattern: 7
              ModCoding: 5
            TimeAdvance: 11
                  NSAID: 8


allocfields =

  struct with fields:

    RIV: 9
```

Inspect the returned structure to see the bit length of each field in the SCI message.

```
fieldsLength = sci0.FreqHopping + sci0.Allocation.RIV + ...
```

```
    sci0.TimeResourcePattern + sci0.ModCoding + sci0.TimeAdvance + ...
    sci0.NSAID
bitsLength = size(bits,1)
isequal(fieldsLength,bitsLength)


fieldsLength =

  uint64

   41


bitsLength =

    41


ans =

  logical

   1
```

The sum of the field sizes matches the length of the returned `bits` output.

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a structure containing these parameter fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: 6, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`opts` — Format options for output SCI structure

`{'fieldvalues', 'includeallfields'}` (default) | `'fieldsizes'` | `'excludeunusedfields'` | optional

Format options for output SCI structure, specified as a character vector or a cell array of character vectors. You can specify a format for the *Field content* and *Fields to include*.

Category	Options	Description
Field content	`'fieldvalues'` (default)	Set the fields to zero or to their input values.
	`'fieldsizes'`	Sets the field values to their bit sizes and adds the `Padding` field to `sciout`. `Padding` indicates the number of padding bits appended.
Fields to include	`'includeallfields'` (default)	`sciout` includes all possible fields for the requested SCI format.
	`'excludeunusedfields'`	`sciout` excludes zero-length fields for the given parameter set.

Example: `{'fieldsizes','excludeunusedfields'}` returns field sizes in `sciout` and excludes zero-length fields for the given parameter set.

Data Types: `char` | `cell`

`sciin` — SCI message settings

structure

SCI message settings, specified as a structure containing any fields returned in `sciout`. See `sciout` for the specific fields output for each `SCIFormat`. SCI format 0 message is defined in TS 36.212 [1], Section 5.4.3.1.

Data Types: `struct`

`bitsin` — Input bits

column vector

Input bits, specified as a column vector. `bitsin` is treated as the SCI message bit payload, that is, `bitsout` == `bitsin`. The length of `bitsin` must align with the number of resource blocks, `ue.NSLRB`. Use `lteSCIInfo` to determine SCI message length for the specified `ue` settings.

Data Types: `double`

Output Arguments

`sciout` — DCI message structure

structure

SCI message structure, returned as a structure whose fields match the associated SCI format contents.

The field names associated with `sciout` depend on the SCI format field in `sciin`. By default, all values are set to zero. However, if any of the SCI fields are already present in the input `sciin`, their values are carried forward into `sciout`. The input field values appear in the associated bit positions in `bitsout`. Carrying the values forward allows for easy initialization of SCI field values. `sciout` also carries forward the `NSLRB` field specified in `sciin`.

This table presents the fields associated with each SCI format, as defined in TS 36.212 [1], Section 5.4.3.1.

SCI Formats	`sciout` Fields	Size	Description
`'Format0'`	`SCIFormat`	-	`'Format0'`
	`FreqHopping`	1 bit	PSSCH frequency hopping flag
	`Allocation`	from 5 to 13 bits, $\lceil \log_2(N_{\mathrm{RB}}^{\mathrm{SL}}(N_{\mathrm{RB}}^{\mathrm{SL}}+$	Resource block assignment and hopping resource allocation substructure, type 0 or type 1 allocation
	`TimeResourcePat`	7 bits	Time resource pattern (I_{TRP})
	`ModCoding`	5 bits	Modulation and coding scheme (I_{MCS})
	`TimeAdvance`	11 bits	Timing advance indication
	`NSAID`	8 bits	Group destination ID, as defined by higher layers
	`Padding`	0 bits	Always zero for SCI Format 0

`bitsout` — SCI message in bit payload form

column vector of binary values

SCI message in bit payload form, returned as a column vector. `bitsout` represents the set of message fields mapped to the information bit payload (including any zero-padding).

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCI` | `lteSCIDecode` | `lteSCIEncode` | `lteSCIInfo`

Introduced in R2016b

lteSCIDecode

SCI decoding

Syntax

```
[scibits,err] = lteSCIDecode(scilen,softbits)
[scibits,err] = lteSCIDecode(ue,softbits)
```

Description

`[scibits,err] = lteSCIDecode(scilen,softbits)` recovers a sidelink control information (SCI) message and also returns the cyclic redundancy check indication, given the SCI vector length and input vector of soft bits. For more information, see "SCI Message Decoding" on page 1-1121.

`[scibits,err] = lteSCIDecode(ue,softbits)` uses a UE settings structure to determine the SCI message length.

Examples

Decode Format 0 SCI Message

Decode an SCI format 0 message given the SCI message length. Use the length of an SCI format 0 message, determined using `lteSCIInfo`, to create and encode an SCI message.

Create a UE settings structure with 10 MHz bandwidth and normal cyclic prefix length.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
```

Use `lteSCIInfo` to determine the SCI message length. Encode the SCI message.

```
sciInfo = lteSCIInfo(ue);
scilen = sciInfo.Format0;
sciBits = zeros(scilen,1);
```

```
cw = lteSCIEncode(ue,sciBits);
```

Decode the SCI message payload bit vector.

```
[sciBits,crcErr] = lteSCIDecode(scilen,cw);
crcErr
```

```
crcErr =

  logical

   0
```

The cyclic redundancy check returns a zero, indicating that the decoded SCI message has no errors.

Decode Format 0 SCI Message Using UE Settings

Decode an SCI format 0 message using UE settings. Encode a bit vector representing an SCI information payload, and then decode and error-check the result. Use a UE settings structure to create and encode an SCI message.

Create a UE settings structure with 5 MHz bandwidth and extended cyclic prefix length. Generate and encode an SCI format 0 message.

```
ue = struct('NSLRB','5MHz','CyclicPrefixSL','Extended');

[~,sciBits] = lteSCI(ue);
cw = lteSCIEncode(ue,sciBits);
```

Decode the SCI message payload bit vector, `cw`. Use the UE settings structure to determine the SCI message length.

```
[sciBits,crcErr] = lteSCIDecode(ue,cw);
crcErr
```

```
crcErr =

  logical

   0
```

The cyclic redundancy check returns a zero, indicating that the decoded SCI message has no errors.

Input Arguments

`scilen` — Length of recovered SCI message vector

positive integer

Length of recovered SCI message vector, specified as a positive integer. This argument is normally equal to the length of the SCI format 0 message for the sidelink bandwidth. Use `lteSCIInfo` to determine the expected SCI message length.

Data Types: `double`

`softbits` — Floating-point soft bits

column vector

Floating-point soft bits, specified as a column vector. The length of `softbits` is nominally 288 bits for normal cyclic prefix or 240 extended cyclic prefix, matching the bit capacity of the PSCCH (ignoring the SC-FDMA guard symbol). Otherwise, the number of soft bits must be a multiple of 2 and should be a multiple of 12 or 10 for normal and extended cyclic prefix respectively, corresponding to the number of data SC-FDMA symbols in a PSCCH subfame.

Data Types: `double | int8`

`ue` — User equipment settings

structure

User equipment settings, specified as a structure containing these parameter fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

Output Arguments

`scibits` — Recovered SCI message bits

column vector of binary values

Recovered SCI message bits, returned as a column vector. For more information, see "SCI Message Decoding" on page 1-1121.

`err` — CRC error status

0 | 1

CRC error status, returned as 0 for no errors or 1 when the CRC fails.

Definitions

SCI Message Decoding

Sidelink control information (SCI) message decoding performs the inverse SCI processing operation as specified in TS 36.212 [1], Section 5.4.3. Specifically, `lteSCIDecode` performs PUSCH deinterleaving, rate recovery, and Viterbi and CRC decoding to recover the SCI message bit vector (`scibits`) from an input vector of received soft bits previously coded by the SCI processing. `lteSCIDecode` also returns the CRC error status, signaled by 0 for no errors and 1 when CRC fails.

If `scilen` is provided as an input argument, the function uses it for the length of the SCI information payload to be recovered. Otherwise the function computes the length, using the fields in `ue` that specify the bandwidth (`NSLRB`) and cyclic prefix length (`CyclicPrefixSL`).

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSCCHDecode` | `lteSCI` | `lteSCIEncode` | `lteSCIInfo`

Introduced in R2016b

lteSCIEncode

SCI encoding

Syntax

```
cw = lteSCIEncode(ue,scibits)
cw = lteSCIEncode(ue,scibits,outlen)
```

Description

`cw = lteSCIEncode(ue,scibits)` returns the codeword resulting from the sidelink control information (SCI) encoding of the input bit vector, `scibits`, given the field settings in the user equipment structure, `ue`. As defined in TS 36.212 [1], Section 5.4.3, the encoding process includes 16 bit CRC attachment, tail biting convolutional coding, rate matching and PUSCH interleaving. This processing takes in an SCI message generated with `lteSCI`. The codeword returned is ready for transmission on the `ltePSCCH` physical channel.

`cw = lteSCIEncode(ue,scibits,outlen)` rate matches the returned codeword to the output length provided by `outlen`.

Examples

Encode Format 0 SCI Message

Create an SCI format 0 message structure, modify selected information field values, and generate the new SCI message and payload bits. Encode the SCI message payload bits.

Create a UE settings structure and SCI message structure.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
sci0 = lteSCI(ue);
```

Modify the SCI message structure settings and generate an SCI message bit vector.

```
sci0.FreqHopping = 1;
sci0.ModCoding = 3;
```

```
[sci0,scibits] = lteSCI(ue,sci0);
```

Generate an encoded SCI message codeword.

```
cw = lteSCIEncode(ue,scibits);
```

Encode Format 0 SCI Message of Specified Length

Create an SCI format 0 message structure, and generate the new SCI message and payload bits. Encode the SCI message payload bits in a codeword of length specified by `outlen`.

Create a UE settings structure and SCI message structure.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Extended');
[sci0,scibits] = lteSCI(ue);
```

Generate an encoded SCI message codeword of length specified by `outlen`.

```
outlen = 144;
cw = lteSCIEncode(ue,scibits,outlen);
size(cw)
```

```
ans =

   144     1
```

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a structure containing this parameter field:

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

`scibits` — SCI message bit vector

column vector

SCI message bit vector, specified as a column vector. `scibits` are the SCI processing input bits to be transmitted on a single PSCCH.

Data Types: `double` | `int8`

`outlen` — Codeword length

nonnegative integer | optional

Codeword length, specified as a nonnegative integer. `outlen` must be a multiple of 2 and should be a multiple of 14 or 12 for normal and extended cyclic prefix respectively. The output length is meant to match the number of data-carrying SC-FDMA symbols in a PSCCH subframe and align with the dimensions of the PUSCH interleaver stage.

Output Arguments

`cw` — Codeword

288 bit or 240 bit column vector | column vector with zero rows | column vector with length equal to `outlen`

Codeword resulting from SCI processing, returned as a column vector of binary values. `cw` is the result of SCI processing the input vector, `scibits`. The output codeword matches the normal or extended cyclic prefix bit capacity available in the `ltePSCCHIndices` output, not accounting for the sidelink SC-FDMA guard symbol. Depending on the function syntax used and input configuration, the length of `cw` is:

- 288 bits for nonempty data input and normal cyclic prefix
- 240 bits for nonempty data input and extended cyclic prefix
- An empty 0-by-1 matrix for an empty data input
- Rate-matched to `outlen`

References

[1] 3GPP TS 36.212. “Multiplexing and channel coding.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCIEncode` | `ltePSCCH` | `lteSCI` | `lteSCIDecode` | `lteSCIInfo`

Introduced in R2016b

lteSCIInfo

SCI message information

Syntax

```
info = lteSCIInfo(ue)
```

Description

`info = lteSCIInfo(ue)` returns an information structure indicating the payload sizes for SCI message formats. Release 12 defines a single SCI format 0, so the output structure contains one field with the message length for format 0.

To access the individual bit field sizes for the specified format, use `lteSCI`.

Examples

Get SCI Message Information

Get the information payload size of SCI message format 0 for UE settings configuration with 10 MHz channel bandwidth.

A channel bandwidth of 10 MHz requires 50 resource blocks, `NSLRB = 50`.

```
ue = struct('NSLRB',50);
sciOlength = lteSCIInfo(ue)
```

```
sciOlength =

  struct with fields:

    Format0: 43
```

Get SCI Message Information for Standard Bandwidths

Get the information payload size of SCI message format 0 for standard bandwidths.

```
cbw = {'1.4MHz' '3MHz' '5MHz' '10MHz' '15MHz' '20MHz'};
disp('Bandwidth  SCI Message Length (bits)')
for ii = 1:size(cbw,2)
    ue = struct('NSLRB',cbw(1,ii));
    sciOlength = lteSCIInfo(ue);
    bw = cbw{1,ii};
    fprintf('%6s     %3d\n',bw, sciOlength.Format0)
end
```

```
Bandwidth  SCI Message Length (bits)
1.4MHz      37
  3MHz      39
  5MHz      41
 10MHz      43
 15MHz      44
 20MHz      45
```

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a structure containing this parameter field:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

Output Arguments

`info` — Payload size for the SCI message format

structure

Payload size for the SCI message format, returned as a structure with the following parameter field:

`Format0` — Format 0 payload size

integer

Format 0 payload size, returned as an integer indicating the SCI message length used for the scheduling of PSSCH.

Data Types: `double`

See Also

See Also

`lteDCIInfo` | `lteSCI` | `lteSCIDecode` | `lteSCIEncode`

Introduced in R2016b

lteSCIResourceAllocation

SCI message physical resource blocks allocation

Syntax

```
prbset = lteSCIResourceAllocation(ue,scistr)
```

Description

`prbset = lteSCIResourceAllocation(ue,scistr)` returns a column vector containing the zero-based physical resource block (PRB) indices for the specified UE settings and as defined by the resource allocation substructure of the sidelink control information (SCI) message structure. The PRB indices created are for a single PSSCH transmission in a subframe within the PSSCH subframe pool.

For more information, see “SCI Resource Allocation” on page 1-1141.

Examples

Allocate Nonhopping PSSCH Subframe Pool PRBs

Display the PRB allocations associated with the sequence of subframes in a PSSCH subframe pool.

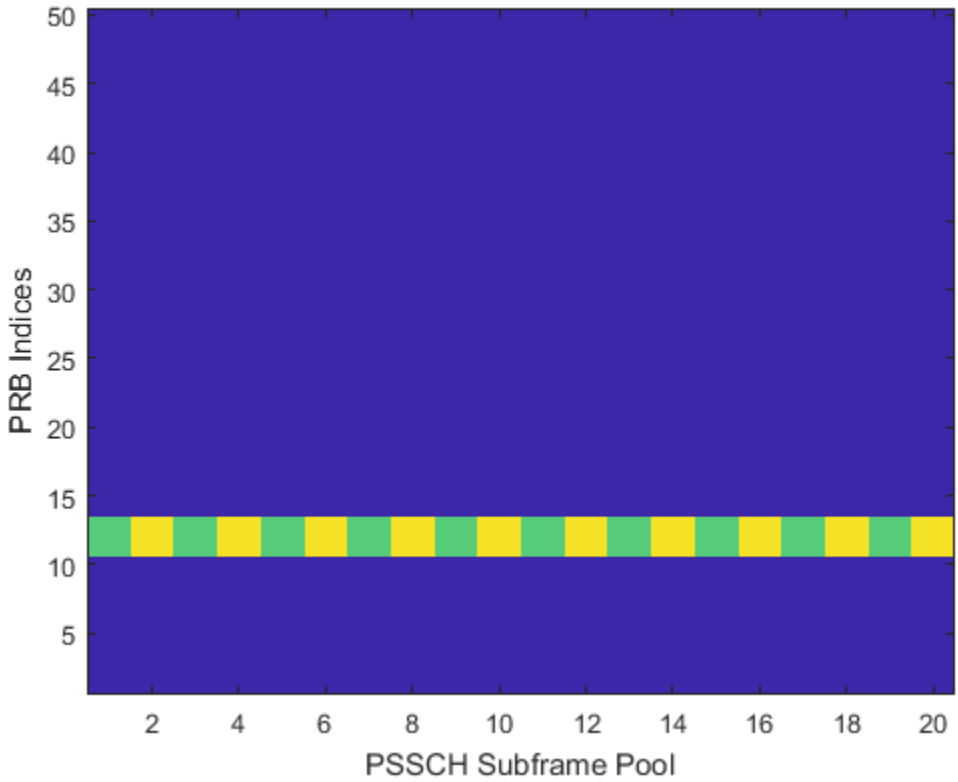
Configure a nonhopping allocation of 3 PRBs according to the RIV calculation specified in TS 36.213, Section 8.1.1.

```
ue = struct('NSLRB',50);
sci = struct('FreqHopping',0);
sci.Allocation.RIV = 110;
```

Display an image of the PRBs used in each slot of each subframe in a pool of 10 PSSCH subframes.

```
subframeslots = zeros(ue.NSLRB,20);
for i = 0:9
    ue.NSubframePSSCH = i;
    prbSet = lteSCIResourceAllocation(ue,sci);
```

```
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots)
axis xy
xlabel('PSSCH Subframe Pool')
ylabel('PRB Indices')
```



Allocate Type 2 Hopping PSSCH Subframe Pool PRBs

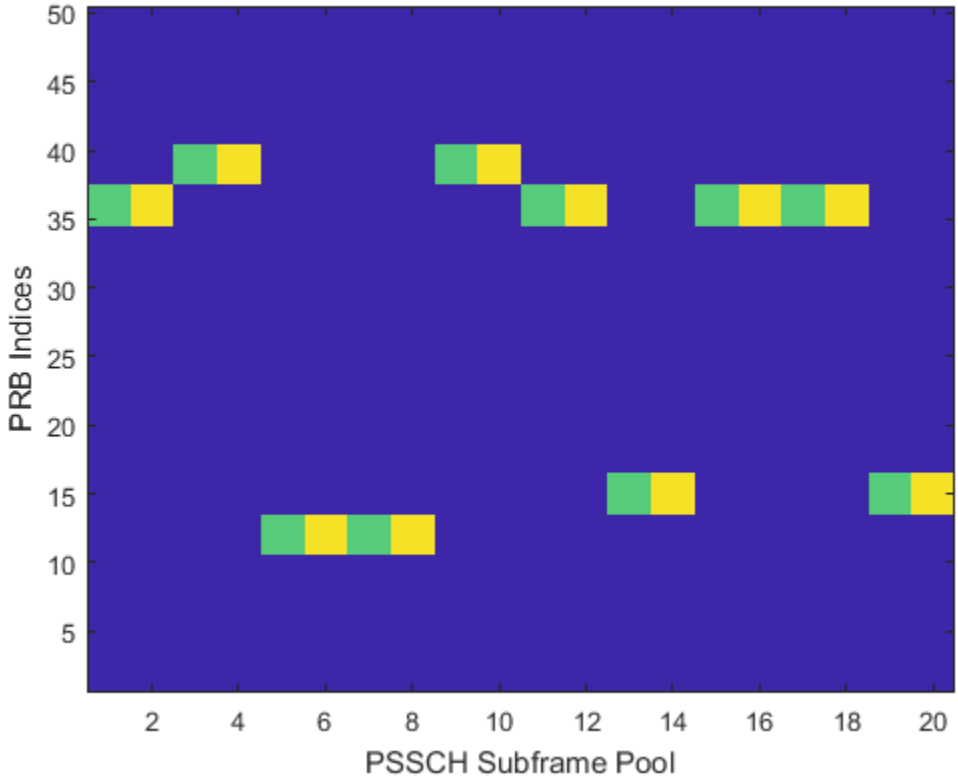
Configure a type 2 hopping allocation of 3 PRBs. Display the PRB allocations that are associated with the sequence of subframes in a PSSCH subframe pool.

Configure UE and SCI settings structures for a type 2 hopping allocation of 3 PRBs.

```
ue = struct('NSLRB',50);
ue.PSSCHHoppingParameter = 10;
ue.NSubbands = 2;
ue.PSSCHHoppingOffset = 1;
sci = struct('FreqHopping',1);
sci.Allocation.RIV = 110;
sci.Allocation.HoppingBits = 3;
```

Display an image of the PRBs used in each slot of each subframe in a pool of 10 PSSCH subframes.

```
subframeslots = zeros(ue.NSLRB,20);
for i = 0:9
    ue.NSubframePSSCH = i;
    prbSet = lteSCIResourceAllocation(ue,sci);
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots)
axis xy
xlabel('PSSCH Subframe Pool')
ylabel('PRB Indices')
```



Allocate Type 1 Hopping PSSCH Subframe Pool PRBs

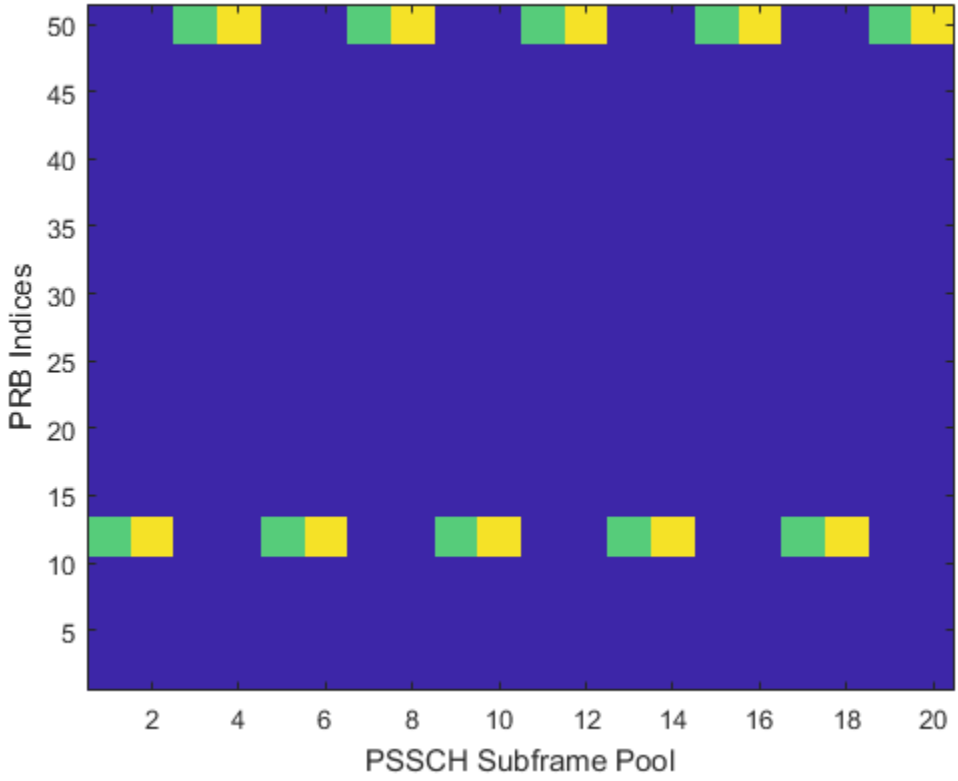
Configure a type 1 hopping allocation of 3 PRBs. Display the PRB allocations that are associated with the sequence of subframes in a PSSCH subframe pool.

Configure UE and SCI settings structures for a type 1 hopping allocation of 3 PRBs.

```
ue = struct('NSLRB',50);
sci = struct('FreqHopping',1);
sci.Allocation.RIV = 110;
sci.Allocation.HoppingBits = 1;
```

Display an image of the PRBs used in each slot of each subframe in a pool of 10 PSSCH subframes.

```
subframeslots = zeros(ue.NSLRB,20);
for i = 0:9
    ue.NSubframePSSCH = i;
    prbSet = lteSCIResourceAllocation(ue,sci);
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots)
axis xy
xlabel('PSSCH Subframe Pool')
ylabel('PRB Indices')
```



Allocate Type 1 Hopping PSSCH Pool Restricting PRBs

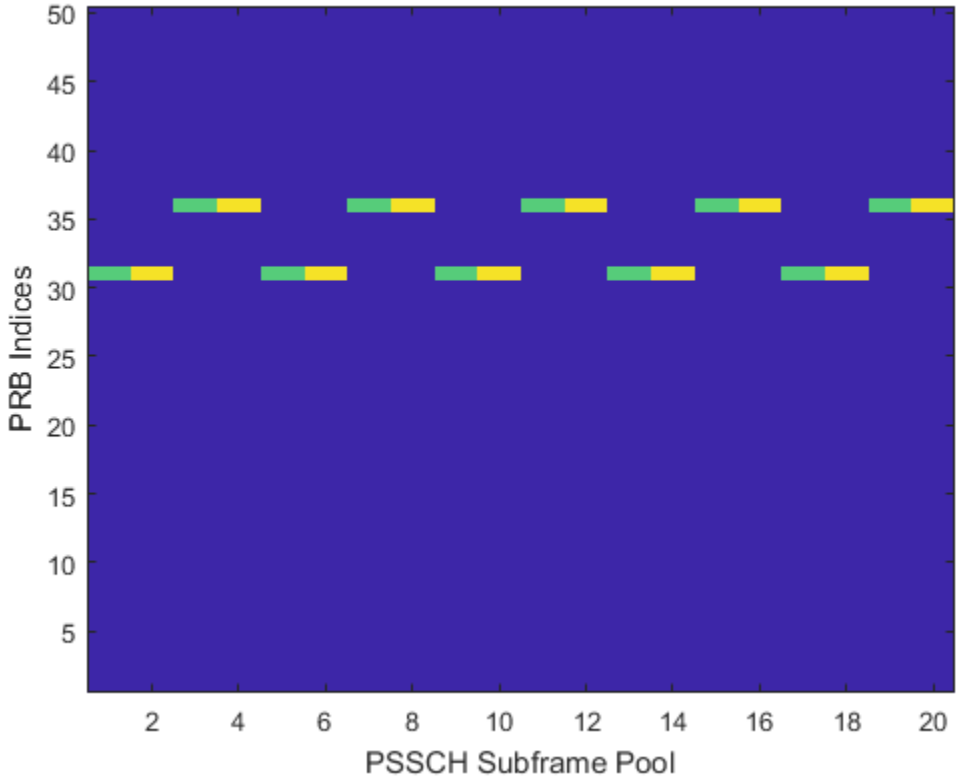
Configure PRB pool restriction for transmission mode 2. Display the PRB allocations that are associated with the sequence of subframes in a PSSCH subframe pool.

Configure a UE settings structure with specified PRB indices. Default settings are used for other UE and SCI fields.

```
ue = struct('NSLRB',50);
ue.PRBPool = (30:49);
sci = struct('FreqHopping',1);
```

Display an image of the PRBs used in each slot of each subframe in a pool of 10 PSSCH subframes.

```
subframeslots = zeros(ue.NSLRB,20);
for i = 0:9
    ue.NSubframePSSCH = i;
    prbSet = lteSCIResourceAllocation(ue,sci);
    prbSet = repmat(prbSet,1,2/size(prbSet,2));
    for s = 1:2
        subframeslots(prbSet(:,s)+1,2*i+s) = 20+s*20;
    end
end
image(subframeslots)
axis xy
xlabel('PSSCH Subframe Pool')
ylabel('PRB Indices')
```



Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: 6, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: double

NSubframePSSCH — PSSCH subframe number

integer scalar

PSSCH subframe number in PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

Note: This parameter applies for frequency hopping only. (scistr.FreqHopping = 1)

Data Types: double

PSSCHHoppingParameter — PSSCH hopping parameter

0 (default) | integer scalar from 0 to 510

PSSCH hopping parameter, specified as an integer scalar from 0 to 510. (*SL-HoppingConfigComm-r12 {hoppingParameter-r12}*)

All values ≥ 504 are treated as 510.

Note: This parameter applies for frequency hopping only. (scistr.FreqHopping = 1)

Data Types: double

NSubbands — Number of subbands

1 (default) | 2 | 4

Number of subbands, specified as 1, 2, or 4. (*SL-HoppingConfigComm-r12 {numSubbands-r12}*)

Note: This parameter applies for frequency hopping only. (scistr.FreqHopping = 1)

Data Types: double

`PSSCHHoppingOffset` — PSSCH hopping offset

0 (default) | integer scalar from 0 to 110

PSSCH hopping offset, specified as an integer scalar from 0 to 110. (*SL-HoppingConfigComm-r12 {rb-Offset-r12}*)

Note: This parameter applies for frequency hopping only. (`scistr.FreqHopping` = 1)

Data Types: `double`

`PRBPool` — PSSCH resource block pool

optional | zero-based integer vector

PSSCH resource block pool (sidelink transmission mode 2), specified as a zero-based integer vector of indices giving the PRBs in the pool. If `PRBPool` is absent or empty, the pool is assumed to be the full transmission bandwidth.

Note: This parameter applies for frequency hopping only. (`scistr.FreqHopping` = 1)

Data Types: `double`

Data Types: `struct`

`scistr` — Sidelink control information settings

structure

Sidelink control information settings, specified as a parameter structure containing these PRB allocation fields associated with an SCI format 0 message:

`FreqHopping` — Frequency hopping flag

0 (default) | 1

Frequency hopping flag, specified as 0 for nonhopping allocation type or 1 for hopping allocation type. When `scistr.FreqHopping` = 1, the hopping allocation type is signalled by `scistr.Allocation.HoppingBits`.

Data Types: `double`

`Allocation` — Resource allocation parameter substructure

structure

Resource allocation parameter substructure, specified as a structure.

`HoppingBits` — Hopping bits

0 (default) | bit vector with 0, 1, or 2 bits

Hopping bits, specified as a bit vector with 0, 1, or 2 bits. The `HoppingBits` parameter signals the hopping type. For more information, see "SCI Resource Allocation" on page 1-1141.

Data Types: `double`

`RIV` — Resource indication value

0 (default) | bit vector with 5 to 13 bits

Resource indication value, specified as a bit vector with 5 to 13 bits. The resource indication value assignment for sidelink follows the specifications for uplink, as modified in TS 36.213 [2], Sections 14.1.1.2 and 14.1.1.4. For more information, see "SCI Resource Allocation" on page 1-1141.

Data Types: `double`

Data Types: `struct`

Data Types: `struct`

Output Arguments

`prbset` — Physical resource block indices

nonnegative integer column vector | nonnegative integer column matrix

Physical resource block indices, returned as a nonnegative integer column vector or *N*-by-2 integer matrix of zero-based indices.

- When the allocation type defines one set of PRB indices to use in the first and second slots of the subframe, `prbset` is returned as an integer column vector.
- When the allocation type defines a different set of PRB indices in the first and second slots of the subframe, `prbset` is returned as two-column integer matrix.

The PRB indices created are for a single PSSCH transmission in a subframe within the PSSCH subframe pool.

Definitions

SCI Resource Allocation

Sidelink control information (SCI) resource allocation mapping is described in TS 36.211 [1], Section 9.3.6. The `sciout` structure returned by `lteSCI` can be directly used as the `scistr` structure input to `lteSCIResourceAllocation`. Using `lteSCI` creates a properly formatted SCI format 0 message, ensuring that the field values adhere to the underlying field bit lengths. The `scistr` field values are read modulo to the SCI message bit lengths. Any fields missing from `scistr` default to 0. PSSCH allocations are based on uplink resource allocation type 0 (see `lteDCI`, DCI format 0). In these allocations, the same single contiguous PRB allocation must be used for both slots in the subframe. As with uplink, for sidelink:

- A `FreqHopping` value of 1 signals a hopping allocation type. There are two types of hopping: type 1 PUSCH hopping and type 2 PUSCH hopping (frequency hopping with a predefined pattern). `scistr.Allocation.HoppingBits` signals the hopping type, as specified in TS 36.213 [2], Table 8.4-2.
- A `FreqHopping` value of 0 signals a nonhopping allocation type

Alternatively, you can use `lteDCIResourceAllocation` with a DCI format 5 message and the same message fields to generate the PSSCH allocations. This PSSCH allocation represents sidelink transmission mode 1, with the eNodeB using a DCI format 5 message to provide the transmitting UE with a PSSCH resource allocation.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDCIResourceAllocation` | `ltePSCCH` | `lteSCI` | `lteSLSCH`

Introduced in R2016b

lteSLBCH

Sidelink broadcast channel

Syntax

```
cw = lteSLBCH(ue,trblk)
```

Description

`cw = lteSLBCH(ue,trblk)` returns a column vector of sidelink broadcast channel (SL-BCH) transport channel coded bits for the specified UE settings structure and transport block payload. The encoding process includes 16-bit CRC calculation and attachment, tail-biting convolutional encoding, rate matching, and PUSCH interleaving, as defined in TS 36.212 [1], Section 5.4.1. This transport channel carries the `lteSLMIB` RRC message. The sidelink BCH codeword output, `cw`, is ready for transmission on the physical sidelink broadcast channel using `ltePSBCH`.

Examples

Generate SL-BCH Codeword

Generate an SL-BCH coded vector of length 1152, corresponding to the SL-BCH codeword for normal cyclic prefix.

Create UE-specific configuration structure with 10 MHz bandwidth and normal cyclic prefix.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Normal';
```

Generate the MIB-SL transport block and SL-BCH codeword.

```
slmib = lteSLMIB(ue);
```

```
slbchCodeword = lteSLBCH(ue,slmib);
```

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing this field:

CyclicPrefixSL — Cyclic prefix length

'Normal' (default) | 'Extended' | optional

Cyclic prefix length, specified as 'Normal' or 'Extended'.

Data Types: char

Data Types: struct

trblk — Transport block

40-bit vector

Transport block, specified as a 40-bit vector containing MIB-SL information bits. These bits are delivered at the input to the SL-BCH transport channel.

Output Arguments

cw — Codeword representing the MIB-SL information bits

integer column vector

Codeword representing the MIB-SL information bits, returned as an integer column vector with 1152 bits for normal cyclic prefix or 864 for extended cyclic prefix. If the input MIB-SL message is empty, this function returns an empty 0-by-1 matrix. The output codeword matches the bit capacity available in the PSBCH. The PSBCH bit capacity is based on the specified cyclic prefix setting and does not account for the sidelink SC-FDMA guard symbol. For more information, see ltePSBCHIndices.

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCH` | `ltePSBCH` | `ltePSBCHIndices` | `lteSLBCHDecode` | `lteSLMIB`

Introduced in R2016b

lteSLBCHDecode

Sidelink broadcast channel decoding

Syntax

```
[trblkout,crcerr] = lteSLBCHDecode(ue,softbits)
```

Description

`[trblkout,crcerr] = lteSLBCHDecode(ue,softbits)` returns a 40-by-1 column vector of information bits and the cyclic redundancy check (CRC) result for the specified UE settings structure and recovered soft bits.

The SL-BCH decoder performs the inverse of the sidelink broadcast channel processing performed by `lteSLBCH`, and as defined in TS 36.212 [1], Section 5.4.1. The decoding operation includes PUSCH deinterleaving, rate recovery, tail-biting convolutional decoding, and CRC decoding.

Examples

Decode SL-BCH Codeword

Decode a sidelink broadcast channel (SL-BCH) codeword.

Create a UE-specific configuration structure with normal cyclic prefix.

```
ue.CyclicPrefixSL = 'Normal';
```

Generate an SL-BCH codeword by using an MIB-SL transport block of all ones. Display the CRC result.

```
trblk = ones(40,1);
slbchCoded = lteSLBCH(ue,trblk);
[slbchDecoded,err] = lteSLBCHDecode(ue,slbchCoded);
err
```

```
err =

  uint32

   0
```

The CRC result indicates no error. `isequal` reconfirms the decoded output matches the input transport block.

```
isequal(slbchDecoded,trblk)


ans =

  logical

   1
```

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a parameter structure containing this field:

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

`softbits` — Log-likelihood ratio soft bits

vector

Log-likelihood ratio (LLR) soft bits, specified as a vector. Nominally, `softbits` contains 1152 bits for normal cyclic prefix or 864 bits for extended cyclic prefix. These lengths match the bit capacity of the PSBCH, ignoring the SC-FDMA guard symbol.

Because PSBCH uses a low code rate and the decoder can successfully decode much shorter blocks than the entire coded block, input `softbits` can be any length.

Data Types: `double`

Output Arguments

`trblkout` — Transport block

40-by-1 column bit vector

Transport block, returned as a 40-by-1 column bit vector representing the MIB-SL information bits sent by a transmitting UE on the SL-BCH transport channel. The MIB-SL information bits are decoded from the soft log-likelihood (LLR) codeword data.

Data Types: `int8`

`crcerr` — CRC error status

0 | 1

CRC error status, returned as 0 for a pass and 1 for a block error.

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteBCHDecode` | `ltePSBCHDecode` | `lteSLBCH` | `lteSLMIB`

Introduced in R2016b

lteSLChannelEstimatePSBCH

PSBCH sidelink channel estimation

Syntax

```
[hest] = lteSLChannelEstimatePSBCH(ue,rxgrid)
[hest] = lteSLChannelEstimatePSBCH(ue,cec,rxgrid)
[hest,noiseest] = lteSLChannelEstimatePSBCH( ___ )
```

Description

`[hest] = lteSLChannelEstimatePSBCH(ue,rxgrid)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these estimates across the allocated resource elements within the time frequency grid. The channel estimation configuration uses the method described in TS 36.101 [1], Annex F.

`[hest] = lteSLChannelEstimatePSBCH(ue,cec,rxgrid)` also accepts the channel estimator configuration structure, `cec`, to adjust the default method and parameters defined for estimating the channel.

`[hest,noiseest] = lteSLChannelEstimatePSBCH( ___ )` also returns an estimate of the noise power spectral density for the channel. This syntax supports input options from prior syntaxes.

Examples

Estimate Channel Using PSBCH DM-RS and Default CE Settings

Estimate the channel characteristics given the PSBCH-received resource grid containing PSBCH DM-RS symbols. Use the default channel estimation configuration method, as defined in TS 36.101, Annex F.

Create parameter structure

Define UE-specific settings in a parameter structure.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','NSLID',1);
```

Populate a subframe with PSBCH symbols

Create the subframe grid and indices for the subframe. Create broadcast channel and demodulation reference symbols and populate the subframe.

```
subframe = lteSLResourceGrid(ue);
psbchIndices = ltePSBCHIndices(ue);
psbchdmrsIndices = ltePSBCHDRSIndices(ue);

psbchSymbols = ltePSBCH(ue,lteSLBCH(ue,zeros(40,1)));
subframe(psbchIndices) = psbchSymbols;
subframe(psbchdmrsIndices) = ltePSBCHDRS(ue);
```

Estimate the channel characteristics

Use the received resource grid containing PSBCH DM-RS symbols to estimate the channel characteristics.

- Perform sidelink SC-FDMA modulation.
- No channel impairment is applied, so set the received waveform equal to the transmit waveform.
- Perform sidelink SC-FDMA demodulation and channel estimation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);
rxWaveform = txWaveform;
rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
hest = lteSLChannelEstimatePSBCH(ue,rxGrid);
```

Estimate Channel Using PSBCH DM-RS

Estimate the channel characteristics given the PSBCH-received resource grid containing PSBCH DM-RS symbols. The default channel estimation configuration is adjusted.

Create parameter structures

Define UE-specific settings and channel estimation configuration settings in parameter structures.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','NSLID',1);
cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic','PilotAverage','UserDe
```

Populate a subframe with PSBCH symbols

Create the subframe grid and indices for the subframe. Create broadcast channel and demodulation reference (DM-RS) symbols.

```
subframe = lteSLResourceGrid(ue);
psbchIndices = ltePSBCHIndices(ue);

psbchSymbols = ltePSBCH(ue,lteSLBCH(ue,zeros(40,1)));

subframe(psbchIndices) = psbchSymbols;
subframe(ltePSBCHDRSIndices(ue)) = ltePSBCHDRS(ue);
```

Estimate the channel characteristics

Use the received resource grid containing PSBCH DM-RS symbols to estimate the channel characteristics.

- Perform sidelink SC-FDMA modulation.
- No channel impairment is applied, so set the received waveform equal to the transmit waveform.
- Perform sidelink SC-FDMA demodulation and channel estimation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);

rxWaveform = txWaveform;

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
hest = lteSLChannelEstimatePSBCH(ue,cec,rxGrid);
```

Estimate Channel and Noise Using PSBCH DM-RS

Estimate the channel characteristics and noise power spectral density given the PSBCH-received resource grid containing PSBCH DM-RS symbols.

Create parameter structures

Define UE-specific settings and channel estimation configuration settings in parameter structures.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','NSLID',1);
cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic','PilotAverage','UserDe
```

Populate a subframe with PSBCH symbols

Create the subframe grid and indices for the subframe. Create broadcast channel and demodulation reference symbols.

```
subframe = lteSLResourceGrid(ue);
```

```
psbchIndices = ltePSBCHIndices(ue);

psbchSymbols = ltePSBCH(ue,lteSLBCH(ue,zeros(40,1)));
subframe(psbchIndices) = psbchSymbols;

subframe(ltePSBCHDRSIndices(ue)) = ltePSBCHDRS(ue);
```

Estimate the channel characteristics

Use the received resource grid containing PSBCH DM-RS symbols to estimate the channel characteristics.

- Perform sidelink SC-FDMA modulation.
- Add noise to the transmitted signal.
- Perform sidelink SC-FDMA demodulation and channel estimation.
- View the noise estimate.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);

rxWaveform = awgn(txWaveform,15,'measured');

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
[hest,noiseest] = lteSLChannelEstimatePSBCH(ue,cec,rxGrid);

noiseest
```

```
noiseest = 8.7693e-04
```

Input Arguments

ue — UE-specific settings

structure

User equipment settings, specified as a structure containing these fields.

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: 6, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NSLID` — Physical layer sidelink synchronization identity

integer from 0 to 355

Physical layer sidelink synchronization identity, specified as an integer from 0 to 355. ($N_{\mathrm{ID}}^{\mathrm{SL}}$)

Data Types: `double`

Data Types: `struct`

`rxgrid` — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_{R} array of complex symbols.

- N_{SC} is the number of subcarriers.
- $N_{\mathrm{Sym}} = N_{\mathrm{SF}} \times N_{\mathrm{SymPerSF}} = 1 \times N_{\mathrm{SymPerSF}}$
  - N_{SF} is the total number of subframes. For this function `rxgrid` must contain one subframe.
  - N_{SymPerSF} is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, a subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, a subframe contains 12 SC-FDMA symbols.
  - N_{R} is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

`cec` — PSBCH channel estimation settings

structure

PSBCH channel estimation settings, specified as a structure that can contain these fields.

`FreqWindow` — Size of frequency window

integer

Size of frequency window, specified as an integer that is odd or a multiple of 12. `FreqWindow` is the number of resource elements (REs) used to average over frequency.

Data Types: `double`

`TimeWindow` — Size of time window

integer

Size of time window, specified as an odd integer. `TimeWindow` is the number of resource elements (REs) used to average over time.

Data Types: `double`

`InterpType` — Type of 2-D interpolation

`'nearest'` | `'linear'` | `'natural'` | `'cubic'` | `'v4'` | `'none'`

Type of 2-D interpolation used during interpolation, specified as one of these supported choices.

Value	Description
`'nearest'`	Nearest neighbor interpolation
`'linear'`	Linear interpolation
`'natural'`	Natural neighbor interpolation
`'cubic'`	Cubic interpolation
`'v4'`	MATLAB 4 `griddata` method
`'none'`	Disables interpolation

For details, see `griddata`.

`PilotAverage` — Type of pilot averaging

`'UserDefined'` (default) | `'TestEVM'` | optional

Type of pilot averaging, specified as `'UserDefined'` or `'TestEVM'`.

The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation on the pilots. Pilots near the edge of the resource grid are averaged less because they have no neighbors outside of the grid.

For `cec.FreqWindow` = 12×*X* (that is, any multiple of 12) and `cec.TimeWindow` = 1, the estimator enters a special case where an averaging window of (12×*X*)-in-frequency is used to average the pilot estimates. The averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges. Therefore, the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and for the transmitter EVM testing, it follows the method described in TS 36.101, Annex F.

Data Types: `struct`

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

3-D array

Channel estimate between each transmit and receive antenna, returned as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols. N_{SC} is the total number of subcarriers, N_{Sym} is the number of SC-FDMA symbols, and N_R is the number of receive antennas.

For `cec.InterpType` = `'none'`,

- No interpolation between the pilot symbol estimates is performed and no virtual pilots are created
- `hest` contains channel estimates in the locations of transmitted DM-RS symbols for each received antenna and all other elements of `hest` are `0`
- The averaging of pilot symbol estimates, described by `cec.TimeWindow` and `cec.FreqWindow`, is still performed

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. When `cec.PilotAverage` is `'UserDefined'`, this output is the power spectral density of the noise present on the estimated channel response coefficients. Otherwise, `noiseest` returns `0`.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteSLChannelEstimatePSCCH` | `lteSLChannelEstimatePSSCH`

Introduced in R2017a

lteSLChannelEstimatePSCCH

PSCCH sidelink channel estimation

Syntax

```
[hest] = lteSLChannelEstimatePSCCH(ue,rxgrid)
[hest] = lteSLChannelEstimatePSCCH(ue,cec,rxgrid)
[hest,noiseest] = lteSLChannelEstimatePSCCH( ___ )
```

Description

`[hest] = lteSLChannelEstimatePSCCH(ue,rxgrid)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these estimates across the allocated resource elements within the time frequency grid. The channel estimation configuration uses the method described in TS 36.101 [1], Annex F.

`[hest] = lteSLChannelEstimatePSCCH(ue,cec,rxgrid)` also accepts the channel estimator configuration structure, `cec`, to adjust the default method and parameters defined for estimating the channel.

`[hest,noiseest] = lteSLChannelEstimatePSCCH( ___ )` also returns an estimate of the noise power spectral density for the channel. This syntax supports input options from prior syntaxes.

Examples

Estimate Channel Using PSCCH DM-RS and Default CE Settings

Estimate the channel characteristics given the PSCCH-received resource grid containing PSCCH DM-RS symbols. Use the default channel estimation configuration method, as defined in TS 36.101, Annex F.

Create a structure defining UE-specific settings.

```
ue = struct('NSLRB',25,'CyclicPrefixSL','Normal','PRBSet',5);
```

Create the subframe grid, control channel, and indices for a subframe. Populate the subframe with PSCCH symbols.

```
subframe = lteSLResourceGrid(ue);

[pscchIndices,pscchInfo] = ltePSCCHIndices(ue);
pscchSymbols = ltePSCCH(randi([0 1],pscchInfo.G,1));

subframe(pscchIndices) = pscchSymbols;
```

Create the control DM-RS and indices. Add the PSCCH DM-RS symbols to the subframe.

```
subframe(ltePSCCHDRSIndices(ue)) = ltePSCCHDRS;
```

Perform sidelink SC-FDMA modulation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);
```

No channel impairment is applied, so set the received waveform equal to the transmit waveform. Perform sidelink SC-FDMA demodulation and channel estimation.

```
rxWaveform = txWaveform;

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
hest = lteSLChannelEstimatePSCCH(ue,rxGrid);
```

Estimate Channel Using PSCCH DM-RS

Estimate the channel characteristics given the PSCCH-received resource grid containing PSCCH DM-RS symbols. The default channel estimation configuration is adjusted.

Create structures defining UE-specific settings and channel estimation configuration settings.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','PRBSet',5);

cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic', ...
    'PilotAverage','UserDefined');
```

Create the subframe grid, control channel, and indices for a subframe. Populate the subframe with PSCCH symbols.

```
subframe = lteSLResourceGrid(ue);

[pscchIndices,pscchInfo] = ltePSCCHIndices(ue);
```

```
pscchSymbols = ltePSCCH(randi([0 1],pscchInfo.G,1));

subframe(pscchIndices) = pscchSymbols;
```

Create the control DM-RS and indices. Add the PSCCH DM-RS symbols to the subframe.

```
subframe(ltePSCCHDRSIndices(ue)) = ltePSCCHDRS;
```

Perform sidelink SC-FDMA modulation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);
```

No channel impairment is applied, so set the received waveform equal to the transmit waveform. Perform sidelink SC-FDMA demodulation and channel estimation.

```
rxWaveform = txWaveform;

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
hest = lteSLChannelEstimatePSCCH(ue,cec,rxGrid);
```

Estimate Channel and Noise Using PSCCH DM-RS

Estimate the channel characteristics and noise power spectral density given the PSCCH-received resource grid containing PSCCH DM-RS symbols.

Create structures defining UE-specific and channel estimation configuration settings.

```
ue = struct('NSLRB',25,'CyclicPrefixSL','Normal','PRBSet',5);
cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic', ...
    'PilotAverage','UserDefined');
```

Create the subframe grid, control channel, and indices for a subframe. Populate the subframe with PSCCH symbols.

```
subframe = lteSLResourceGrid(ue);

[pscchIndices,pscchInfo] = ltePSCCHIndices(ue);
pscchSymbols = ltePSCCH(randi([0 1],pscchInfo.G,1));

subframe(pscchIndices) = pscchSymbols;
```

Create the control DM-RS and indices. Add the PSCCH DM-RS symbols to the subframe.

```
subframe(ltePSCCHDRSIndices(ue)) = ltePSCCHDRS;
```

Perform sidelink SC-FDMA modulation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);
```

Add noise to impair the channel. Perform sidelink SC-FDMA demodulation and channel estimation. View the noise estimate.

```
rxWaveform = awgn(txWaveform,15,'measured');

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
[hest,noiseest] = lteSLChannelEstimatePSCCH(ue,cec,rxGrid);
noiseest
```

```
noiseest =

   4.3822e-04
```

Input Arguments

ue — UE-specific settings

structure

User equipment settings, specified as a structure containing these fields.

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: 6, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

CyclicPrefixSL — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

PRBSet — Zero-based physical resource block index

integer | integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) index, specified as an integer, an integer column vector, or a two-column integer matrix.

The PSCCH is intended to be transmitted in a single PRB in a subframe. Therefore, specifying `PRBSet` as a scalar PRB index is recommended. However, for a more general nonstandard multi-PRB allocation, `PRBSet` can be a set of indices specified as an integer column vector or as a two-column integer matrix corresponding to slot-wise resource allocations for PSCCH.

Data Types: `double`

Data Types: `struct`

`rxgrid` — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols.

- N_{SC} is the number of subcarriers.
- $N_{Sym} = N_{SF} \times N_{SymPerSF} = 1 \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. For this function `rxgrid` must contain one subframe.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, a subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, a subframe contains 12 SC-FDMA symbols.
  - N_R is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

`cec` — PSCCH channel estimation settings

structure

PSCCH channel estimation settings, specified as a structure that can contain these fields.

`FreqWindow` — Size of frequency window

integer

Size of frequency window, specified as an integer that is odd or a multiple of 12. `FreqWindow` is the number of resource elements (REs) used to average over frequency.

Data Types: `double`

`TimeWindow` — Size of time window

integer

Size of time window, specified as an odd integer. `TimeWindow` is the number of resource elements (REs) used to average over time.

Data Types: `double`

`InterpType` — Type of 2-D interpolation

`'nearest'` | `'linear'` | `'natural'` | `'cubic'` | `'v4'` | `'none'`

Type of 2-D interpolation used during interpolation, specified as one of these supported choices.

Value	Description
`'nearest'`	Nearest neighbor interpolation
`'linear'`	Linear interpolation
`'natural'`	Natural neighbor interpolation
`'cubic'`	Cubic interpolation
`'v4'`	MATLAB 4 `griddata` method
`'none'`	Disables interpolation

For details, see `griddata`.

`PilotAverage` — Type of pilot averaging

`'UserDefined'` (default) | `'TestEVM'` | optional

Type of pilot averaging, specified as `'UserDefined'` or `'TestEVM'`.

The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation on the pilots. Pilots near the edge of the resource grid are averaged less because they have no neighbors outside of the grid.

For `cec.FreqWindow` = 12×*X* (that is, any multiple of 12) and `cec.TimeWindow` = 1, the estimator enters a special case where an averaging window of (12×*X*)-in-

frequency is used to average the pilot estimates. The averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges. Therefore, the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and for the transmitter EVM testing, it follows the method described in TS 36.101, Annex F.

Data Types: `struct`

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

3-D array

Channel estimate between each transmit and receive antenna, returned as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols. N_{SC} is the total number of subcarriers, N_{Sym} is the number of SC-FDMA symbols, and N_R is the number of receive antennas.

For `cec.InterpType = 'none'`,

- No interpolation between the pilot symbol estimates is performed and no virtual pilots are created
- `hest` contains channel estimates in the locations of transmitted DM-RS symbols for each received antenna and all other elements of `hest` are `0`
- The averaging of pilot symbol estimates, described by `cec.TimeWindow` and `cec.FreqWindow`, is still performed

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. When `cec.PilotAverage` is `'UserDefined'`, this output is the power spectral density of the noise present on the estimated channel response coefficients. Otherwise, `noiseest` returns `0`.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

`lteSLChannelEstimatePSBCH` | `lteSLChannelEstimatePSSCH`

Introduced in R2017a

lteSLChannelEstimatePSSCH

PSSCH sidelink channel estimation

Syntax

```
[hest] = lteSLChannelEstimatePSSCH(ue,rxgrid)
[hest] = lteSLChannelEstimatePSSCH(ue,cec,rxgrid)
[hest,noiseest] = lteSLChannelEstimatePSSCH( ___ )
```

Description

`[hest] = lteSLChannelEstimatePSSCH(ue,rxgrid)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these estimates across the allocated resource elements within the time frequency grid. The channel estimation configuration uses the method described in TS 36.101 [1], Annex F.

`[hest] = lteSLChannelEstimatePSSCH(ue,cec,rxgrid)` also accepts the channel estimator configuration structure, `cec`, to adjust the default method and parameters defined for estimating the channel.

`[hest,noiseest] = lteSLChannelEstimatePSSCH( ___ )` also returns an estimate of the noise power spectral density for the channel. This syntax supports input options from prior syntaxes.

Examples

Estimate Channel Using PSSCH DM-RS and Default CE Settings

Estimate the channel characteristics given the PSSCH-received resource grid containing PSSCH DM-RS symbols. Use the default channel estimation configuration method, as defined in TS 36.101, Annex F.

Create parameter structure

Define UE-specific settings in a parameter structure.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','NSAID',255, ...
            'Modulation','QPSK','NSubframePSSCH',0,'PRBSet',(30:39)');
```

Populate a subframe with PSSCH symbols

Create the subframe grid and indices for the subframe. Create shared channel and demodulation reference signal (DM-RS) symbols. Populate the subframe with the shared channel and DM-RS symbols.

```
subframe = lteSLResourceGrid(ue);
[psschIndices,psschInfo] = ltePSSCHIndices(ue);

psschSymbols = ltePSSCH(ue,zeros(psschInfo.G,1));
subframe(psschIndices) = psschSymbols;

subframe(ltePSSCHDRSIndices(ue)) = ltePSSCHDRS(ue);
```

Estimate the channel characteristics

Use the received resource grid containing PSSCH DM-RS symbols to estimate the channel characteristics.

- Perform sidelink SC-FDMA modulation.
- No channel impairment is applied, so set the received waveform equal to the transmit waveform.
- Perform sidelink SC-FDMA demodulation and channel estimation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);

rxWaveform = txWaveform;

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
hest = lteSLChannelEstimatePSSCH(ue,rxGrid);
```

Estimate Channel Using PSSCH DM-RS

Estimate the channel characteristics given the PSSCH-received resource grid containing PSSCH DM-RS symbols. The default channel estimation configuration is adjusted.

Create parameter structures

Define UE-specific settings and channel estimation configuration settings in parameter structures.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','NSAID',255, ...
```

```
           'Modulation','QPSK','NSubframePSSCH',0,'PRBSet',(30:39)');
cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic', ...
             'PilotAverage','UserDefined');
```

Populate a subframe with PSSCH symbols

Create the subframe grid and indices for the subframe. Create shared channel and demodulation reference signal (DM-RS) symbols. Populate the subframe with shared channel and DM-RS symbols.

```
subframe = lteSLResourceGrid(ue);
[psschIndices,psschInfo] = ltePSSCHIndices(ue);

psschSymbols = ltePSSCH(ue,zeros(psschInfo.G,1));
subframe(psschIndices) = psschSymbols;

subframe(ltePSSCHDRSIndices(ue)) = ltePSSCHDRS(ue);
```

Estimate the channel characteristics

Use the received resource grid containing PSSCH DM-RS symbols to estimate the channel characteristics.

- Perform sidelink SC-FDMA modulation.
- No channel impairment is applied, so set the received waveform equal to the transmit waveform.
- Perform sidelink SC-FDMA demodulation and channel estimation.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);

rxWaveform = txWaveform;

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
hest = lteSLChannelEstimatePSSCH(ue,cec,rxGrid);
```

Estimate Channel and Noise Using PSSCH DM-RS

Estimate the channel characteristics and noise power spectral density given the PSSCH-received resource grid containing PSSCH DM-RS symbols.

Create parameter structures

Define UE-specific settings and channel estimation configuration settings in parameter structures.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal','NSAID',255, ...
     'Modulation','QPSK','NSubframePSSCH',0,'PRBSet',(30:39)');
cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic', ...
     'PilotAverage','UserDefined');
```

Populate a subframe with PSSCH symbols

Create the subframe grid and indices for the subframe. Create shared channel and demodulation reference signal (DM-RS) symbols. Populate the subframe with shared channel and DM-RS symbols.

```
subframe = lteSLResourceGrid(ue);

[psschIndices,psschInfo] = ltePSSCHIndices(ue);
psschSymbols = ltePSSCH(ue,zeros(psschInfo.G,1));

subframe(psschIndices) = psschSymbols;
```

Create the control DM-RS and indices. Add the PSSCH DM-RS symbols to the subframe.

```
subframe(ltePSSCHDRSIndices(ue)) = ltePSSCHDRS(ue);
```

Estimate the channel characteristics

Use the received resource grid containing PSSCH DM-RS symbols to estimate the channel characteristics.

- Perform sidelink SC-FDMA modulation.
- Add noise to the transmitted signal.
- Perform sidelink SC-FDMA demodulation and channel estimation.
- View the noise estimate.

```
txWaveform = lteSLSCFDMAModulate(ue,subframe);

rxWaveform = awgn(txWaveform,15,'measured');

rxGrid = lteSLSCFDMADemodulate(ue,rxWaveform);
[hest,noiseest] = lteSLChannelEstimatePSSCH(ue,cec,rxGrid);

noiseest
```

```
noiseest = 0.0026
```

Input Arguments

ue — UE-specific settings
structure

User equipment settings, specified as a structure containing these fields.

NSLRB — Number of sidelink resource blocks
integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

NSAID — Sidelink group destination identity
integer scalar from 0 to 255

Sidelink group destination identity, specified as an integer scalar from 0 to 255. ($n_{\mathrm{ID}}^{\mathrm{SA}}$)

`NSAID` is the lower 8 bits of the full 24-bit ProSe Layer-2 group destination ID. `NSAID` and `NSubframePSSCH` control the value of the scrambling sequence at the start of each subframe.

Data Types: `double`

CyclicPrefixSL — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

NSubframePSSCH — PSSCH subframe number
integer scalar

PSSCH subframe number in the PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

`NSubframePSSCH` and `NSAID` control the values of the scrambling sequence.

Data Types: `double`

`PRBSet` — Zero-based physical resource block indices

integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) indices, specified as an integer column vector or a two-column integer matrix.

The PSSCH is intended to be transmitted in the same PRB in each slot of a subframe. Therefore, specifying `PRBSet` as a single column of PRB indices is recommended. However, for a nonstandard slot-hopping PRB allocation, `PRBSet` can be specified as a two-column matrix of indices corresponding to slot-wise resource allocations for PSSCH.

Data Types: `double`

Data Types: `struct`

`rxgrid` — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols.

- N_{SC} is the number of subcarriers.
- $N_{Sym} = N_{SF} \times N_{SymPerSF} = 1 \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. For this function `rxgrid` must contain one subframe.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, a subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, a subframe contains 12 SC-FDMA symbols.
  - N_R is the number of receive antennas.

Data Types: `double`
Complex Number Support: Yes

`cec` — PSSCH channel estimation settings

structure

PSSCH channel estimation settings, specified as a structure that can contain these fields.

`FreqWindow` — Size of frequency window

integer

Size of frequency window, specified as an integer that is odd or a multiple of 12. `FreqWindow` is the number of resource elements (REs) used to average over frequency.

Data Types: `double`

`TimeWindow` — Size of time window

integer

Size of time window, specified as an odd integer. `TimeWindow` is the number of resource elements (REs) used to average over time.

Data Types: `double`

`InterpType` — Type of 2-D interpolation

`'nearest'` | `'linear'` | `'natural'` | `'cubic'` | `'v4'` | `'none'`

Type of 2-D interpolation used during interpolation, specified as one of these supported choices.

Value	Description
`'nearest'`	Nearest neighbor interpolation
`'linear'`	Linear interpolation
`'natural'`	Natural neighbor interpolation
`'cubic'`	Cubic interpolation
`'v4'`	MATLAB 4 `griddata` method
`'none'`	Disables interpolation

For details, see `griddata`.

`PilotAverage` — Type of pilot averaging

`'UserDefined'` (default) | `'TestEVM'` | optional

Type of pilot averaging, specified as `'UserDefined'` or `'TestEVM'`.

The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation on the pilots. Pilots near the edge of the resource grid are averaged less because they have no neighbors outside of the grid.

For `cec.FreqWindow` = 12×*X* (that is, any multiple of 12) and `cec.TimeWindow` = 1, the estimator enters a special case where an averaging window of (12×*X*)-in-frequency is used to average the pilot estimates. The averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges. Therefore, the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and for the transmitter EVM testing, it follows the method described in TS 36.101, Annex F.

Data Types: `struct`

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

3-D array

Channel estimate between each transmit and receive antenna, returned as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols. N_{SC} is the total number of subcarriers, N_{Sym} is the number of SC-FDMA symbols, and N_R is the number of receive antennas.

For `cec.InterpType` = `'none'`,

- No interpolation between the pilot symbol estimates is performed and no virtual pilots are created
- `hest` contains channel estimates in the locations of transmitted DM-RS symbols for each received antenna and all other elements of `hest` are `0`
- The averaging of pilot symbol estimates, described by `cec.TimeWindow` and `cec.FreqWindow`, is still performed

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. When `cec.PilotAverage` is `'UserDefined'`, this output is the power spectral density of the noise present on the estimated channel response coefficients. Otherwise, `noiseest` returns `0`.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

`lteSLChannelEstimatePSBCH` | `lteSLChannelEstimatePSCCH`

Introduced in R2017a

lteSLFrameOffsetPSBCH

PSBCH DM-RS sidelink subframe timing estimate

Syntax

```
offset = lteSLFrameOffsetPSBCH(ue,waveform)
[offset,corr] = lteSLFrameOffsetPSBCH(ue,waveform)
```

Description

`offset = lteSLFrameOffsetPSBCH(ue,waveform)` performs synchronization using PSBCH demodulation reference signal (DM-RS) symbols for the time-domain waveform, `waveform`, given UE-specific settings, `ue`.

The returned `offset` indicates the number of samples from the start of the input waveform to the position in that waveform where the first subframe containing the DM-RS begins.

`[offset,corr] = lteSLFrameOffsetPSBCH(ue,waveform)` also returns a complex matrix, `corr`, which is used to extract the timing offset.

Examples

Synchronize and Demodulate Transmission Containing PSBCH DM-RS

Synchronize and demodulate a transmission that has been delayed by five samples. The transmission contains PSBCH demodulation reference signal (DM-RS) symbols that are used when estimating the waveform timing offset.

Create a UE configuration specifying 15 resource blocks, a sidelink identity of 1, and a normal cyclic prefix.

```
ue = struct('NSLRB',15,'NSLID',1,'CyclicPrefixSL','Normal');
```

Create a resource grid and modulate the waveform containing PSBCH DM-RS symbols.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSBCHDRSIndices(ue)) = ltePSBCHDRS(ue);
txwaveform = lteSLSCFDMAModulate(ue,txgrid);
```

Add a time delay of five samples.

```
rxwaveform = [zeros(5,1); txwaveform];
```

Calculate the timing offset in samples.

```
offset = lteSLFrameOffsetPSBCH(ue,rxwaveform)
```

```
offset =

     5
```

Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSLSCFDMADemodulate(ue,rxwaveform(1+offset:end));
```

View Correlation Peak in PSBCH DM-RS Transmission

View the correlation peak for a transmission waveform that has been delayed by five samples. The transmission contains PSBCH demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

Create a UE configuration specifying 15 resource blocks, a sidelink identity of 1, and a normal cyclic prefix.

```
ue = struct('NSLRB',15,'NSLID',1,'CyclicPrefixSL','Normal');
```

Create a resource grid and modulate the waveform containing PSBCH DM-RS symbols.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSBCHDRSIndices(ue)) = ltePSBCHDRS(ue);
txwaveform = lteSLSCFDMAModulate(ue,txgrid);
```

Calculate the timing offset in samples.

```
[offset corr] = lteSLFrameOffsetPSBCH(ue,txwaveform);
```

Add a time delay of five samples.

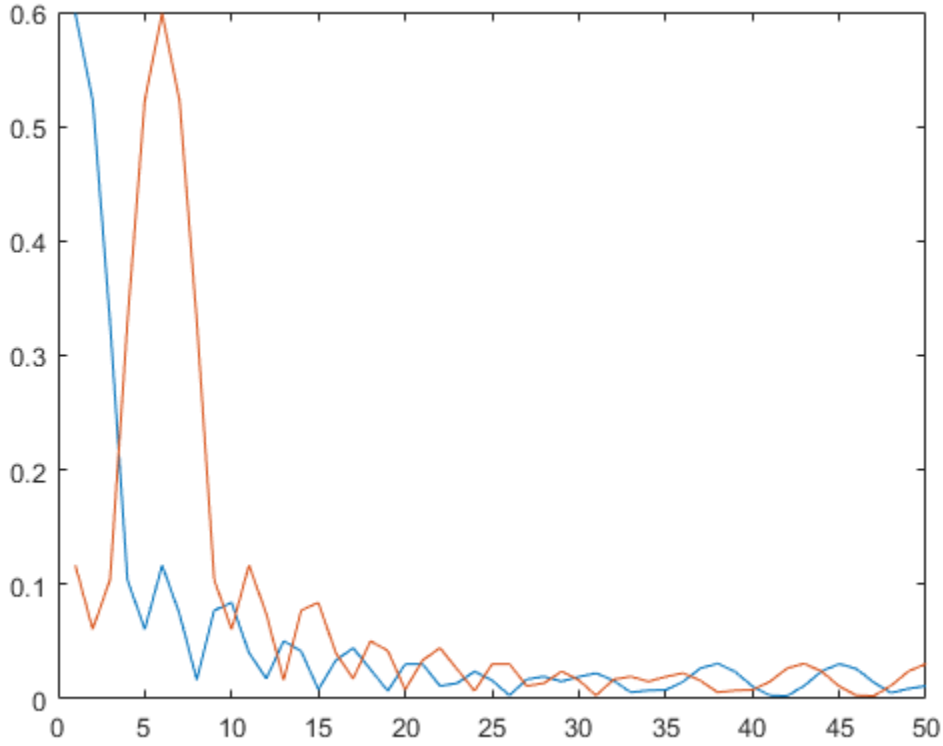
```
rxwaveform = [zeros(5,1); txwaveform];
```

Calculate the timing offset in samples.

```
[offset corrDelayed] = lteSLFrameOffsetPSBCH(ue,rxwaveform);
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
hold off
xlim([0 50])
```



Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSLSCFDMADemodulate(ue,rxwaveform(1+offset:end));
```

Input Arguments

`ue` — UE-specific settings
scalar structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks
integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NSLID` — Physical layer sidelink synchronization identity
integer from 0 to 355

Physical layer sidelink synchronization identity, specified as an integer from 0 to 355. ($N_{\mathrm{ID}}^{\mathrm{SL}}$)

Data Types: `double`

`waveform` — Modulated sidelink waveform
numeric matrix

Modulated sidelink waveform, specified as an N_{S}-by-N_{R} numeric matrix, where N_{S} is the number of time-domain samples and N_{R} is the number of receive antennas.

You can generate this matrix by performing SC-FDMA modulation on a resource matrix. To perform this modulation, use the `lteSLSCFDMAModulate` function or one of the channel model functions, such as `lteFadingChannel` or `lteMovingChannel`.

Data Types: `double`
Complex Number Support: Yes

Data Types: `struct`

Output Arguments

`offset` — Offset number of samples

scalar integer

Offset number of samples, returned as a scalar integer. This output is the number of samples from the start of the waveform to the position in that waveform where the first subframe containing the DM-RS begins. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna. The antenna with the strongest correlation is used to compute `offset`.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`corr` — Signal used to extract the timing offset

numeric matrix

Signal used to extract the timing offset, returned as a complex numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteMovingChannel` | `lteSCFDMADemodulate`

Introduced in R2017a

lteSLFrameOffsetPSCCH

PSCCH DM-RS sidelink subframe timing estimate

Syntax

```
offset = lteSLFrameOffsetPSCCH(ue,waveform)
[offset,corr] = lteSLFrameOffsetPSCCH(ue,waveform)
```

Description

`offset = lteSLFrameOffsetPSCCH(ue,waveform)` performs synchronization using PSCCH demodulation reference signal (DM-RS) symbols for the time-domain waveform, `waveform`, given UE-specific settings, `ue`.

The returned `offset` indicates the number of samples from the start of the input waveform to the position in that waveform where the first subframe containing DM-RS begins.

`[offset,corr] = lteSLFrameOffsetPSCCH(ue,waveform)` also returns a complex matrix, `corr`, which is used to extract the timing offset.

Examples

Synchronize and Demodulate Transmission Containing PSCCH DM-RS

Synchronize and demodulate a transmission that has been delayed by five samples. The transmission contains PSCCH demodulation reference signal (DM-RS) symbols that are used when estimating the waveform timing offset.

Create a UE configuration specifying 15 resource blocks, a normal cyclic prefix, and a `PRBSet` of 1.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',1);
```

Create a resource grid and modulate the waveform containing PSCCH DM-RS symbols.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSCCHDRSIndices(ue)) = ltePSCCHDRS;
txwaveform = lteSLSCFDMAModulate(ue,txgrid);
```

Add a time delay of five samples.

```
rxwaveform = [zeros(5,1); txwaveform];
```

Calculate the timing offset in samples.

```
offset = lteSLFrameOffsetPSCCH(ue,rxwaveform)
```

```
offset =

     5
```

Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSLSCFDMADemodulate(ue,rxwaveform(1+offset:end));
```

View Correlation Peak in PSCCH DM-RS Transmission

View the correlation peak for a transmission waveform that has been delayed by five samples. The transmission contains PSCCH demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

Create a UE configuration specifying 15 resource blocks, a normal cyclic prefix, and a `PRBSet` of 1.

```
ue = struct('NSLRB',15,'CyclicPrefixSL','Normal','PRBSet',1);
```

Create a resource grid and modulate the waveform containing PSCCH DM-RS symbols.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSCCHDRSIndices(ue)) = ltePSCCHDRS;
txwaveform = lteSLSCFDMAModulate(ue,txgrid);
```

Calculate the timing offset in samples.

```
[offset corr] = lteSLFrameOffsetPSCCH(ue,txwaveform);
```

Add a time delay of five samples.

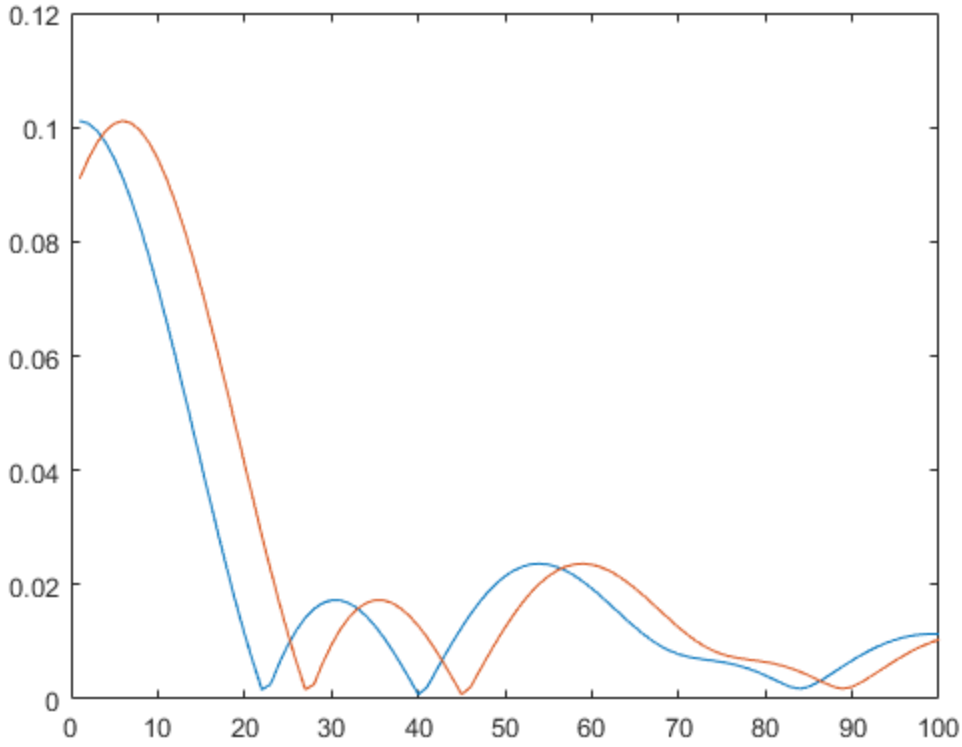
```
rxwaveform = [zeros(5,1); txwaveform];
```

Calculate the timing offset in samples.

```
[offset corrDelayed] = lteSLFrameOffsetPSCCH(ue,rxwaveform);
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
hold off
xlim([0 100])
```



Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSLSCFDMADemodulate(ue,rxwaveform(1+offset:end));
```

Input Arguments

ue — UE-specific settings

scalar structure

User equipment settings, specified as a parameter structure containing these fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

CyclicPrefixSL — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

PRBSet — Zero-based physical resource block index

integer | integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) index, specified as an integer, an integer column vector, or a two-column integer matrix.

The PSCCH is intended to be transmitted in a single PRB in a subframe. Therefore, specifying `PRBSet` as a scalar PRB index is recommended. However, for a more general nonstandard multi-PRB allocation, `PRBSet` can be a set of indices specified as an integer column vector or as a two-column integer matrix corresponding to slot-wise resource allocations for PSCCH.

Data Types: `double`

Data Types: `struct`

waveform — Modulated sidelink waveform

numeric matrix

Modulated sidelink waveform, specified as an N_S-by-N_R numeric matrix, where N_S is the number of time-domain samples and N_R is the number of receive antennas.

You can generate this matrix by performing SC-FDMA modulation on a resource matrix. To perform this modulation, use the `lteSLSCFDMAModulate` function or one of the channel model functions, such as `lteFadingChannel` or `lteMovingChannel`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`offset` — Offset number of samples

scalar integer

Offset number of samples, returned as a scalar integer. This output is the number of samples from the start of the waveform to the position in that waveform where the first subframe containing the DM-RS begins. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna. The antenna with the strongest correlation is used to compute `offset`.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`corr` — Signal used to extract the timing offset

numeric matrix

Signal used to extract the timing offset, returned as a complex numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteMovingChannel` | `lteSCFDMADemodulate`

Introduced in R2017a

lteSLFrameOffsetPSSCH

PSSCH DM-RS sidelink subframe timing estimate

Syntax

```
offset = lteSLFrameOffsetPSSCH(ue,waveform)
[offset,corr] = lteSLFrameOffsetPSSCH(ue,waveform)
```

Description

`offset = lteSLFrameOffsetPSSCH(ue,waveform)` performs synchronization using PSSCH demodulation reference signal (DM-RS) symbols for the time-domain waveform, `waveform`, given UE-specific settings, `ue`.

The returned `offset` indicates the number of samples from the start of the input waveform to the position in that waveform where the first subframe containing DM-RS begins.

`[offset,corr] = lteSLFrameOffsetPSSCH(ue,waveform)` also returns a complex matrix, `corr`, which is used to extract the timing offset.

Examples

Synchronize and Demodulate Transmission Containing PSSCH DM-RS

Synchronize and demodulate a transmission that has been delayed by five samples. The transmission contains PSSCH demodulation reference signal (DM-RS) symbols that are used when estimating the waveform timing offset.

Create a UE configuration specifying 15 resource blocks, a sidelink identity of 1, a normal cyclic prefix, a PSSCH subframe number of 0, and a `PRBSet` of 1.

```
ue = struct('NSLRB',15,'NSAID',1,'CyclicPrefixSL','Normal', ...
    'NSubframePSSCH',0,'PRBSet',1);
```

Create a resource grid and modulate the waveform containing PSSCH DM-RS symbols.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSSCHDRSIndices(ue)) = ltePSSCHDRS(ue);
txwaveform = lteSLSCFDMAModulate(ue,txgrid);
```

Add a time delay of five samples.

```
rxwaveform = [zeros(5,1); txwaveform];
```

Calculate the timing offset in samples.

```
offset = lteSLFrameOffsetPSSCH(ue,rxwaveform)
```

```
offset =

     5
```

Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSLSCFDMADemodulate(ue,rxwaveform(1+offset:end));
```

View Correlation Peak in PSSCH DM-RS Transmission

View the correlation peak for a transmission waveform that has been delayed by five samples. The transmission contains PSSCH demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

Create a UE configuration specifying 15 resource blocks, a sidelink identity of 1, a normal cyclic prefix, a PSSCH subframe number of 0, and a `PRBSet` of 1.

```
ue = struct('NSLRB',15,'NSAID',1,'CyclicPrefixSL','Normal', ...
    'NSubframePSSCH',0,'PRBSet',1);
```

Create a resource grid and modulate the waveform containing PSSCH DM-RS symbols.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSSCHDRSIndices(ue)) = ltePSSCHDRS(ue);
txwaveform = lteSLSCFDMAModulate(ue,txgrid);
```

Calculate the timing offset in samples.

```
[offset corr] = lteSLFrameOffsetPSSCH(ue,txwaveform);
```

Add a time delay of five samples.

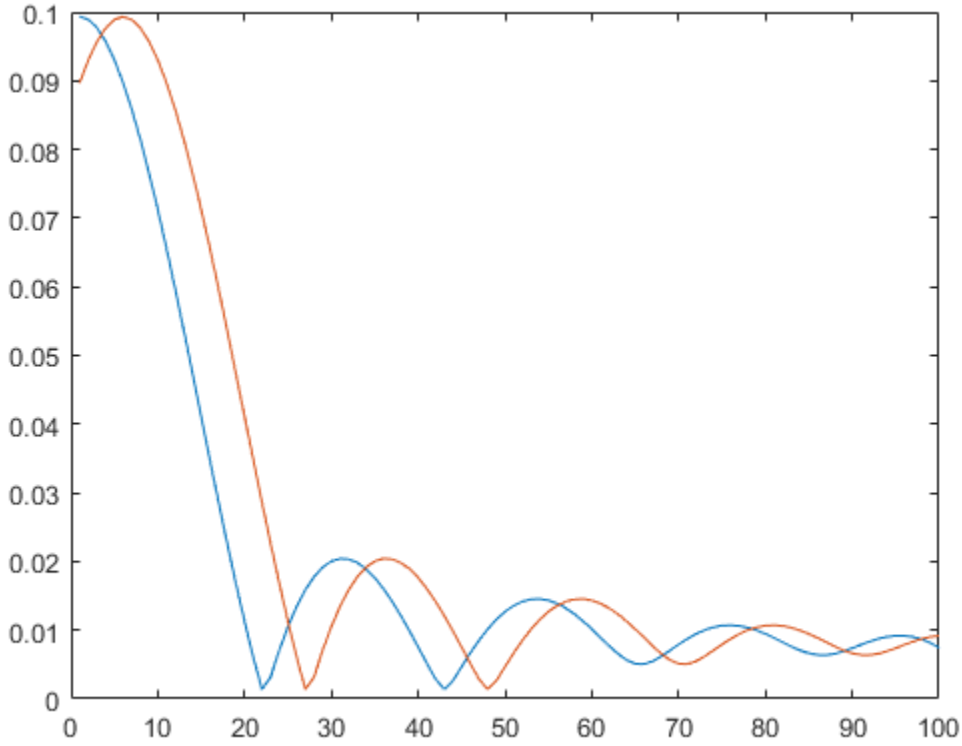
```
rxwaveform = [zeros(5,1); txwaveform];
```

Calculate the timing offset in samples.

```
[offset corrDelayed] = lteSLFrameOffsetPSSCH(ue,rxwaveform);
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
hold off
xlim([0 100])
```



Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSLSCFDMADemodulate(ue,rxwaveform(1+offset:end));
```

Input Arguments

ue — UE-specific settings

scalar structure

User equipment settings, specified as a parameter structure containing these fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

NSAID — Sidelink group destination identity

integer scalar from 0 to 255

Sidelink group destination identity, specified as an integer scalar from 0 to 255. ($n_{\mathrm{ID}}^{\mathrm{SA}}$)

`NSAID` is the lower 8 bits of the full 24-bit ProSe Layer-2 group destination ID. `NSAID` and `NSubframePSSCH` control the value of the scrambling sequence at the start of each subframe.

Data Types: `double`

CyclicPrefixSL — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

NSubframePSSCH — PSSCH subframe number

integer scalar

PSSCH subframe number in the PSSCH subframe pool, specified as an integer scalar. ($n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$)

`NSubframePSSCH` and `NSAID` control the values of the scrambling sequence.

Data Types: `double`

`PRBSet` — Zero-based physical resource block indices

integer column vector | two-column integer matrix

Zero-based physical resource block (PRB) indices, specified as an integer column vector or a two-column integer matrix.

The PSSCH is intended to be transmitted in the same PRB in each slot of a subframe. Therefore, specifying `PRBSet` as a single column of PRB indices is recommended. However, for a nonstandard slot-hopping PRB allocation, `PRBSet` can be specified as a two-column matrix of indices corresponding to slot-wise resource allocations for PSSCH.

Data Types: `double`

Data Types: `struct`

`waveform` — Modulated sidelink waveform

numeric matrix

Modulated sidelink waveform, specified as an N_S-by-N_R numeric matrix, where N_S is the number of time-domain samples and N_R is the number of receive antennas.

You can generate this matrix by performing SC-FDMA modulation on a resource matrix. To perform this modulation, use the `lteSLSCFDMAModulate` function or one of the channel model functions, such as `lteFadingChannel` or `lteMovingChannel`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`offset` — Offset number of samples

scalar integer

Offset number of samples, returned as a scalar integer. This output is the number of samples from the start of the waveform to the position in that waveform where the first

subframe containing the DM-RS begins. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna. The antenna with the strongest correlation is used to compute `offset`.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`corr` — Signal used to extract the timing offset

numeric matrix

Signal used to extract the timing offset, returned as a complex numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteMovingChannel` | `lteSCFDMADemodulate`

Introduced in R2017a

lteSLMIB

Sidelink master information block encoding and decoding

Syntax

```
mibslout = lteSLMIB(ue)
ueout = lteSLMIB(mibsl)
ueout = lteSLMIB(mibsl,ue)
```

Description

`mibslout = lteSLMIB(ue)` returns the encoded sidelink *MasterInformationBlock-SL* (MIB-SL) RRC message bits for the specified UE settings structure.

For more information, see "*MasterInformationBlock-SL* Message Processing" on page 1-1197.

`ueout = lteSLMIB(mibsl)` performs the inverse processing of the preceding syntax, returning a UE parameter structure after decoding the input *MasterInformationBlock-SL* message bits.

`ueout = lteSLMIB(mibsl,ue)` returns the UE settings structure, updating any fields contained in the input UE parameter structure with values decoded from `mibsl`.

Examples

Create MIB-SL Message

Create the 40-bit MIB-SL associated with the parameter values to be carried on the message.

Initialize a UE-specific configuration structure with 10 MHz bandwidth for TDD.

```
ue.NSLRB = 50;
ue.DuplexMode = 'TDD';
ue.TDDConfig  = 6;
```

```
ue.NFrame = 5;
ue.NSubframe = 1;
ue.InCoverage = 1;
```

Generate the 40-bit MIB-SL message using the `ue` structure.

```
mibsl = lteSLMIB(ue);
```

Decode MIB-SL Message

Decode the 40-bit MIB-SL message, creating a received parameter structure from the message.

Initialize a UE-specific configuration structure with 5 MHz bandwidth for TDD.

```
ue.NSLRB = 25;
ue.DuplexMode = 'TDD';
ue.TDDConfig = 6;
ue.NFrame = 5;
ue.NSubframe = 1;
ue.InCoverage = 1
```

```
ue =

  struct with fields:

         NSLRB: 25
    DuplexMode: 'TDD'
     TDDConfig: 6
        NFrame: 5
     NSubframe: 1
    InCoverage: 1
```

Generate the 40-bit MIB-SL message using the `ue` structure.

```
mibsl = lteSLMIB(ue);
```

Convert the MIB-SL bit vector back into a parameter set. Compare this parameter set with the transmission set.

```
rxparams = lteSLMIB(mibsl)
isequal(rxparams,ue)
```

```
rxparams =

  struct with fields:

         NSLRB: 25
    DuplexMode: 'TDD'
     TDDConfig: 6
        NFrame: 5
     NSubframe: 1
    InCoverage: 1


ans =

  logical

   1
```

Update UE Structure Using MIB-SL Message

Update UE-specific parameter configuration structure settings using the 40-bit MIB-SL message. Encode an MIB-SL message based on one ue structure parameter set.

Encode an MIB-SL message from one UE-specific configuration

Initialize a UE-specific configuration structure with 5 MHz bandwidth for TDD. Encode a 40-bit MIB-SL message using the `ue1` structure.

```
ue1.NSLRB = 25;
ue1.DuplexMode = 'TDD';
ue1.TDDConfig = 6;
ue1.NFrame = 5;
ue1.NSubframe = 1;
ue1.InCoverage = 1;

mibsl = lteSLMIB(ue1);
```

Create a second UE-specific configuration

Initialize a second UE-specific configuration structure with a different configuration. Compare `ue2` with `ue1`.

```
ue2.NSLRB = 75;
ue2.DuplexMode = 'TDD';
```

```
ue2.TDDConfig = 2;
ue2.NFrame = 2;
ue2.NSubframe = 2;
ue2.InCoverage = 0;

isequal(ue2,ue1)


ans =

  logical

   0
```

Update the second UE-specific configuration based on the MIB-SL message

Using `mibsl`, update the settings in `ue2` to match `ue1`. Compare `ue2` with `ue1`.

```
ue2 = lteSLMIB(mibsl,ue2);
isequal(ue2,ue1)


ans =

  logical

   1
```

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`DuplexMode` — Duplexing mode
`'FDD'` (default) | `'TDD'` | optional

Duplexing mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration
0 (default) | integer from 0 to 6 | optional

Uplink or downlink configuration, specified as an integer from 0 to 6. (*tdd-ConfigSL-r12*)

`TDDConfig` is applicable for TDD duplex mode only.

Data Types: `double`

`NFrame` — Direct frame number
0 (default) | nonnegative integer | optional

Direct frame number, specified as a nonnegative integer. (*directFrameNumber-r12*)

Data Types: `double`

`NSubframe` — Direct subframe number
0 (default) | nonnegative integer | optional

Direct subframe number, specified as a nonnegative integer. (*directSubframeNumber-r12*)

Data Types: `double`

`InCoverage` — Indicates whether UE is in E-UTRAN coverage
0 (default) | 1 | optional

Indicates whether the UE transmitting the MIB-SL is in E-UTRAN coverage, specified as 0 (not in coverage) or 1 (in coverage). (*inCoverage-r12*).

Data Types: `double`

Data Types: `struct`

`mibsl` — MIB-SL message bit sequence
40-bit column vector

MIB-SL message bit sequence, specified as a 40-bit column vector.

For more information, see "*MasterInformationBlock-SL* Message Processing" on page 1-1197.

Data Types: `double | int8 | logical`

Output Arguments

`mibslout` — MIB-SL message bit sequence

40-bit column vector

MIB-SL message bit sequence, returned as a 40-bit column vector.

For more information, see "*MasterInformationBlock-SL* Message Processing" on page 1-1197.

Data Types: `double | int8 | logical`

`ueout` — User equipment settings

structure

User equipment settings, returned as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks

0, 6, 15, 25, 50, 75, or 100

Number of sidelink resource blocks, returned as an integer from the set {0, 6, 15, 25, 50, 75, 100}. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

For more information on sidelink bandwidths, see "*MasterInformationBlock-SL* Message Processing" on page 1-1197.

Data Types: `double`

`DuplexMode` — Duplexing mode

`'FDD' | 'TDD'`

Duplexing mode, returned as `'FDD'` or `'TDD'`.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration
integer from 0 to 6

Uplink or downlink configuration, returned as an integer from 0 to 6. (*tdd-ConfigSL-r12*)

`TDDConfig` is applicable for TDD duplex mode only.

Data Types: `double`

`NFrame` — Direct frame number
nonnegative integer

Direct frame number, returned as a nonnegative integer. (*directFrameNumber-r12*)

Data Types: `double`

`NSubframe` — Direct subframe number
nonnegative integer

Direct subframe number, returned as a nonnegative integer. (*directSubframeNumber-r12*)

Data Types: `double`

`InCoverage` — Indicates when UE is in E-UTRAN coverage
0 | 1

Indicates when UE is in E-UTRAN coverage, returned as 0 or 1. (*inCoverage-r12*) The UE transmitting the *MasterInformationBlock-SL* is:

- Not in E-UTRAN coverage when `InCoverage` = 0.
- In E-UTRAN coverage when `InCoverage` = 1.

Data Types: `double`

Data Types: `struct`

Definitions

MasterInformationBlock-SL Message Processing

The *MasterInformationBlock-SL* (MIB-SL) message is a 40 bits long and defined in TS 36.331 [1], Section 6.5.2. The message is sent from UE to UE on the PC5 interface via

the SL-BCH transport channel on the SBCCH logical channel. MIB-SL contains *sl-Bandwidth-r12*, *tdd-ConfigSL-r12*, *directFrameNumber-r12*, *directSubframeNumber-r12*, *inCoverage-r12*, and 19 bits reserved for future.

- When encoding theMIB-SL message:
  - If `NSLRB` is not one of the set {6,15,25,50,75,100}, then all ones are inserted into the first three bits (*sl-Bandwidth-r12* bit field) of the master information block message.
- When decoding the MIB-SL message:
  - If the first three bits (*sl-Bandwidth-r12* bit field) of the input MIB-SL message do not contain the equivalent of a decimal from 0 to 5 (MSB first, corresponding to the PRB set {6,15,25,50,75, 100}) then NSLRB is returned as 0.
  - If the input MIB-SL messages are not 40 bits, the messages are either truncated to 40 elements or zero padded as needed.

References

[1] 3GPP TS 36.331. "Radio resource control (RRC); Protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteMIB` | `lteSLBCH` | `lteSLBCHDecode`

Introduced in R2016b

lteSLResourceGrid

Sidelink subframe resource array

Syntax

```
grid = lteSLResourceGrid(ue)
grid = lteSLResourceGrid(ue,ntxants)
```

Description

`grid = lteSLResourceGrid(ue)` returns an empty resource grid matrix that represents the resource elements for one subframe, for the specified UE-specific setting structure.

For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see "Data Structures".

`grid = lteSLResourceGrid(ue,ntxants)` returns a 3-D resource grid array for the specified UE settings structure and number of antenna planes.

Examples

Create Empty Sidelink Resource Grid

Create an empty resource array representing the resource elements for 10 MHz bandwidth.

```
reGrid = lteSLResourceGrid(struct('NSLRB',50));
```

```
Warning: Using default value for parameter field CyclicPrefixSL (Normal)
```

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a structure containing these parameter fields:

`NSLRB` — Number of sidelink resource blocks
integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. (N_{RB}^{SL})

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`ntxants` — Number of transmit antenna planes
positive integer

Number of transmit antenna planes, specified as a positive integer.

Data Types: `double`

Output Arguments

`grid` — Resource element grid
matrix | 3-D array

Resource element grid, returned as an N_{SC}-by-N_{SYM}-by-N_{TX} array.

- N_{SC} is the number of subcarriers, `12*ue.NSLRB`.
- N_{SYM} is the number of SC-FDMA symbols in a subframe—14 for normal cyclic prefix or 12 for extended cyclic prefix.
- N_{TX} is the number of transmission antenna planes.

See Also

See Also

`lteSLResourceGridSize` | `lteSLSCFDMAModulate` | `lteULResourceGrid`

Introduced in R2016b

lteSLResourceGridSize

Sidelink subframe resource array size

Syntax

```
dim = lteSLResourceGridSize(ue)
dim = lteSLResourceGridSize(ue,ntxants)
```

Description

`dim = lteSLResourceGridSize(ue)` returns a 3-element row vector of dimension lengths for the resource grid array that you can generate from the specified UE settings structure. By default, the number of antennas is set to 1 for single-port sidelink transmissions.

For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see "Data Structures".

`dim = lteSLResourceGridSize(ue,ntxants)` accepts the number of antenna planes as an optional input.

Examples

Create Empty Sidelink Resource Array Using Grid Size

Use the vector returned by `lteSLResourceGridSize` to create a MATLAB® array. Valid and equivalent sidelink subframe resource grids can be created using the `lteSLResourceGrid` function or the MATLAB `zeros` function.

Create a UE settings structure. Use the output from `lteSLResourceGridSize` as input to `zeros` to generate an empty resource grid.

```
ue = struct('NSLRB',6,'CyclicPrefixSL','Normal');

reGrid1 = zeros(lteSLResourceGridSize(ue));
```

Generate another empty resource grid, this time use `lteSLResourceGrid`.

```
reGrid2 = lteSLResourceGrid(ue);
```

Confirm the two grids are identical.

```
isequal(reGrid1,reGrid2)
```

```
ans =

  logical

   1
```

Create Two Antenna Empty Sidelink Resource Array Using Grid Size

Create an empty resource grid for two antenna planes using the vector returned by `lteSLResourceGridSize` and the function `zeros`.

Create a UE settings structure and define a local variable for the number of antennas.

```
ue = struct('NSLRB',6,'CyclicPrefixSL','Normal');
ntxant = 2;
```

Generate an epmty resource grid.

```
reGrid = zeros(lteSLResourceGridSize(ue,ntxant));
size(reGrid)
```

```
ans =

    72    14     2
```

The third dimension indicates that two antenna planes are defined in the output grid.

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a structure containing these parameter fields:

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`ntxants` — Number of transmit antenna planes

positive integer

Number of transmit antenna planes, specified as a positive integer.

Data Types: `double`

Output Arguments

`dim` — Dimension lengths of resource grid array

3-element row vector

Dimension lengths of resource grid array, returned as a 3-element row vector, [N_{SC} N_{SYM} N_{TX}].

- N_{SC} is the number of subcarriers, `12*ue.NSLRB`.
- N_{SYM} is the number of SC-FDMA symbols in a subframe—14 for normal cyclic prefix or 12 for extended cyclic prefix.
- N_{TX} is the number of transmission antenna planes.

See Also

See Also

`lteSLResourceGrid` | `lteULResourceGridSize`

Introduced in R2016b

lteSLSCFDMADemodulate

Sidelink SC-FDMA demodulation

Syntax

```
grid = lteSLSCFDMADemodulate(ue,waveform)
grid = lteSLSCFDMADemodulate(ue,waveform,cpfraction)
```

Description

`grid = lteSLSCFDMADemodulate(ue,waveform)` performs sidelink SC-FDMA demodulation of the input time-domain waveform for the specified UE settings structure. For more information, see “Sidelink SC-FDMA Demodulation” on page 1-1210.

`grid = lteSLSCFDMADemodulate(ue,waveform,cpfraction)` allows the specification of the starting waveform sample for demodulation as a fraction of the cyclic prefix.

Examples

Sidelink Demodulatation

Perform sidelink SC-FDMA modulation of one subframe containing the sidelink synchronization signals and add noise at an SNR of 3.0 dB. The demodulator zeros the resource elements in the last SC-FDMA symbol. This behavior is consistent with the operation of the SC-FDMA modulator which does not modulate the last SC-FDMA symbol of the subframe. Plot the received waveform and the demodulated resource grid magnitude.

Create a UE settings structure.

```
ue.NSLRB = 15;
ue.CyclicPrefixSL = 'Normal';
ue.NSLID = 17;
```

Populate the resource grid with PSSS and SSSS. Modulate the PSSS and SSSS.

```
txgrid = lteSLResourceGrid(ue);
txgrid(ltePSSSIndices(ue)) = ltePSSS(ue);
txgrid(lteSSSSIndices(ue)) = lteSSSS(ue);

[txwaveform,info] = lteSLSCFDMAModulate(ue,txgrid);
```

Add AWGN with an SNR of 3.0 dB.

```
rxwaveform = awgn(txwaveform,3.0,'measured');
```

Perform sidelink SC-FDMA demodulation.

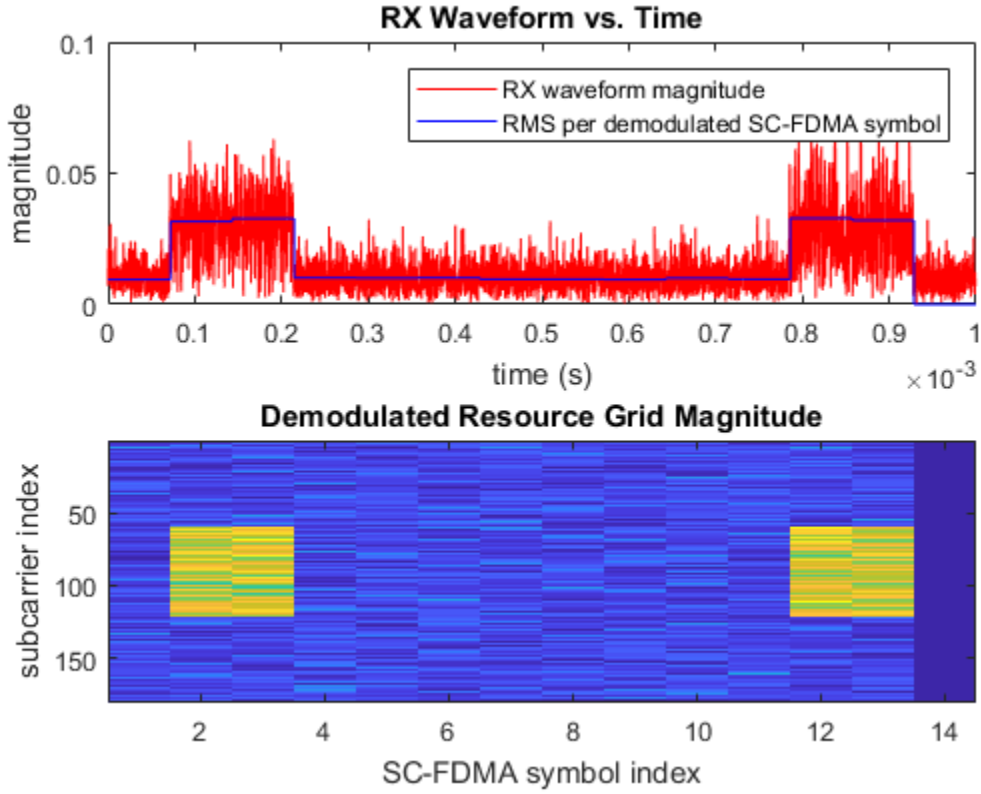
```
rxgrid = lteSLSCFDMADemodulate(ue,rxwaveform);
```

Calculate the RMS of each SC-FDMA symbol in the received resource grid.

```
rms = sqrt(sum(abs((rxgrid./double(info.Nfft)).^2)));
```

Plot the magnitude of the resulting time-domain waveform, overlaying the RMS for each SC-FDMA symbol after demodulation. Plot the demodulated resource grid magnitude.

```
t = (0:size(rxwaveform,1))/info.SamplingRate;
figure

subplot(2,1,1)
plot(t(1:end-1),abs(rxwaveform),'r')
hold on
n = cumsum([1 info.CyclicPrefixLengths + info.Nfft]);
n = [n(1:end-1); n(2:end)];
rmsplot = repmat(rms,[2 1]);
plot(t(n(:)),rmsplot(:),'b')
xlabel('time (s)')
ylabel('magnitude')
title('RX Waveform vs. Time')
legend('RX waveform magnitude','RMS per demodulated SC-FDMA symbol')

subplot(2,1,2)
imagesc(abs(rxgrid))
title('Demodulated Resource Grid Magnitude')
xlabel('SC-FDMA symbol index')
ylabel('subcarrier index')
```



Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

NSLRB — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: 6, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: double

CyclicPrefixSL — Cyclic prefix length

'Normal' (default) | 'Extended' | optional

Cyclic prefix length, specified as 'Normal' or 'Extended'.

Data Types: char

Data Types: struct

waveform — Sidelink SC-FDMA modulated waveform

numeric matrix

Sidelink SC-FDMA modulated waveform, specified as an N_S-by-N_T numeric matrix, where N_S is the number of the time-domain samples and N_T is the number of transmission antennas. $N_S = K \times 30720 / 2048 \times N_{fft}$, where N_{fft} is the FFT size and K is the number of subframes in waveform.

For more information about the FFT size, see lteSLSCFDMAInfo.

Data Types: double
Complex Number Support: Yes

cpfraction — Fraction of cyclic prefix

0.55 (default) | numeric scalar from 0 to 1

Fraction of cyclic prefix, specified as a numeric scalar from 0 to 1. A value of 0 represents the start of the cyclic prefix and a value of 1 represents the end of the cyclic prefix. The default value is 0.55 which assumes for the default level of windowing in the lteSLSCFDMAModulate function.

Data Types: double

Output Arguments

grid — Resource element grid

numeric 3-D array

Resource element grid, returned as an N_{SC}-by-N_{SYM}-by-N_T numeric array. N_{SC} is $12 \times$ NSLRB subcarriers. N_{SYM} is a multiple of the number of SC-FDMA symbols in a

subframe (14 for normal cyclic prefix and 12 for extended cyclic prefix). N_T is the number of antenna ports. `grid` defines the RE allocation across one or more subframes. Multiple subframes are defined by concatenation across the columns (second dimension).

Each antenna plane in `grid` is SC-FDMA modulated, resulting in the columns of `waveform`, as described in "Data Structures".

Data Types: `double`
Complex Number Support: Yes

Definitions

Sidelink SC-FDMA Demodulation

Sidelink SC-FDMA demodulation recovers the received subcarrier values by performing one FFT operation per received sidelink SC-FDMA symbol. The recovered subcarrier values are used to construct each column of the output resource array grid. The FFT is positioned partway through the cyclic prefix, to account for some channel delay spread while avoiding the overlap between adjacent SC-FDMA symbols. The input FFT is also shifted by half of one subcarrier. The position of the FFT chosen in the function avoids the SC-FDMA symbol overlapping used in the `lteSLSCFDMAModulate` function. Because the FFT is performed away from the original zero-phase point on the transmitted subcarriers, `lteSLSCFDMADemodulate` applies a phase correction to each subcarrier after the FFT.

Note:

- TS 36.211 specifies that for PSSCH (Section 9.3.6), PSCCH (9.4.6), PSDCH (9.5.6) and PSBCH (9.6.6), resource elements in the last SC-FDMA symbol within a subframe should be counted in the mapping process but not transmitted. The resource elements of the last SC-FDMA symbol in each subframe of the output resource array grid are set to zero by `lteSLSCFDMADemodulate`. This behavior is consistent with SC-FDMA modulation, performed by `lteSLSCFDMAModulate`.
- The sampling rate of the time-domain sidelink waveform must be the same as the rate used in the `lteSLSCFDMAModulate` function, for the specified number of resource blocks, `NSLRB`.

- The input `waveform` must be time aligned, such that the first sample is the first sample of the cyclic prefix of the first sidelink SC-FDMA symbol in a subframe.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteSLSCFDMAInfo` | `lteSLSCFDMAModulate`

Introduced in R2016b

lteSLSCFDMAInfo

Sidelink SC-FDMA modulation information

Syntax

```
info = lteSLSCFDMAInfo(ue)
```

Description

`info = lteSLSCFDMAInfo(ue)` returns a structure containing information related to the sidelink SC-FDMA modulation performed by `lteSLSCFDMAModulate`, using the specified UE settings structure.

For details, see “Sidelink SC-FDMA Modulation” on page 1-1215.

Examples

Sidelink Waveform Sampling Rate for 5 MHz Channel

Calculate the sampling rate of a 5 MHz sidelink waveform after sidelink SC-FDMA modulation.

Create a UE settings structure. Specify 25 resource blocks, which corresponds to 5 MHz channel bandwidth.

```
ue = struct('NSLRB',25);
```

For the specified channel bandwidth, find the sidelink SC-FDMA modulation sampling rate.

```
slscfdmaInfo = lteSLSCFDMAInfo(ue);
samplingRate = slscfdmaInfo.SamplingRate
```

```
samplingRate =

     7680000
```

Input Arguments

`ue` — User equipment settings
structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks
integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Windowing` — Number of time-domain samples
positive integer scalar | optional

Number of time-domain samples over which windowing and overlapping of sidelink SC-FDMA symbols is applied, specified as a positive integer scalar.

`ue.Windowing` must be even. For the `ue.Windowing` field, the default depends on `NSLRB` and `CyclicPrefixSL`.

Data Types: `double`

Data Types: `struct`

Output Arguments

`info` — Sidelink SC-FDMA modulated waveform information
structure

Sidelink SC-FDMA modulated waveform information, returned as a parameter structure containing these fields:

`SamplingRate` — Sampling rate
positive numeric scalar

Sampling rate of the time-domain sidelink waveform, in Hz, returned as a positive numeric scalar. `SamplingRate` = `Nfft` × (30.72e6 / 2048).

`Nfft` — Number of FFT points
positive integer scalar

The number of FFT points, returned as a positive integer scalar. `Nfft` is a function of the number of resource blocks ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

`NSLRB` ($N_{\mathrm{RB}}^{\mathrm{SL}}$)	**`Nfft`**
6	128
15	256
25	512
50	1024
75	2048
100	2048

In general, `Nfft` is the smallest power of 2 greater than or equal to (12 × $N_{\mathrm{RB}}^{\mathrm{SL}}$) / 0.85. Specifically, `Nfft` is the smallest FFT that spans all subcarriers and results in no more than 85% of bandwidth occupancy (12 × $N_{\mathrm{RB}}^{\mathrm{SL}}$ / `Nfft`).

`Windowing` — Number of time-domain samples
positive integer scalar

Number of time-domain samples over which windowing and overlapping of sidelink SC-FDMA symbols is applied, returned as a positive integer scalar.

`CyclicPrefixLengths` — Cyclic prefix length
positive integer vector

Cyclic prefix length in symbols for each sidelink SC-FDMA symbol in a subframe, returned as an N_{SYM}-by-1 integer vector. N_{SYM} is 14 for normal cyclic prefix and 12 for extended cyclic prefix.

The vector returned for `info.CyclicPrefixLengths` depends on the FFT size.

- When `info.Nfft` = `2048`, then `CyclicPrefixLengths` is:
  - `[160 144 144 144 144 144 144 160 144 144 144 144 144 144]` for normal cyclic prefix
  - `[512 512 512 512 512 512 512 512 512 512 512 512]` for extended cyclic prefix
- For other values of `info.Nfft`, these element values in `CyclicPrefixLengths` are scaled by `info.Nfft` / 2048.

Definitions

Sidelink SC-FDMA Modulation

The sidelink SC-FDMA modulation processing in `lteSLSCFDMAModulate` performs IFFT calculation, half-subcarrier shifting, cyclic prefix insertions, and optional raised-cosine windowing and overlapping of adjacent sidelink SC-FDMA symbols. TS 36.211 specifies that for PSSCH (Section 9.3.6), PSCCH (9.4.6), PSDCH (9.5.6) and PSBCH (9.6.6), resource elements in the last SC-FDMA symbol within a subframe should be counted in the mapping process but not transmitted. Therefore, before performing the IFFT, the last SC-FDMA symbol of each subframe in the input resource grid is set to zero.

For sidelink SC-FDMA modulation, calling `lteSLSCFDMAModulate` on a multi-subframe array of resource grids is recommended.

- When the resource element grid input to `lteSLSCFDMAModulate` spans multiple subframes, the windowing and overlapping is applied between all adjacent SC-FDMA symbols, including the last symbol of the previous subframe and the first symbol of the next subframe. Multi-subframe modulation processing results in a waveform that does not have discontinuities between subframes.
- A time-domain waveform that concatenates individually modulated subframes has discontinuities at the start and end of each subframe. To avoid these discontinuities,

the resulting multi-subframe time-domain waveform must be created by manually overlapping symbols at the subframe boundaries.

- If the value for windowing is zero, issues concerning concatenation of subframes before sidelink SC-FDMA modulation do not apply.

If `ue.Windowing` is absent, `info.Windowing` returns a default value chosen as a function of `ue.NSLRB`. The chosen value is a compromise between:

- The effective duration of cyclic prefix, and therefore the channel delay spread tolerance
- The spectral characteristics of the transmitted signal, not considering any additional FIR filtering

See Also

See Also

`lteSLSCFDMADemodulate` | `lteSLSCFDMAModulate`

Introduced in R2016b

lteSLSCFDMAModulate

Sidelink SC-FDMA modulation

Syntax

```
waveform = lteSLSCFDMAModulate(ue,grid)
[waveform,info] = lteSLSCFDMAModulate(ue,grid)
[ ___ ] = lteSLSCFDMAModulate(ue,grid,windowing)
```

Description

`waveform = lteSLSCFDMAModulate(ue,grid)` returns a modulated sidelink SC-FDMA waveform for the specified UE settings structure and allocated resource element grid of a number of subframes across one or more antenna planes. For more information, see "Sidelink SC-FDMA Modulation" on page 1-1223.

`[waveform,info] = lteSLSCFDMAModulate(ue,grid)` also returns a SC-FDMA information structure array.

`[ ___ ] = lteSLSCFDMAModulate(ue,grid,windowing)` specifies in `windowing` the number of windowed and overlapped samples to use in the time-domain windowing. For this syntax, the value reported in `info.Windowing` equals `windowing`. Any value provided in `ue.Windowing` is ignored.

This syntax supports output options from prior syntaxes.

Examples

Sidelink Broadcast Channel Modulation

Perform sidelink SC-FDMA modulation of one subframe containing a sidelink broadcast transmission. Any resource elements present in the last SC-FDMA symbol of the subframe are not modulated, so the resulting waveform magnitude is zero during that SC-FDMA symbol. Plot the magnitude of the resulting time-domain waveform and the transmitted resource grid magnitude.

Create a UE settings structure and an empty resource grid

```
ue.NSLRB = 6;
ue.CyclicPrefixSL = 'Extended';
ue.InCoverage = 1;
ue.DuplexMode = 'FDD';
ue.NFrame = 0;
ue.NSubframe = 0;
ue.NSLID = 42;

grid = lteSLResourceGrid(ue);
```

Transmit the PSBCH

Populate the PSBCH resource grid with an encoded SL-MIB message, and its DM-RS. Perform sidelink SC-FDMA modulation.

```
grid(ltePSBCHIndices(ue)) = ltePSBCH(ue,lteSLBCH(ue,lteSLMIB(ue)));
grid(ltePSBCHDRSIndices(ue)) = ltePSBCHDRS(ue);

[waveform,info] = lteSLSCFDMAModulate(ue,grid);
```

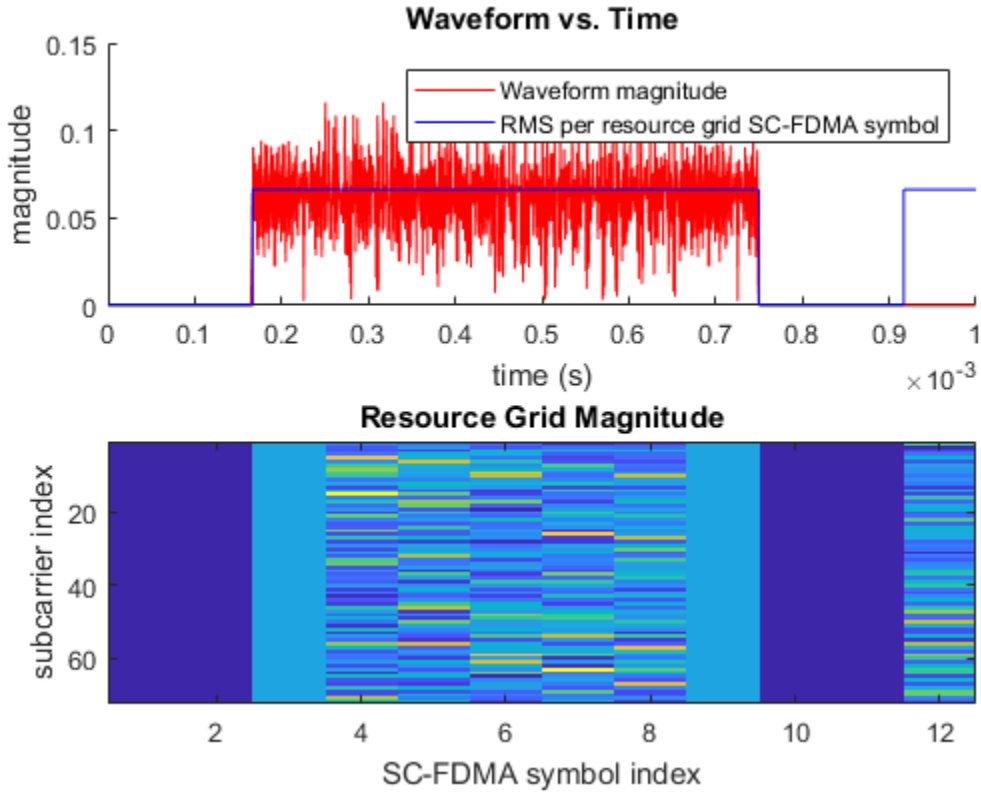
Calculate the expected RMS for each SC-FDMA symbol from the resource grid prior to modulation.

```
rms = sqrt(sum(abs((grid./double(info.Nfft)).^2)));
```

Plot the waveform magnitude overlaying the RMS for each SC-FDMA symbol. Plot the transmitted resource grid magnitude.

```
t = (0:size(waveform,1))/info.SamplingRate;
figure

subplot(2,1,1)
hold on

plot(t(1:end-1),abs(waveform),'r');
n = cumsum([1 info.CyclicPrefixLengths + info.Nfft]);
n = [n(1:end-1); n(2:end)];
rmsplot = repmat(rms,[2 1]);

plot(t(n(:)),rmsplot(:),'b')
xlabel('time (s)')
ylabel('magnitude')
title('Waveform vs. Time')
```

```
legend('Waveform magnitude','RMS per resource grid SC-FDMA symbol')

subplot(2,1,2)
imagesc(abs(grid))
title('Resource Grid Magnitude')
xlabel('SC-FDMA symbol index');
ylabel('subcarrier index');
```



Input Arguments

ue — User equipment settings
structure

User equipment settings, specified as a parameter structure containing these fields:

`NSLRB` — Number of sidelink resource blocks
integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. (N_{RB}^{SL})

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length
`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Windowing` — Number of time-domain samples
positive integer scalar | optional

Number of time-domain samples over which windowing and overlapping of sidelink SC-FDMA symbols is applied, specified as a positive integer scalar.

`ue.Windowing` must be even. For the `ue.Windowing` field, the default depends on `NSLRB` and `CyclicPrefixSL`.

Data Types: `double`

Data Types: `struct`

`grid` — Resource element grid
numeric 3-D array

Resource element grid, specified as an N_{SC}-by-N_{SYM}-by-N_T numeric array. N_{SC} must be 12 × `NSLRB` subcarriers. N_{SYM} must be a multiple of the number of SC-FDMA symbols in a subframe (14 for normal cyclic prefix and 12 for extended cyclic prefix). N_T is the number of antenna ports. `grid` defines the RE allocation across one or more subframes. Multiple subframes are defined by concatenation across the columns (second dimension).

Each antenna plane in `grid` is SC-FDMA modulated, resulting in the columns of `waveform`, as described in “Data Structures”.

Data Types: `double`

Complex Number Support: Yes

`windowing` — Number of time-domain samples

positive integer scalar | optional

Number of time-domain samples over which windowing and overlapping of sidelink SC-FDMA symbols is applied, specified as a positive integer.

If you specify `windowing` this value is returned in `info.Windowing` and any value provided in `ue.Windowing` is ignored.

Data Types: `double`

Output Arguments

`waveform` — Sidelink SC-FDMA modulated waveform

numeric matrix

Sidelink SC-FDMA modulated waveform, returned as an N_S-by-N_T numeric matrix, where N_S is the number of the time-domain samples and N_T is the number of transmission antennas. $N_S = K \times 30720 / 2048 \times$ `Nfft`, where `Nfft` is the IFFT size and K is the number of subframes in the `grid` input.

`info` — Sidelink SC-FDMA modulated waveform information

structure

Sidelink SC-FDMA modulated waveform information, returned as a parameter structure containing these fields:

`SamplingRate` — Sampling rate

positive numeric scalar

Sampling rate of the time-domain sidelink waveform, in Hz, returned as a positive numeric scalar. `SamplingRate` = `Nfft` × (30.72e6 / 2048).

`Nfft` — Number of FFT points

positive integer scalar

The number of FFT points, returned as a positive integer scalar. `Nfft` is a function of the number of resource blocks (N_{RB}^{SL})

NSLRB (N_{RB}^{SL})	**Nfft**
6	128
15	256
25	512
50	1024
75	2048
100	2048

In general, `Nfft` is the smallest power of 2 greater than or equal to (12 × N_{RB}^{SL}) / 0.85. Specifically, `Nfft` is the smallest FFT that spans all subcarriers and results in no more than 85% of bandwidth occupancy (12 × N_{RB}^{SL} / `Nfft`).

`Windowing` — Number of time-domain samples

positive integer scalar

Number of time-domain samples over which windowing and overlapping of sidelink SC-FDMA symbols is applied, returned as a positive integer scalar.

`CyclicPrefixLengths` — Cyclic prefix length

positive integer vector

Cyclic prefix length in symbols for each sidelink SC-FDMA symbol in a subframe, returned as an N_{SYM}-by-1 integer vector. N_{SYM} is 14 for normal cyclic prefix and 12 for extended cyclic prefix.

The vector returned for `info.CyclicPrefixLengths` depends on the FFT size.

- When `info.Nfft = 2048`, then `CyclicPrefixLengths` is:
  - `[160 144 144 144 144 144 144 160 144 144 144 144 144 144]` for normal cyclic prefix
  - `[512 512 512 512 512 512 512 512 512 512 512 512]` for extended cyclic prefix
- For other values of `info.Nfft`, these element values in `CyclicPrefixLengths` are scaled by `info.Nfft` / 2048.

Definitions

Sidelink SC-FDMA Modulation

The sidelink SC-FDMA modulation processing in `lteSLSCFDMAModulate` performs IFFT calculation, half-subcarrier shifting, cyclic prefix insertions, and optional raised-cosine windowing and overlapping of adjacent sidelink SC-FDMA symbols. TS 36.211 specifies that for PSSCH (Section 9.3.6), PSCCH (9.4.6), PSDCH (9.5.6) and PSBCH (9.6.6), resource elements in the last SC-FDMA symbol within a subframe should be counted in the mapping process but not transmitted. Therefore, before performing the IFFT, the last SC-FDMA symbol of each subframe in the input resource grid is set to zero.

For sidelink SC-FDMA modulation, calling `lteSLSCFDMAModulate` on a multi-subframe array of resource grids is recommended.

- When the resource element grid input to `lteSLSCFDMAModulate` spans multiple subframes, the windowing and overlapping is applied between all adjacent SC-FDMA symbols, including the last symbol of the previous subframe and the first symbol of the next subframe. Multi-subframe modulation processing results in a waveform that does not have discontinuities between subframes.
- A time-domain waveform that concatenates individually modulated subframes has discontinuities at the start and end of each subframe. To avoid these discontinuities, the resulting multi-subframe time-domain waveform must be created by manually overlapping symbols at the subframe boundaries.
- If the value for windowing is zero, issues concerning concatenation of subframes before sidelink SC-FDMA modulation do not apply.

If `ue.Windowing` is absent, `info.Windowing` returns a default value chosen as a function of `ue.NSLRB`. The chosen value is a compromise between:

- The effective duration of cyclic prefix, and therefore the channel delay spread tolerance
- The spectral characteristics of the transmitted signal, not considering any additional FIR filtering

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteSLResourceGridSize` | `lteSLSCFDMADemodulate` | `lteSLSCFDMAInfo`

Introduced in R2016b

lteSLSCH

Sidelink shared channel

Syntax

```
cw = lteSLSCH(ue,outlen,trblkin)
```

Description

`cw = lteSLSCH(ue,outlen,trblkin)` returns the codeword column vector for the specified UE settings structure and output length. `lteSLSCH` applies the complete sidelink shared channel (SL-SCH) transport channel processing to the input data, `trblkin`.

For more information, see “Sidelink Shared Transport Channel Processing” on page 1-1228.

Examples

Create and Decode SL-SCH Codeword

Use the physical channel bit capacity information to configure the output codeword size for SL-SCH coding. Decode the resulting codeword and check for CRC errors.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
ue.PRBSet = (10:12)';
ue.Modulation = '16QAM';
ue.RV = 0;

[~,psschinfo] = ltePSSCHIndices(ue);
cwlength = psschinfo.G;

trblk = randi([0 1],100,1);
cw = lteSLSCH(ue,cwlength,trblk);
[rxtrblk,err] = lteSLSCHDecode(ue,length(trblk),cw);
```

```
err
```

```
err =

  logical

   0
```

The transport block is recovered with no error.

Create SL-SCH Codeword Sequence

Create a cell array containing the redundancy version (RV) sequence of four codewords that is ready for transmission on the PSSCH.

Initialize a UE settings structure.

```
ue = struct('NSLRB',50,'CyclicPrefixSL','Normal');
ue.PRBSet = (10:12)';
ue.Modulation = '16QAM';
```

Use the physical channel bit capacity information to configure the output codeword size for SL-SCH coding. Create a transport block of information bits.

```
[~,psschinfo] = ltePSSCHIndices(ue);
cwlength = psschinfo.G;

trblk = randi([0 1],100,1);
```

Use a `for` loop to create a cell array containing the sequence of four SL-SCH codewords. `RV` = 0,2,3,1 for transmission on the PSSCH.

```
rvseq = [0 2 3 1];
for ii = 1:length(rvseq)
    ue.RV = rvseq(ii);
    cwseq = lteSLSCH(ue,cwlength,trblk);
    cwseqCell{ii} = cwseq;
end
```

Alternatively, the same cell array of SL-SCH codeword sequences can be created using an anonymous function handle.

```
rvseq = [0 2 3 1];
cwgenfn = @(rv)lteSLSCH(setfield(ue,'RV',rv),cwlength,trblk); %#ok<SFLD>
cwseqCell2 = arrayfun(cwgenfn,rvseq,'UniformOutput',false);
```

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Modulation` — Modulation type

`'QPSK'` | `'16QAM'`

Modulation type, specified as `'QPSK'` or `'16QAM'`.

Data Types: `char`

`RV` — Redundancy version indicator

0 | 1 | 2 | 3 | vector with element values from 0 to 3

Redundancy version indicator, specified as an integer scalar or vector with element values from 0 to 3.

Example: `[0 2 3 1]`, indicates the RV sequence order for transmission on the PSSCH.

Data Types: `double`

Data Types: `struct`

`outlen` — Codeword length

integer scalar

Codeword length, specified as an integer scalar. For more information, see “Sidelink Shared Transport Channel Processing” on page 1-1228.

Data Types: `double`

`trblkin` — Transport block data bits

bit vector

Transport block data bits, specified as a bit vector.

Data Types: `double`

Output Arguments

`cw` — PSSCH codeword

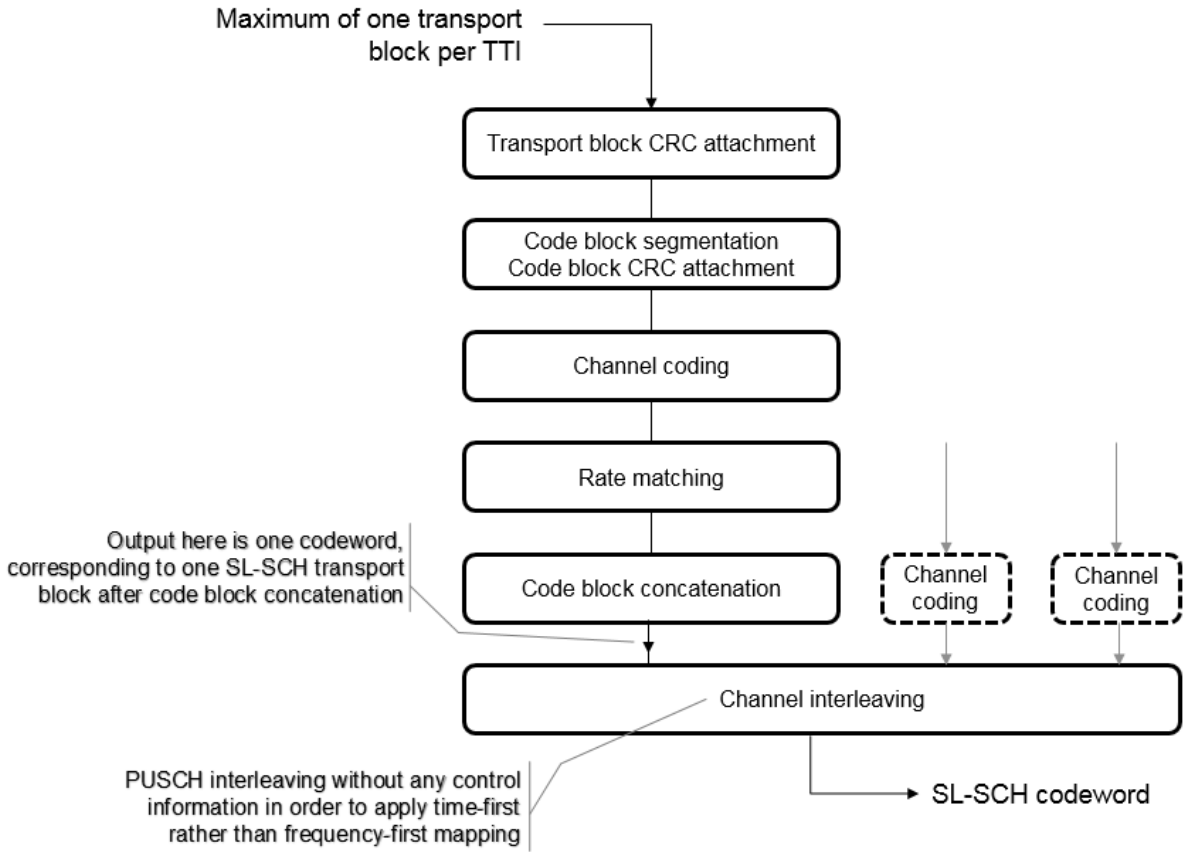
integer vector

PSSCH codeword, returned as an M_{bit}-by-1 integer vector. M_{bit} is equal to `outlen` and is the number of bits transmitted on the physical sidelink shared channel in one subframe. `outlen` must be a multiple of the number of bits per symbol. For more information, see "Sidelink Shared Transport Channel Processing" on page 1-1228.

Definitions

Sidelink Shared Transport Channel Processing

The sidelink shared channel (SL-SCH) transport channel processing includes type-24A CRC calculation, code block segmentation (including type-24B CRC attachment, if present), turbo encoding, rate matching with redundancy version (RV), code block concatenation, and PUSCH interleaving. `lteSLSCH` generates this transport channel codeword as specified by TS 36.212, Section 5.4.2.



The SL-SCH transport channel codeword carrying the information bits of a single transport block is transmitted on the physical sidelink shared channel. Use the `ltePSSCH` and `ltePSSCHIndices` functions to generate the modulated symbols and populate the resource grid for transmission.

The length of the codeword output by `lteSLSCH` represents the bit capacity of the physical channel. For PSSCH, the input codeword length is $M_{\text{bits}} = N_{\text{RE}} \times N_{\text{bps}}$, where N_{bps} is the number of bits per symbol. The PSSCH modulation is either QPSK (2 bits per symbol) or 16QAM (4 bits per symbol). The number of PSSCH resource elements (N_{RE}) in a subframe is $N_{\text{RE}} = N_{\text{PRB}} \times N_{\text{REperPRB}} \times N_{\text{SYM}}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission.
- $N_{REperPRB}$ is the number of resource elements in a PRB. Each PRB has 12 resource elements.
- N_{SYM} is the number of SC-FDMA symbols in a PSSCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. N_{SYM} is 12 for normal cyclic prefix or 10 for extended cyclic prefix.

The SL-SCH codeword carrying the information bits of a single transport block is always transmitted four times on four consecutive PSSCH subframes. The transmission subframes are selected from a subset of the PSSCH subframe pool. There is no HARQ feedback involved in the process. For more information on the SL-SCH transmission and the sidelink HARQ process, see TS 36.321, Section 5.14.2.2.

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.321. "Medium Access Control (MAC) protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSCH` | `lteSLSCHDecode`

Introduced in R2016b

lteSLSCHDecode

Sidelink shared channel decoding

Syntax

```
trblkout,blkcrc,stateout = lteSLSCHDecode(ue,trblklen,cwin)
[trblkout,blkcrc,stateout] = lteSLSCHDecode(ue,trblklen,cwin,
statein)
```

Description

`trblkout,blkcrc,stateout = lteSLSCHDecode(ue,trblklen,cwin)` returns a column vector of information bits,`trblkout`, decoded from the soft log-likelihood ratio (LLR) codeword data vector `cwin` for the specified UE settings structure and transport block length. Additional outputs contains the result from a block cyclic redundancy check, `blkcrc` and a structure containing the HARQ process decoding state, `stateout`.

The SL-SCH decoder processing includes PUSCH deinterleaving, rate recovery, turbo decoding, block concatenation, and CRC calculations. The SL-SCH decoder performs the inverse of the sidelink shared channel processing defined in TS 36.212 [1], Section 5.4.2. For more information, see “Sidelink Shared Transport Channel Processing” on page 1-1237.

`[trblkout,blkcrc,stateout] = lteSLSCHDecode(ue,trblklen,cwin, statein)` accepts an input structure specifying the initial HARQ process state that is used in support of HARQ soft combining.

The `stateout` array is normally reapplied via the `statein` argument of subsequent `lteSLSCHDecode` function calls, as part of a fixed sequence of HARQ retransmissions used by the SL-SCH. When a transport block is transmitted, it is always sent four times on four consecutive PSSCH subframes using the fixed RV sequence of {0,2,3,1}. The consecutive PSSCH subframes are selected from a subset of the PSSCH subframe pool. The `statein` and `stateout` variables allow this set of transmissions to be soft combined.

Examples

Decode SL-SCH Transport Channel

Encode and decode an information block using the SL-SCH transport channel.

Create a UE settings structure. Generate a 100-bit transport block and SL-SCH codeword.

```
ue = struct('CyclicPrefixSL','Normal','Modulation','16QAM','RV',0);
trblk = randi([0 1],100,1);
cw = lteSLSCH(ue,5760,trblk);
```

Decode the SL-SCH codeword.

```
rxtrblk = lteSLSCHDecode(ue,length(trblk),cw);
```

Decode SL-SCH Transport Channel and Check CRC

Encode and decode an information block using the SL-SCH transport channel, and display the CRC error result.

Create a UE settings structure. Generate a 100-bit transport block and SL-SCH codeword.

```
ue = struct('CyclicPrefixSL','Normal','Modulation','16QAM','RV',0);
trblk = randi([0 1],100,1);
cw = lteSLSCH(ue,5760,trblk);
```

Decode the SL-SCH codeword and check for block errors.

```
[rxtrblk,err] = lteSLSCHDecode(ue,length(trblk),cw);
err
```

```
err =

  logical

   0
```

The decoded transport block has no errors.

Decode SL-SCH Using HARQ Soft Combining

Use soft combining while decoding the sequence of four transmissions used to send every transport block on the SL-SCH. The rate matching and noise level are set so that successful decoding of the block requires multiple transmissions.

Initialize parameters

- Create a UE settings structure for the SL-SCH.
- Generate a transport block of 100 random bits.
- Create a local variable specifying an SL-SCH bit capacity of 288.
- Define the fixed redundancy version sequence used by the HARQ process.
- Clear the HARQ process decoding state.

```
ue = struct('CyclicPrefixSL','Normal','Modulation','QPSK');
trblk = randi([0 1],100,1);
bitcapacity = 288;
rvseq = [0 2 3 1];
decstate = [];
```

Transmit and recover the SL-SCH transport block

- Send the transport block four times.
- Display result of decoding successive transmissions.

```
for i = 1:4
    % Encode information bits with the next RV value.
    ue.RV = rvseq(i);
    cw = lteSLSCH(ue,bitcapacity,trblk);

    % Modulate the codeword and add noise.
    sym = awgn(lteSymbolModulate(cw,ue.Modulation),-4,'measured');
    softdata = lteSymbolDemodulate(sym,ue.Modulation);

    % Decode the current transmission and combine with decoding state.
    [rxtrblk,err,decstate] = lteSLSCHDecode(ue,length(trblk), ...
        softdata,decstate);
    X = ['Decoding error ', num2str(err), ' for transmission #', ...
        num2str(i), ' with RV ', num2str(ue.RV)];
    disp(X)
```

```
end

Decoding error 1 for transmission #1 with RV 0
Decoding error 1 for transmission #2 with RV 2
Decoding error 0 for transmission #3 with RV 3
Decoding error 0 for transmission #4 with RV 1
```

The soft-combined data is recovered without error on the third transmission.

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a parameter structure containing these fields:

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Modulation` — Modulation type

`'QPSK'` | `'16QAM'`

Modulation type, specified as `'QPSK'` or `'16QAM'`.

Data Types: `char`

`RV` — Redundancy version indicator

0 | 1 | 2 | 3 | vector with element values from 0 to 3

Redundancy version indicator, specified as an integer scalar or vector with element values from 0 to 3.

Example: `[0 2 3 1]`, indicates the RV sequence order for transmission on the PSSCH.

Data Types: `double`

`NTurboDecIts` — Number of turbo decoder iteration cycles

5 (default) | integer scalar from 1 to 30 | optional

Number of turbo decoder iteration cycles, specified as an integer scalar from 1 to 30.

Data Types: `double`

Data Types: `struct`

`trblklen` — Transport block length

positive integer scalar

Transport block length, specified as a positive integer scalar. `trblklen` defines the decoded transport block length.

Data Types: `double`

`cwin` — LLR codeword data

bit vector

LLR codeword data, specified as a soft bit vector.

Data Types: `double`

`statein` — Decoder buffer state

structure | optional

Decoder buffer state, specified as a structure. Use `statein` to input the current decoder buffer state for the transport block in an active HARQ process. `statein` can be an empty structure or a structure array with one or two elements. If nonempty, `statein.CBSBuffers` should contain a cell array of vectors representing the log-likelihood ratio (LLR) soft buffer states for the set of code blocks at the input to the turbo decoder, after explicit rate recovery. The updated buffer states after decoding are returned in the `CBSBuffers` field of `stateout`.

The `statein` array is normally generated and recycled from the `stateout` of previous calls to `lteSLSCHDecode`, as part of the fixed sequence of SL-SCH HARQ (re)transmissions.

The `statein` structure contains this field:

`CBSBuffers` — LLR soft buffer states

cell array of numeric vectors

LLR soft buffer states, specified as a cell array of numeric vectors. `CBSBuffers` contains the LLR soft buffer states for the set of code blocks associated with a single transport

block. The LLR soft buffer states are positioned at the input to the turbo decoder. The states are available after the explicit rate recovery.

Data Types: `cell`

Data Types: `struct`

Output Arguments

`trblkout` — Decoded information bits

integer column vector

Decoded information bits, returned as a column vector. The `trblkout` information bits are decoded from the soft log-likelihood ratio (LLR) codeword data vector, `cwin`.

`blkcrc` — CRC failure check of block

`true` | `false`

CRC failure check of block, returned as `true` or `false`.

- `blkcrc` = `false` indicates that the subframe was recovered with no block errors.
- `blkcrc` = `true` indicates a block error.

`stateout` — Internal state of decoder

structure

Internal state of decoder, returned as a structure containing these fields:

`CBSBuffers` — LLR soft buffer states

cell array of integer vectors

LLR soft buffer states, returned as a cell array of integer vectors. `CBSBuffers` contains the LLR soft buffer states for the set of code blocks associated with a single transport block. The LLR soft buffer states are positioned at the input to the turbo decoder. The states are available after the explicit rate recovery.

Data Types: `cell`

`CBSCRC` — CRC decoding results of type-24B code block set

integer array | empty array

CRC decoding results of type-24B code block set, returned as an integer array or empty array.

Data Types: `double`

`BLKCRC` — CRC decoding error in type-24A transport block
logical

CRC decoding error in type-24A transport block, returned as a logical.

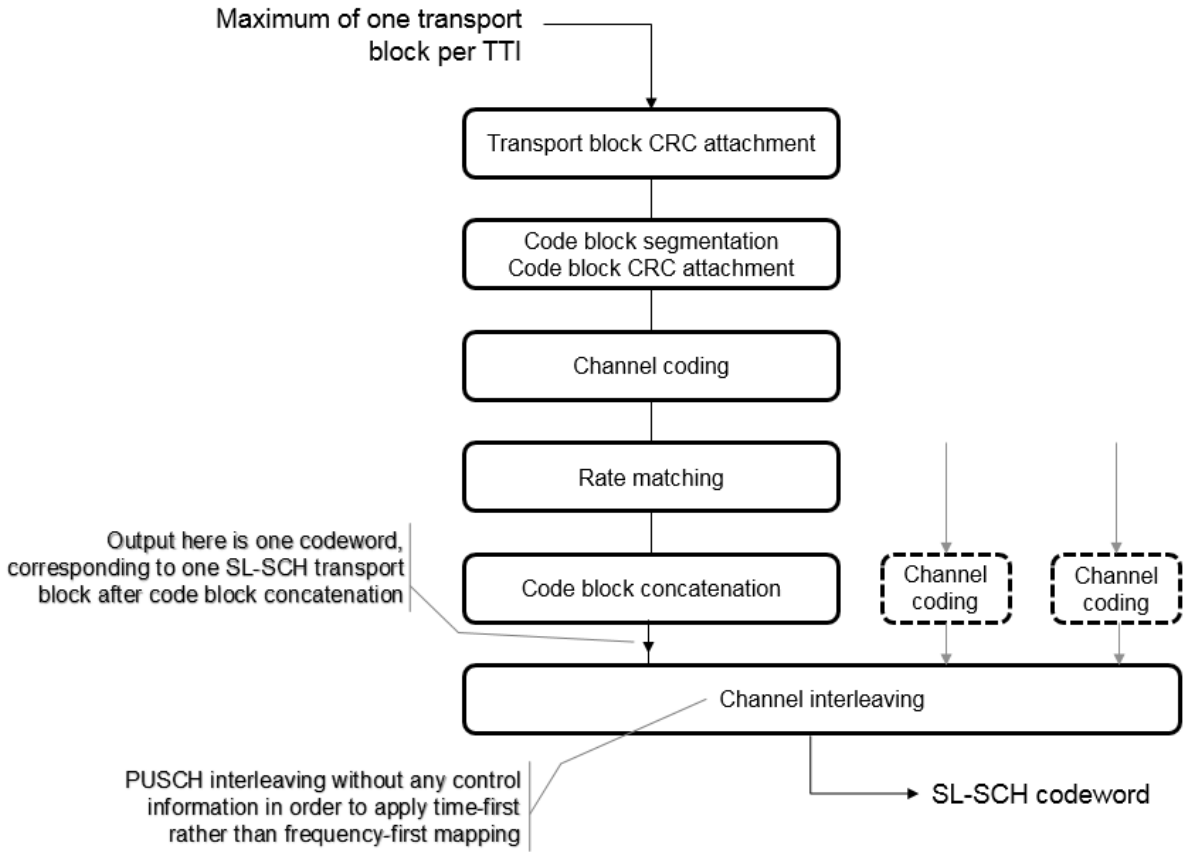
- `BLKCRC` = 0 indicates that the subframe was recovered with no block errors.
- `BLKCRC` = 1 indicates a block error.

Data Types: `logical`

Definitions

Sidelink Shared Transport Channel Processing

The sidelink shared channel (SL-SCH) transport channel processing includes type-24A CRC calculation, code block segmentation (including type-24B CRC attachment, if present), turbo encoding, rate matching with redundancy version (RV), code block concatenation, and PUSCH interleaving. `lteSLSCH` generates this transport channel codeword as specified by TS 36.212, Section 5.4.2.



The SL-SCH transport channel codeword carrying the information bits of a single transport block is transmitted on the physical sidelink shared channel. Use the `ltePSSCH` and `ltePSSCHIndices` functions to generate the modulated symbols and populate the resource grid for transmission.

The length of the codeword output by `lteSLSCH` represents the bit capacity of the physical channel. For PSSCH, the input codeword length is $M_{\text{bits}} = N_{\text{RE}} \times N_{\text{bps}}$, where N_{bps} is the number of bits per symbol. The PSSCH modulation is either QPSK (2 bits per symbol) or 16QAM (4 bits per symbol). The number of PSSCH resource elements (N_{RE}) in a subframe is $N_{\text{RE}} = N_{\text{PRB}} \times N_{\text{REperPRB}} \times N_{\text{SYM}}$ and includes symbols associated with the sidelink SC-FDMA guard symbol.

- N_{PRB} is the number of physical resource blocks (PRB) used for transmission.
- $N_{REperPRB}$ is the number of resource elements in a PRB. Each PRB has 12 resource elements.
- N_{SYM} is the number of SC-FDMA symbols in a PSSCH subframe, including symbols associated with the sidelink SC-FDMA guard symbol. N_{SYM} is 12 for normal cyclic prefix or 10 for extended cyclic prefix.

The SL-SCH codeword carrying the information bits of a single transport block is always transmitted four times on four consecutive PSSCH subframes. The transmission subframes are selected from a subset of the PSSCH subframe pool. There is no HARQ feedback involved in the process. For more information on the SL-SCH transmission and the sidelink HARQ process, see TS 36.321, Section 5.14.2.2.

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.321. "Medium Access Control (MAC) protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSCHDecode` | `lteSLSCH`

Introduced in R2016b

lteSRS

Uplink sounding reference signal

Syntax

```
seq = lteSRS(ue,chs)
[seq,info] = lteSRS(ue,chs)
```

Description

`seq = lteSRS(ue,chs)` returns a complex matrix, `seq`, containing uplink sounding reference signal (SRS) values and information structure array given structures containing UE-specific settings, and signal transmission configuration settings. For more information, see "SRS Processing" on page 1-1247 and TS 36.213 [1], Section 8.2.

`[seq,info] = lteSRS(ue,chs)` also returns an SRS information structure array, `info`.

Examples

Generate Uplink SRS Values

This example generates SRS values for 1.4 MHz bandwidth using the default SRS configuration.

Set the signal transmission configuration, chs structure fields.

```
chs.BWConfig = 7;
chs.BW = 0;
chs.CyclicShift = 0;
chs.SeqGroup = 0;
chs.SeqIdx = 0;
chs.ConfigIdx = 7;
```

Set ue structure fields.

```
ue.DuplexMode = 'FDD';
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
ue.NFrame = 0;
ue.NULRB = 6;
ue.NSubframe = 0;
```

Generate Uplink SRS resource element values.

```
srs = lteSRS(ue,chs);
srs(1:4)
```

```
ans =

   0.7071 - 0.7071i
  -0.7071 + 0.7071i
   0.7071 + 0.7071i
  -0.7071 - 0.7071i
```

Generate SRS Symbols for Two Antennas

Generate the SRS symbols for two transmit antenna paths. Display the information structure.

Initialize UE-specific and channel configuration structures (`ue` and `chs`) for 3 MHz bandwidth and two antennas using the default SRS configuration. Generate SRS symbols and the information structure (`ind` and `info`).

```
ue.DuplexMode = 'FDD';
ue.CyclicPrefixUL = 'Normal';
ue.NFrame = 0;
ue.NULRB = 15;
ue.NSubframe = 0;

chs = struct();
chs.NTxAnts = 2;
chs.BWConfig = 7;
chs.BW = 0;
chs.CyclicShift = 0;
chs.ConfigIdx = 7;
chs.SeqIdx = 0;
chs.SeqGroup = 0;
```

```
[ind,info] = lteSRS(ue,chs);
```

Since there are two antennas, the SRS symbols are output as a two column vector and the `info` output structure contains two elements.

```
ind(1:6,:)
size(info)
```

```
ans =

   0.5000 - 0.5000i   0.5000 - 0.5000i
  -0.5000 + 0.5000i   0.5000 - 0.5000i
   0.5000 + 0.5000i   0.5000 + 0.5000i
  -0.5000 - 0.5000i   0.5000 + 0.5000i
  -0.5000 + 0.5000i  -0.5000 + 0.5000i
   0.5000 - 0.5000i  -0.5000 + 0.5000i


ans =

     1     2
```

View the contents of the two `info` structure elements.

```
info(1)
info(2)
```

```
ans =

  struct with fields:

       Alpha: 0
    SeqGroup: 0
      SeqIdx: 0
     RootSeq: -1
         NZC: -1


ans =

  struct with fields:
```

```
    Alpha: 3.1416
 SeqGroup: 0
   SeqIdx: 0
  RootSeq: -1
      NZC: -1
```

Input Arguments

`ue` — UE-specific settings

structure

UE-specific settings, specified as a structure containing these following fields.

`NULRB` — Number of uplink resource blocks

positive integer

Number of uplink resource blocks, specified as a positive integer.

Data Types: `double`

`NSubframe` — Subframe number

0 (default) | optional | nonnegative integer

Subframe number, specified as a nonnegative integer.

Data Types: `double`

`NTxAnts` — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as 1, 2, or 4.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length for uplink

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length for uplink, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NFrame` — Initial frame number
0 (default) | optional | nonnegative integer

Initial frame number, specified as a nonnegative integer.

Data Types: `double`

`DuplexMode` — Duplexing mode
`'FDD'` (default) | optional | `'TDD'`

Duplexing mode, specified as `'FDD'` or `'TDD'` to indicate the frame structure type of the generated waveform.

Example: `'TDD'`

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration
0 (default) | integer from 0 to 6 | optional

Uplink or downlink configuration, specified as an integer from 0 to 6. Only required for `TDD` duplex mode.

Data Types: `double`

`SSC` — Special subframe configuration
0 (default) | integer from 0 to 9 | optional

Special subframe configuration, specified as an integer from 0 to 9. Only required for `TDD` duplex mode.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length in the downlink
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length in the downlink, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

Data Types: `struct`

`chs` — Signal transmission configuration
structure

Signal transmission configuration, specified as a structure containing these fields.

`NTxAnts` — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as 1, 2, or 4.

Data Types: `double`

`BWConfig` — SRS bandwidth configuration

7 (default) | integer from 0 to 7 | optional

SRS bandwidth configuration, specified as an integer from 0 to 7. (C_{SRS})

Data Types: `double`

`BW` — UE-specific SRS bandwidth

0 (default) | optional | 1 | 2 | 3

UE-specific SRS bandwidth, specified as an integer from 0 to 3. (B_{SRS})

Data Types: `double`

`ConfigIdx` — Configuration index for UE-specific periodicity

7 (default) | integer from 0 to 644 | optional

Configuration index for UE-specific periodicity, specified as a nonnegative integer from 0 to 644. This parameter contains the configuration index for UE-specific periodicity (T_{SRS}) and subframe offset (T_{offset}).

Data Types: `double`

`CyclicShift` — UE-specific cyclic shift

0 (default) | integer from 0 to 7 | optional

UE-specific cyclic shift, specified as an integer from 0 to 7. ($n_{\mathrm{SRS}}^{\mathrm{cs}}$)

Data Types: `double`

`SeqGroup` — SRS sequence group number

0 (default) | integer from 0 to 29 | optional

SRS sequence group number, specified as an integer from 0 to 29. (u)

Data Types: `double`

`SeqIdx` — Base sequence number

0 (default) | optional | 1

Base sequence number, specified as either 0 or 1. (v)

Data Types: `double` | `logical`

`OffsetIdx` — SRS subframe offset

0 (default) | optional | 1

SRS subframe offset choice for 2 ms SRS periodicity, specified as 0 or 1. Only required for `'TDD'` duplex mode. This parameter indexes the two SRS subframe offset entries in the row of TS 36.213 [1], Table 8.2-2 for the SRS configuration index specified by the `ConfigIdx` parameter.

Data Types: `double`

Data Types: `struct`

Output Arguments

`seq` — Uplink SRS values

complex matrix

Uplink SRS values, returned as a complex matrix. The symbols for each antenna are in the columns of the matrix, `seq`. The symbols for each antenna are in the columns of `seq`, with the number of columns determined by the number of transmission antennas configured.

Data Types: `double`
Complex Number Support: Yes

`info` — Information related to SRS

structure

Information related to SRS, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`Alpha` — Reference signal cyclic shift

numeric scalar

Reference signal cyclic shift, returned as a numeric scalar. (a)

Data Types: `double`

`SeqGroup` — SRS sequence group number
0,...,29

SRS sequence group number, returned as an integer from 0 to 29. (u)

Data Types: `double`

`SeqIdx` — Base sequence number
0 | 1

Base sequence number, returned as 0 or 1. (v)

Data Types: `double`

`RootSeq` — Root Zadoff-Chu sequence index
integer

Root Zadoff-Chu sequence index, returned as an integer. (q)

Data Types: `double`

`NZC` — Zadoff-Chu sequence length
integer

Zadoff-Chu sequence length, returned as an integer. (N_{ZC}^{RS})

Data Types: `double`

Data Types: `struct`

Definitions

SRS Processing

As specified in TS 36.213, Section 8.2, a UE shall transmit the sounding reference symbol (SRS) on per serving cell SRS resources, based on two trigger types:

- trigger type 0 — periodic SRS from higher layer signalling
- trigger type 1 — aperiodic SRS from DCI formats 0/4/1A for FDD or TDD and from DCI formats 2B/2C/2D for TDD.

If type 1 triggered SRS transmission is intended, then:

- `chs.ConfigIdx` indexes trigger type 1 UE-specific periodicity $T_{\mathrm{SRS},1}$ and subframe offset $T_{\mathrm{offset},1}$. The valid range of `chs.ConfigIdx` (I_{SRS}) is from 0 to 16 for FDD and from 0 to 24 for TDD.
- Frequency hopping is not permitted. Therefore, set `chs.HoppingBW` to be greater than or equal to `BW`. ($b_{\mathrm{hop}} \geq B_{\mathrm{SRS}}$).

To control whether to call the `lteSRS` and `lteSRSIndices` functions in a subframe, use `info.IsSRSSubframe`, returned by `lteSRSInfo`.

UE-specific configurations determine how `lteSRS` and `lteSRSIndices` operate. When no SRS is scheduled, calling `lteSRS` or `lteSRSIndices` in a subframe:

- May generate an SRS depending on the cell-specific SRS subframe configuration.
- Returns an empty `seq` or `ind` vector, for a given UE-specific SRS configuration. Also, the `info` structure scalar fields are set to –1, and any undefined vector fields are empty.

For short-base reference sequences, used with SRS transmissions spanning 4 PRBs, the `lteSRS` function does not use Zadoff Chu sequences and it sets `info.RootSeq` and `info.NZC` to –1.

`lteSRSIndices` returns the UE-specific SRS periodicity, `info.UePeriod`, and subframe offset, `info.UeOffset`. These parameters are distinct from the cell-specific SRS periodicity and subframe offset that `lteSRSInfo` returns.

If `chs.NTxAnts` is not present, `ue.NTxAnts` is used. If neither is present, the function assumes one antenna. In `lteSRSIndices`, for SRS transmission on multiple antennas:

- When `chs.NTxAnts` is set to 2 or 4, the value of `info.Port` matches the position in the structure array (0,...,`NTxAnts` – 1).
- If `chs.NTxAnts` is set to 1, `lteSRSIndices` uses `info.Port` to indicate the port chosen by SRS transmit antenna selection. `info.Port` indicates the selected antenna port, 0 or 1.

References

[1] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCellRS` | `lteCSIRS` | `lteDMRS` | `ltePRS` | `lteSRSIndices` | `lteSRSInfo`

Introduced in R2014a

lteSRSIndices

Uplink SRS resource element indices

Syntax

```
ind = lteSRSIndices(ue,chs)
[ind,info] = lteSRSIndices(ue,chs)
[ ___ ] = lteSRSIndices(ue,chs,opts)
```

Description

`ind = lteSRSIndices(ue,chs)` returns a column vector of resource element (RE) indices for the Uplink sounding reference signal (SRS) given structures with the UE-specific settings, and the signal transmission configuration settings. For more information, see "SRS Processing" on page 1-1262 and TS 36.213 [1], Section 8.2.

`[ind,info] = lteSRSIndices(ue,chs)` also returns an SRS information structure array, `info`.

`[ ___ ] = lteSRSIndices(ue,chs,opts)` formats the returned indices using options defined in `opts`.

This syntax supports output options from prior syntaxes.

Examples

Generate Uplink SRS Indices

This example creates SRS indices for 3 MHz bandwidth.

Set the signal transmission configuration, `chs` structure fields.

```
chs.NTxAnts = 1;
chs.BWConfig = 7;
chs.BW = 0;
chs.ConfigIdx = 7;
chs.TxComb = 0;
```

```
chs.HoppingBW = 0;
chs.FreqPosition = 0;
```

Set `ue` structure fields.

```
ue.DuplexMode = 'FDD';
ue.CyclicPrefixUL = 'Normal';
ue.NFrame = 0;
ue.NULRB = 15;
ue.NSubframe = 0;
```

Generate the Uplink SRS resource element indices.

```
srsIndices = lteSRSIndices(ue,chs);
srsIndices(1:4)
```

```
ans =

  4×1 uint32 column vector

   2401
   2403
   2405
   2407
```

Generate SRS Indices for Two Antennas

Generate the SRS indices for two transmit antenna paths. Display the information structure.

Initialize UE-specific and channel configuration structures (`ue` and `chs`) for 3 MHz bandwidth and two antennas. Generate SRS indices and the information structure (`ind` and `info`).

```
ue.DuplexMode = 'FDD';
ue.CyclicPrefixUL = 'Normal';
ue.NFrame = 0;
ue.NULRB = 15;
ue.NSubframe = 0;

chs.NTxAnts = 2;
chs.BWConfig = 7;
chs.BW = 0;
```

```
chs.ConfigIdx = 7;
chs.TxComb = 0;
chs.HoppingBW = 0;
chs.FreqPosition = 0;

[ind,info] = lteSRSIndices(ue,chs);
```

Since there are two antennas, the SRS indices are output as a two column vector and the `info` output structure contains two elements.

```
ind(1:10,:)
size(info)
```

```
ans =

  10×2 uint32 matrix

   2401   4921
   2403   4923
   2405   4925
   2407   4927
   2409   4929
   2411   4931
   2413   4933
   2415   4935
   2417   4937
   2419   4939


ans =

     1     2
```

View the contents of the two `info` structure elements.

```
info(1)
info(2)
```

```
ans =

  struct with fields:
```

```
         UePeriod: 10
         UeOffset: 0
           PRBSet: [4×1 double]
        FreqStart: 60
          KTxComb: 0
         BaseFreq: 60
          FreqIdx: 0
    HoppingOffset: 0
           NSRSTx: 0
             Port: 0


ans =

  struct with fields:

         UePeriod: 10
         UeOffset: 0
           PRBSet: [4×1 double]
        FreqStart: 60
          KTxComb: 0
         BaseFreq: 60
          FreqIdx: 0
    HoppingOffset: 0
           NSRSTx: 0
             Port: 1
```

Generate SRS Indices Varying Indexing Style

Generate the SRS indices for two transmit antenna paths. Display the information structure.

Initialize UE-specific and channel configuration structures (`ue` and `chs`) for 3 MHz bandwidth and two antennas. Generate SRS indices and the information structure (`ind` and `info`).

```
ue.DuplexMode = 'FDD';
ue.CyclicPrefixUL = 'Normal';
ue.NFrame = 0;
ue.NULRB = 15;
ue.NSubframe = 0;

chs.NTxAnts = 2;
```

```
chs.BWConfig = 7;
chs.BW = 0;
chs.ConfigIdx = 7;
chs.TxComb = 0;
chs.HoppingBW = 0;
chs.FreqPosition = 0;

[ind,info] = lteSRSIndices(ue,chs,{'sub'});
```

Using `'sub'` indexing style, the indices are output in `[subcarrier,symbol,antenna]` subscript form. View the midpoint of `ind` and observe the antenna index change.

```
size(ind)
ind(22:27,:)
```

```
ans =

    48     3


ans =

  6×3 uint32 matrix

   103    14     1
   105    14     1
   107    14     1
    61    14     2
    63    14     2
    65    14     2
```

Since there are two antennas, the `info` output structure contains two elements. View the contents of the second `info` structure element.

```
size(info)
info(2)
```

```
ans =

     1     2
```

```
ans =

  struct with fields:

        UePeriod: 10
        UeOffset: 0
          PRBSet: [4×1 double]
       FreqStart: 60
         KTxComb: 0
        BaseFreq: 60
         FreqIdx: 0
   HoppingOffset: 0
          NSRSTx: 0
            Port: 1
```

Input Arguments

ue — UE-specific settings
structure

UE-specific settings, specified as a structure containing the following fields.

NULRB — Number of uplink resource blocks
positive integer

Number of uplink resource blocks, specified as a positive integer.

Data Types: `double`

NSubframe — Number of subframes
0 (default) | optional | nonnegative integer

Number of subframes, specified as a nonnegative integer.

Data Types: `double`

NTxAnts — Number of transmission antennas
1 (default) | optional | 2 | 4

Number of transmission antennas, specified as a 1, 2, or 4.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NFrame` — Initial frame number
0 (default) | optional | nonnegative integer

Initial frame number, returned as a nonnegative integer.

Data Types: `double`

`DuplexMode` — Duplexing mode
`'FDD'` (default) | optional | `'TDD'`

Duplexing mode, specified as `'FDD'` or `'FDD'` to indicate the frame structure of the generated waveform.

Data Types: `char`

`TDDConfig` — Uplink or downlink configuration
0 (default) | optional | 0,...,6

Uplink or downlink configuration, returned as a nonnegative integer from 0 to 6. Only required for `'TDD'` duplex mode.

Data Types: `double`

`SSC` — Special subframe configuration
0 (default) | optional | 0,...,9

Special subframe configuration, returned as a nonnegative integer from 0 to 9. Only required for `'TDD'` duplex mode.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, returned as `'Normal'` or `'Extended'`. Only required for `'TDD'` duplex mode.

Data Types: `char`

Data Types: `struct`

`chs` — Signal transmission configuration

structure

Signal transmission configuration, specified as a structure containing these fields.

`NTxAnts` — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as a 1, 2, or 4.

Data Types: `double`

`BWConfig` — Cell-specific SRS bandwidth configuration

7 (default) | optional | 0,...,7

Cell-specific SRS bandwidth configuration, specified as a nonnegative integer from 0 to 7. (C_{SRS})

Data Types: `double`

`BW` — UE-specific SRS bandwidth

0 (default) | optional | 1 | 2 | 3

UE-specific SRS bandwidth, specified as a nonnegative integer from 0 to 3. (B_{SRS})

Data Types: `double`

`ConfigIdx` — Configuration index for UE-specific periodicity

7 (default) | optional | 0,...,644

Configuration index for UE-specific periodicity, specified as a nonnegative integer from 0 to 644. This parameter contains the configuration index for UE-specific periodicity (T_{SRS}) and subframe offset (T_{offset}).

Data Types: `double`

`TxComb` — Transmission comb

0 (default) | optional | 1

Transmission comb, specified as a 0 or 1. This parameter controls SRS positions. SRS is transmitted in six carriers per resource block on odd (1) and even (0) resource indices.

Data Types: `double` | `logical`

`HoppingBW` — SRS frequency hopping configuration index
0 (default) | optional | 1 | 2 | 3

SRS frequency hopping configuration index, specified as a nonnegative integer from 0 to 3. (b_{hop})

Data Types: `double`

`FreqPosition` — Frequency-domain position
0 (default) | optional | 0,...,23

Frequency-domain position, specified as a nonnegative integer from 0 to 23. (n_{RRC})

Data Types: `double`

`CyclicShift` — UE-specific cyclic shift
0 (default) | optional | 0,...,7

UE-specific cyclic shift, specified as a nonnegative integer from 0 to 7. This parameter applies only when `NTxAnts` is 4. ($n_{\text{SRS}}^{\text{cs}}$)

Data Types: `double`

`NF4RachPreambles` — Number of RACH preamble frequency resources of format 4 in UpPTS
0 (default) | optional | 0,...,6

Number of RACH preamble frequency resources of format 4 in "UpPTS" on page 1-1263, specified as a nonnegative integer from 0 to 6. Only required for `'TDD'` duplex mode.

Data Types: `double`

`OffsetIdx` — SRS subframe offset
0 (default) | optional | 1

SRS subframe offset choice for 2 ms SRS periodicity, specified as 0 or 1. Only required for `'TDD'` duplex mode. This parameter indexes the two SRS subframe offset entries in the row of TS 36.213 [1], Table 8.2-2 for the SRS configuration index specified by the `ConfigIdx` parameter.

Data Types: `double`

`MaxUpPts` — Option to disable reconfiguration of sounding maximum bandwidth
1 (default) | optional | 0

Option to disable reconfiguration of sounding maximum bandwidth, specified as 0 or 1. Only required for `'TDD'` duplex mode. Enables (1) or disables (0) reconfiguration of $m_{\mathrm{SRS},0}^{\max}$ in "UpPTS" on page 1-1263. See TS 36.331 [2] for information on how the system information element *srs-MaxUpPts* applies to $m_{\mathrm{SRS},0}^{\max}$ configurability.

Data Types: `double | logical`

Data Types: `struct`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — Antenna indices

numeric matrix

Antenna indices, returned as a numeric matrix. By default, the indices are returned in one-based linear indexing form that can directly index elements of a resource matrix. These indices are ordered according to SRS modulation symbols mapping. The `opts` input offers alternative indexing formats. The indices for each antenna are in the columns of `ind`, with the number of columns determined by the number of transmission antennas configured specified in `chs.NTxAnts`.

Data Types: `uint32`

`info` — Information related to SRS

structure array

Information related to SRS, returned as a structure array with elements corresponding to each transmit antenna and containing these fields.

`UePeriod` — UE-specific SRS periodicity

2 | 5 | 10 | 20 | 40 | 80 | 160 | 320

UE-specific SRS periodicity, in ms, returned as a positive integer.

Data Types: `double`

`UeOffset` — UE-specific SRS offset

0,...,319 | integer

UE-specific SRS offset, returned as an integer from 0 to 319.

Data Types: `double`

`PRBSet` — Physical resource block set

vector of integers

Physical resource block set, returned as a vector of integers. `PRBSet` specifies the PRBs occupied by the indices (zero-based).

Data Types: `double`

`FreqStart` — Frequency-domain starting position

numeric scalar

Frequency-domain starting position (k_0), returned as a numeric scalar. This argument is the zero-based subcarrier index of the lowest SRS subcarrier.

Data Types: `double`

`KTxComb` — Offset to the frequency-domain starting position

numeric scalar

Offset to the frequency-domain starting position (k_{TC}), returned as a numeric scalar. This argument is a function of the transmission comb parameter.

Data Types: `double`

`BaseFreq` — Base frequency-domain starting position

numeric scalar

Base (cell-specific) frequency-domain starting position ($\bar{k}_0$), returned as a numeric scalar. This UE-specific SRS is offset as a function of the UE-specific SRS bandwidth value, B_{SRS}. UE-specific SRS configuration cannot result in a frequency-domain starting position (k_0) lower than this value, given the cell-specific SRS bandwidth configuration value, C_{SRS}.

Data Types: `double`

`FreqIdx` — Frequency position index

numeric vector

Frequency position index, returned as a numeric vector. This argument specifies the frequency position index (n_b) for each b in the range $0,\ldots,B_{SRS}$.

Data Types: `double`

`HoppingOffset` — Offset term due to frequency hopping

numeric vector

Offset term due to frequency hopping, returned as a numeric vector. This argument specifies the offset term due to frequency hopping (F_b), used in the calculation of n_b.

Data Types: `double`

`NSRSTx` — Number of UE-specific SRS transmissions

positive integer

Number of UE-specific SRS transmissions (n_{SRS}), returned as a positive integer.

Data Types: `double`

`Port` — Antenna port number used for transmission

positive integer

Antenna port number used for transmission (p), returned as a positive integer.

Data Types: `double`

Data Types: `struct`

Definitions

SRS Processing

As specified in TS 36.213, Section 8.2, a UE shall transmit the sounding reference symbol (SRS) on per serving cell SRS resources, based on two trigger types:

- trigger type 0 — periodic SRS from higher layer signalling
- trigger type 1 — aperiodic SRS from DCI formats 0/4/1A for FDD or TDD and from DCI formats 2B/2C/2D for TDD.

If type 1 triggered SRS transmission is intended, then:

- `chs.ConfigIdx` indexes trigger type 1 UE-specific periodicity $T_{\mathrm{SRS},1}$ and subframe offset $T_{\mathrm{offset},1}$. The valid range of `chs.ConfigIdx` (I_{SRS}) is from 0 to 16 for FDD and from 0 to 24 for TDD.
- Frequency hopping is not permitted. Therefore, set `chs.HoppingBW` to be greater than or equal to `BW`. ($b_{\mathrm{hop}} \geq B_{\mathrm{SRS}}$).

To control whether to call the `lteSRS` and `lteSRSIndices` functions in a subframe, use `info.IsSRSSubframe`, returned by `lteSRSInfo`.

UE-specific configurations determine how `lteSRS` and `lteSRSIndices` operate. When no SRS is scheduled, calling `lteSRS` or `lteSRSIndices` in a subframe:

- May generate an SRS depending on the cell-specific SRS subframe configuration.
- Returns an empty `seq` or `ind` vector, for a given UE-specific SRS configuration. Also, the `info` structure scalar fields are set to –1, and any undefined vector fields are empty.

For short-base reference sequences, used with SRS transmissions spanning 4 PRBs, the `lteSRS` function does not use Zadoff Chu sequences and it sets `info.RootSeq` and `info.NZC` to –1.

`lteSRSIndices` returns the UE-specific SRS periodicity, `info.UePeriod`, and subframe offset, `info.UeOffset`. These parameters are distinct from the cell-specific SRS periodicity and subframe offset that `lteSRSInfo` returns.

If `chs.NTxAnts` is not present, `ue.NTxAnts` is used. If neither is present, the function assumes one antenna. In `lteSRSIndices`, for SRS transmission on multiple antennas:

- When `chs.NTxAnts` is set to 2 or 4, the value of `info.Port` matches the position in the structure array (0,...,`NTxAnts` – 1).
- If `chs.NTxAnts` is set to 1, `lteSRSIndices` uses `info.Port` to indicate the port chosen by SRS transmit antenna selection. `info.Port` indicates the selected antenna port, 0 or 1.

UpPTS

Uplink pilot time slot — the uplink part of the special subframe. This special subframe is only applicable for TDD operation. For more information, see "Frame Structure Type 2: TDD".

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.331. "Radio resource control (RRC); Protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCellRSIndices` | `lteCSIRSIndices` | `lteDMRSIndices` | `ltePRSIndices` | `lteSRS` | `lteSRSInfo`

Introduced in R2014a

lteSRSInfo

Uplink SRS information

Syntax

```
info = lteSRSInfo(ue,chs)
```

Description

`info = lteSRSInfo(ue,chs)` returns information related to the sounding reference signal (SRS) configuration determined by UE-specific settings, `ue`, and signal transmission configuration, `chs`. The information returned relates to the cell-specific SRS subframe configuration as described in TS 36.211[1], Section 5.5.3.3.

Information relating to a particular UE, such as UE-specific SRS configuration defined in TS 36.213[2], Section 8.2, is output by the `lteSRSIndices` and `lteSRS` functions. For a given configuration, if either of these components returns an empty vector, the SRS is not transmitted for that UE in the specified subframe.

Note: `lteSRSIndices` and `lteSRS` may generate an SRS signal and indices even in a subframe that, based on the cell-specific SRS subframe configuration, is not an SRS subframe. Use the field `info.IsSRSSubframe` returned by `lteSRSInfo` to control whether to call the `lteSRSIndices` and `lteSRS` functions in a subframe.

Examples

Get Information Related to SRS

Adjust the length of the PUCCH to allow for SRS transmission using the shortened field.

The setup in this example is consistent with `Simultaneous-ACK/NACK-and-SRS` set to `'True'` as described in TS 36.213, Section 8.2. Generate `pucchSymbols`, using `ue.Shortened=1`.

```
ue = lteRMCUL('A1-1');
```

```
srs.SubframeConfig = 0;
srsInfo = lteSRSInfo(ue,srs);
ue.Shortened = srsInfo.IsSRSSubframe;
harqValues = [];

pucchSymbols = ltePUCCH1(ue,ue.PUSCH,harqValues);
```

For the default case, `Simultaneous-ACK/NACK-and-SRS` is `'False'`, and the PUCCH is transmitted with `ue.Shortened=0`.

Input Arguments

`ue` — UE-specific settings

structure

UE-specific settings, specified as a structure. `ue` contains the following fields.

`NSubframe` — Subframe number

numeric scalar | optional

Subframe number, specified as a numeric scalar.

Data Types: `double`

`DuplexMode` — Duplex mode

`'FDD'` (default) | `'TDD'` | optional

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

Data Types: `struct`

`chs` — Signal transmission configuration

structure

Signal transmission configuration, specified as a structure. `chs` contains the following fields.

`SubframeConfig` — SRS subframe configuration

0...15

SRS subframe configuration, specified as a nonnegative scalar integer from 0 through 15.

Data Types: `double`

Data Types: `struct`

Output Arguments

`info` — Information related to the SRS configuration

structure

Information related to the SRS configuration, returned as a structure. `info` contains the following fields.

`CellPeriod` — Cell-specific SRS periodicity

1 | 2 | 5 | 10

Cell-specific SRS periodicity, in ms, returned as 1, 2, 5, or 10.

Data Types: `uint32`

`CellOffset` — Cell-specific SRS offsets

0...9

Cell-specific SRS offsets, returned as a nonnegative scalar integer from 0 through 9.

Data Types: `int32`

`IsSRSSubframe` — SRS subframe flag

1 | 0

SRS subframe flag, returned as 1 or 0. Present only if `ue` contains `NSubframe`. If `NSubframe` satisfies the expression `mod(NSubframe,CellPeriod)==CellOffset`, this value is 1. Otherwise, this value is 0.

Data Types: `uint32`

Data Types: `struct`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.213. “Physical layer procedures.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteSRS` | `lteSRSIndices`

Introduced in R2014a

lteSSS

Secondary synchronization signal

Syntax

```
sss = lteSSS(enb)
```

Description

`sss = lteSSS(enb)` returns a complex column vector containing the secondary synchronization signal (SSS) values for cell-wide settings in structure `enb`.

This signal is only defined for subframes 0 and 5; therefore, an empty vector is returned for other values of `NSubframe`. This allows this function and the corresponding indices function `lteSSSIndices` to be used to index the resource grid, as described in "Resource Grid Indexing", for any subframe number, but the resource grid is only modified in subframes 0 and 5.

Examples

Generate SSS Values

Generate secondary synchronization signal (SSS) values for a physical layer cell identity of 1.

```
sss = lteSSS(struct('NCellID',1,'NSubframe',0));
sss(1:4)
```

```
ans =

     1
    -1
     1
     1
```

Input Arguments

`enb` — Cell-wide settings
structure

Cell-wide settings, specified as a structure. This structure can contain the following fields.

`NCellID` — Physical layer cell identity
integer

Physical layer cell identity, specified as an integer.

Data Types: `double`

`NSubframe` — Subframe number
0 (default) | optional | integer

Subframe number, specified as an integer.

Data Types: `double`

Data Types: `struct`

Output Arguments

`sss` — Secondary synchronization signal
complex column vector

Secondary synchronization signal (SSS), returned as a complex column vector. The vector contains the SSS values for cell-wide settings in the `enb` structure.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`ltePSS` | `lteSSSIndices` | `lteSSSS`

Introduced in R2014a

lteSSSIndices

SSS resource element indices

Syntax

```
ind = lteSSSIndices(enb)
ind = lteSSSIndices(enb,port)
ind = lteSSSIndices( ___ ,opts)
```

Description

`ind = lteSSSIndices(enb)` returns a column vector of resource element indices, port 0 oriented, given the parameter fields of structure, `enb`. It returns a column vector of resource element (RE) indices for the Secondary Synchronization Signal (SSS). By default, the indices are returned in 1-based linear indexing form that can directly index elements of a 3-D array representing the resource array. These indices are ordered as the SSS modulation symbols should be mapped. Alternative indexing formats can also be generated.

These indices are only defined for subframes 0 and 5; therefore, an empty vector is returned for other values of `NSubframe`. This allows this function and the corresponding sequence function, `lteSSS`, to be used to index the resource grid, as described in "Resource Grid Indexing", for any subframe number. However, the resource grid is only modified in subframes 0 and 5.

`ind = lteSSSIndices(enb,port)` returns indices appropriate for an antenna port, `port`, which must be either 0, 1, 2, or 3.

`ind = lteSSSIndices( ___ ,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate SSS RE Indices in Linear Form

Get 0-based SSS resource element indices in linear form for antenna port 0.

```
enb = lteRMCDL('R.4');
sssIndices = lteSSSIndices(enb,0,{'0based','ind'});
sssIndices(1:4)
```

```
ans =

  4×1 uint32 column vector

   365
   366
   367
   368
```

Generate SSS RE Indices in Subscript Form

Generate 0-based SSS resource element indices in subscript form for antenna port 0. In this case, a matrix is generated where each row has three columns representing subcarrier, symbol, and antenna port.

Generate 0-based SSS resource element indices in subscript form for antenna port 0.

```
enb = lteRMCDL('R.4');
sssIndices = lteSSSIndices(enb,0,{'0based','sub'});
sssIndices(1:4,:)
```

```
ans =

  4×3 uint32 matrix

   5   5   0
   6   5   0
   7   5   0
   8   5   0
```

The first column of the output represents subcarrier. The second column represents symbol. The third column represents antenna port.

Input Arguments

`enb` — Cell-wide settings

structure

Cell-wide settings, specified as a structure. It contains the following fields.

`NDLRB` — Number of downlink resource blocks

integer from 6 to 110

Number of downlink resource blocks, specified as a integer from 6 to 110.

Data Types: `double`

`CyclicPrefix` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NSubframe` — Subframe number

0 (default) | nonnegative integer | optional

Subframe number, specified as a nonnegative integer.

Data Types: `double`

`DuplexMode` — Duplex mode

`'FDD'` (default) | `'TDD'` | optional

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

Data Types: `struct`

`port` — Antenna port

0 | 1 | 2 | 3

Antenna port, specified as 0, 1, 2, or 3.

Data Types: `double`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char` | `cell`

Output Arguments

`ind` — SSS resource element (RE) indices

integer column vector | 3-column integer matrix

SSS resource element (RE) indices, returned as a column vector or 3-column integer matrix. By default, the indices are returned in 1-based linear indexing form that can directly index elements of a 3D array representing the resource array. These indices are ordered as the SSS modulation symbols should be mapped. Alternative indexing formats can be generated using the `opts` input.

Data Types: `uint32`

See Also

See Also

`ltePSSIndices` | `lteSSS` | `lteSSSSIndices`

Topics

"Resource Grid Indexing"

Introduced in R2014a

lteSSSS

Secondary sidelink synchronization signal

Syntax

```
s = lteSSSS(ue)
```

Description

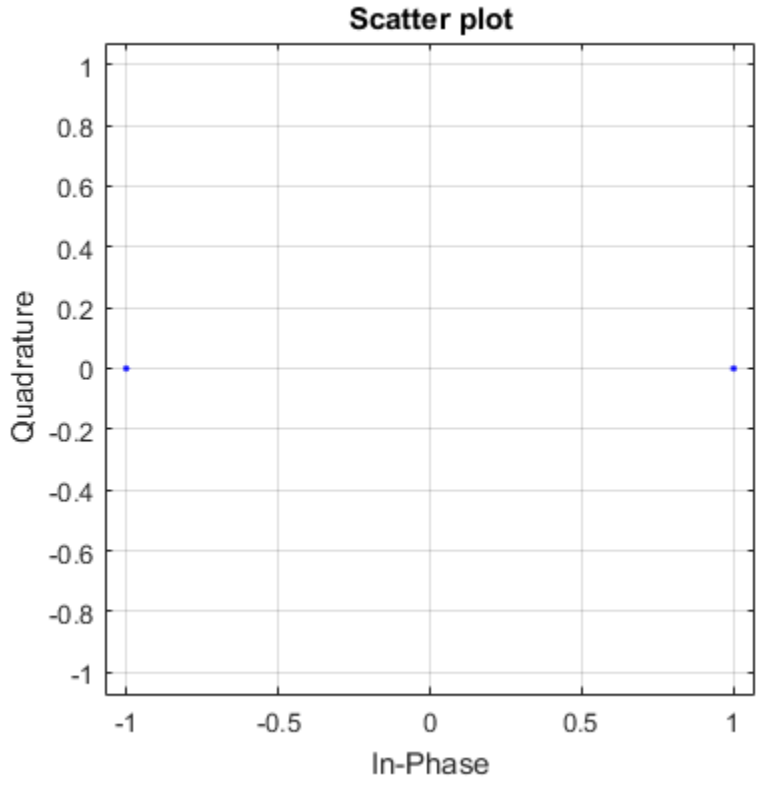
`s = lteSSSS(ue)` returns a 124-by-1 complex column vector containing the secondary sidelink synchronization signal (SSSS) values for user equipment settings in the `ue` structure. For more information, see “Secondary Sidelink Synchronization Signal” on page 1-1278.

Examples

Generate SSSS

Generate and plot the BPSK sidelink secondary synchronization signal values for NSLID = 10.

```
ssss = lteSSSS(struct('NSLID',10));
scatterplot(ssss)
grid
```



Generate All SSSS Sequences

Generate all possible SSSS sequences, contained as columns in a 124-by-336 matrix.

```
ssssfn = @(x)lteSSSS(struct('NSLID',x));
allssss = cell2mat(arrayfun(ssssfn,[0:335],'UniformOutput',false));
```

Input Arguments

ue — User equipment settings

structure

User equipment settings, specified as a structure containing the following field.

`NSLID` — Physical layer sidelink synchronization identity
integer from 0 to 335

Physical layer sidelink synchronization identity, specified as an integer from 0 to 335. ($N_{\mathrm{ID}}^{\mathrm{SL}}$)

For more information, see "Secondary Sidelink Synchronization Signal" on page 1-1278.

Example: 6

Data Types: `double`

Output Arguments

`s` — SSSS values
complex-valued numeric column vector

SSSS values, returned as a 124-by-1 complex-valued numeric column vector. These values are created for the user equipment settings in the `ue` structure. For more information, see "Secondary Sidelink Synchronization Signal" on page 1-1278.

Definitions

Secondary Sidelink Synchronization Signal

The secondary sidelink synchronization signal (SSSS) is transmitted in the central 62 resource elements of two adjacent SC-FDMA symbols in a synchronization subframe. The same sequence of 62 complex values is repeated in each of the symbols, resulting in a 124-by-1 element vector returned by the `lteSSSS` function. The values of this sequence are ordered as they should be mapped into the resource elements of the adjacent symbols using `lteSSSSIndices`. If a terminal is transmitting SSSS, then the SSSS should be sent every 40 ms with the exact subframe dependent on the RCC signaled subframe number offset (*syncOffsetIndicator-r12*). The SSSS is sent on antenna port 1020, along with the primary sidelink synchronization signal (PSSS). A synchronization subframe also contains the PSBCH, which is sent on antenna port 1010. The transmission power of the SSSS symbols should be the same as the PSBCH therefore they should be scaled by $\sqrt{72/62}$ in a subframe. No PSCCH or PSSCH transmission will occur in a sidelink subframe configured for synchronization purposes.

As specified in TS 36.211, Section 9.7, the SSSS identity assignment depends on the network coverage. The set of all $N_{\mathrm{ID}}^{\mathrm{SL}}$ is divided into two sets, id_net {0, ..., 167} and id_oon {168, ..., 335}, which are used by terminals that are in-network and out-of-network coverage, respectively. The sidelink physical layer cell identity number, $N_{\mathrm{ID}}^{\mathrm{SL}}$, corresponds to the `lteSSSS` input UE settings structure field `ue.NSLID`. Within each set, all identities result in the same SSSS. For an in-network terminal, the `ue.NSLID` value corresponds to the RRC sidelink synchronization signal identity (*slssid-r12*) associated with the cell.

Secondary Sidelink Synchronization Signal Indexing

Use the indexing function, `lteSSSSIndices`, and the corresponding sequence function, `lteSSSS`, to populate the resource grid for the desired subframe number. The SSSS values are output by `lteSSSS`, ordered as they should be mapped, applying frequency-first mapping into the resource elements of the adjacent symbols using `lteSSSSIndices`. When indexing is zero-based, the SC-FDMA symbols used are {11,12} for normal cyclic prefix and {9, 10} for extended cyclic prefix.

Note: The indicated symbol indices are based on TS 36.211, Section 9.7. However to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePSSS` | `lteSSS` | `lteSSSSIndices`

Topics

"Resource Grid Indexing"

Introduced in R2016b

lteSSSSIndices

SSSS resource element indices

Syntax

```
ind = lteSSSSIndices(ue)
ind = lteSSSSIndices(ue,opts)
```

Description

`ind = lteSSSSIndices(ue)` returns a 124-by-1 complex column vector of resource element (RE) indices for the secondary sidelink synchronization signal (SSSS) values given the user equipment settings structure. By default, the indices are returned in one-based linear indexing form. You can use this form to directly index elements of a matrix representing the subframe resource grid for antenna port 1020. For more information, see “Secondary Sidelink Synchronization Signal Indexing” on page 1-1286.

`ind = lteSSSSIndices(ue,opts)` formats the returned indices using options defined in `opts`.

Examples

Generate SSSS Indices

Generate SSSS values and indices. Write the values into the SSSS resource elements in a synchronization subframe (extended cyclic prefix) and display an image of their locations.

Create a user equipment settings structure and a resource grid that has a 10 MHz bandwidth and extended cyclic prefix.

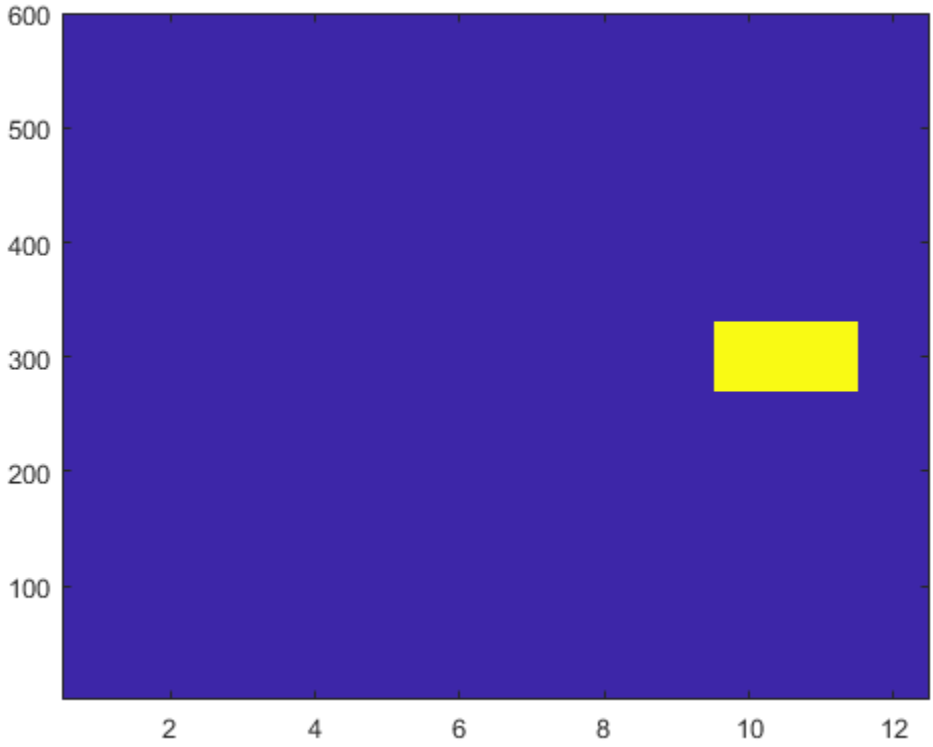
```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Extended';
ue.NSLID = 1;
```

```
subframe = lteSLResourceGrid(ue);
```

Generate SSSS indices and display the first five indices. Load the SSSS symbols into the resource grid. Display an image showing the SSSS symbol locations.

```
ssss_indices = lteSSSSIndices(ue);
ssss_indices(1:5)

subframe(ssss_indices) = lteSSSS(ue);
image(100*abs(subframe))
axis xy
```

```
ans =

  5×1 uint32 column vector

   5670
   5671
   5672
   5673
   5674
```



Generate Zero-Based SSSS Indices

Generate SSSS indices using zero-based indexing style. Compare these indices to one-based indices.

Create a user equipment settings structure that has a 10 MHz bandwidth and extended cyclic prefix.

```
ue.NSLRB = 50;
ue.CyclicPrefixSL = 'Extended';
ue.NSLID = 1;
```

Generate SSSS zero-based indices and view the first five indices.

```
ssss_indices = lteSSSSIndices(ue,'0based');
ssss_indices_size = size(ssss_indices)
ssss_indices(1:5)
```

```
ssss_indices_size =

   124     1


ans =

  5×1 uint32 column vector

   5669
   5670
   5671
   5672
   5673
```

Generate SSSS one-based indices and view the first five indices.

```
ssss_indices = lteSSSSIndices(ue,'1based');
ssss_indices_size = size(ssss_indices)
ssss_indices(1:5)
```

```
ssss_indices_size =

   124     1


ans =

  5×1 uint32 column vector

   5670
   5671
   5672
   5673
   5674
```

For zero-based indexing, the first assigned index is one lower than the one-based indexing style.

Input Arguments

`ue` — User equipment settings

structure

User equipment settings, specified as a structure. `ue` contains the following fields.

`NSLRB` — Number of sidelink resource blocks

integer scalar from 6 to 110

Number of sidelink resource blocks, specified as an integer scalar from 6 to 110. ($N_{\mathrm{RB}}^{\mathrm{SL}}$)

Example: `6`, which corresponds to a channel bandwidth of 1.4 MHz.

Data Types: `double`

`CyclicPrefixSL` — Cyclic prefix length

`'Normal'` (default) | `'Extended'` | optional

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`opts` — Output format options for resource element indices

{`'ind'`, `'1based'`} (default) | character vector | cell array of character vectors | optional

Output format options for resource element indices, specified as `'ind'` or `'sub'`, and `'1based'` or `'0based'`. You can specify a format for the *indexing style* and *index base*.

Category	Options	Description
Indexing style	`'ind'` (default)	The returned indices are in linear index style.
	`'sub'`	The returned indices are in `[subcarrier,symbol,port]` subscript row style.

Category	Options	Description
Index base	`'1based'` (default)	The returned indices are one-based.
	`'0based'`	The returned indices are zero-based.

Example: `'sub'` returns indices in subscript row style using the default one-based indexing style.

Data Types: `char | cell`

Output Arguments

`ind` — SSSS resource element indices

integer column vector | three-column integer matrix

SSSS resource element indices, returned as an integer column vector or a three-column integer matrix. This output is generated using the cell-wide settings structure, `ue`. For more information, see “Secondary Sidelink Synchronization Signal Indexing” on page 1-1286.

Data Types: `uint32`

Definitions

Secondary Sidelink Synchronization Signal Indexing

Use the indexing function, `lteSSSSIndices`, and the corresponding sequence function, `lteSSSS`, to populate the resource grid for the desired subframe number. The SSSS values are output by `lteSSSS`, ordered as they should be mapped, applying frequency-first mapping into the resource elements of the adjacent symbols using `lteSSSSIndices`. When indexing is zero-based, the SC-FDMA symbols used are {11,12} for normal cyclic prefix and {9, 10} for extended cyclic prefix.

Note: The indicated symbol indices are based on TS 36.211, Section 9.7. However to align with the LTE System Toolbox subframe orientation, these indices are expanded from symbol index per slot to symbol index per subframe.

For more information on mapping symbols to the resource element grid, see “Resource Grid Indexing”.

Secondary Sidelink Synchronization Signal

The secondary sidelink synchronization signal (SSSS) is transmitted in the central 62 resource elements of two adjacent SC-FDMA symbols in a synchronization subframe. The same sequence of 62 complex values is repeated in each of the symbols, resulting in a 124-by-1 element vector returned by the `lteSSSS` function. The values of this sequence are ordered as they should be mapped into the resource elements of the adjacent symbols using `lteSSSSIndices`. If a terminal is transmitting SSSS, then the SSSS should be sent every 40 ms with the exact subframe dependent on the RCC signaled subframe number offset (*syncOffsetIndicator-r12*). The SSSS is sent on antenna port 1020, along with the primary sidelink synchronization signal (PSSS). A synchronization subframe also contains the PSBCH, which is sent on antenna port 1010. The transmission power of the SSSS symbols should be the same as the PSBCH therefore they should be scaled by $\sqrt{72/62}$ in a subframe. No PSCCH or PSSCH transmission will occur in a sidelink subframe configured for synchronization purposes.

As specified in TS 36.211, Section 9.7, the SSSS identity assignment depends on the network coverage. The set of all $N_{\mathrm{ID}}^{\mathrm{SL}}$ is divided into two sets, id_net {0, ..., 167} and id_oon {168, ..., 335}, which are used by terminals that are in-network and out-of-network coverage, respectively. The sidelink physical layer cell identity number, $N_{\mathrm{ID}}^{\mathrm{SL}}$, corresponds to the `lteSSSS` input UE settings structure field `ue.NSLID`. Within each set, all identities result in the same SSSS. For an in-network terminal, the `ue.NSLID` value corresponds to the RRC sidelink synchronization signal identity (*slssid-r12*) associated with the cell.

References

[1] 3GPP TS 36.211. “Physical Channels and Modulation.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePSSSIndices` | `lteSSSIndices` | `lteSSSS`

Topics

"Resource Grid Indexing"

Introduced in R2016b

lteSymbolDemodulate

Demodulation and symbol to bit conversion

Syntax

```
out = lteSymbolDemodulate(in,mod)
out = lteSymbolDemodulate(in,mod,dec)
```

Description

`out = lteSymbolDemodulate(in,mod)` returns a column vector containing bits resulting from soft constellation demodulation of complex values in vector `in`. The demodulation algorithm assumes the vector of received symbols are normalized to fall on constellation points as defined by `in`. `lteSymbolModulate` provides an output with the expected constellation scaling.

`out = lteSymbolDemodulate(in,mod,dec)` allows the decision mode, `dec`, to be specified as either `'Hard'` or `'Soft'`.

Examples

Demodulate Complex-Valued Symbols

```
Use |'Hard'| decision to demodulate complex valued symbols.

out = lteSymbolDemodulate([0.7 - 0.7i; -0.7 + 0.7i],'QPSK','Hard')
```

```
out =

     0
     1
     1
     0
```

Input Arguments

`in` — Input symbols to demodulate

numeric column vector

Input symbols to demodulate, specified as a column vector of complex numeric values. Demodulation is performed assuming the input constellation power normalization in accordance with TS 36.211, Section 7.1 [2], as follows:

- `1/sqrt(2)` for `'BPSK'` and `'QPSK'`
- `1/sqrt(10)` for `'16QAM'`
- `1/sqrt(42)` for `'64QAM'`
- `1/sqrt(170)` for `'256QAM'`

Example: For `'BPSK'` and `'QPSK'` `[0.707 - 0.707i; -0.707 + 0.707i]`

Data Types: `double`
Complex Number Support: Yes

`mod` — Modulation format

`'BPSK' | 'QPSK' | '16QAM' | '64QAM' | '256QAM'`

Modulation format, specified as `'BPSK'`, `'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`.

Data Types: `char`

`dec` — Decision mode

`'Hard' | 'Soft'`

Decision mode, specified as `'Hard'` or `'Soft'`.

Data Types: `char`

Output Arguments

`out` — Demodulated output bits

numeric column vector

Demodulated output bits, returned as a numeric column vector. This argument contains bits resulting from soft constellation demodulation of complex values vector, `in`.

`'Hard'` decision mode results in the output containing the bit sequences corresponding to the closest constellation points to the input.

`'Soft'` decision mode results in the output indicating the bit values using the sign (`-ve` for 0, `+ve` for 1). For `'Soft'` decision mode, the magnitude of the output gives a piecewise linear approximation to the log likelihood ratio (LLR) of the demodulated bits. The algorithm used for the LLR approximation is described in [1]. The returned LLRs are scaled such that for a input signal lying on the constellation points in the preceding description, the output values lie on the points with the following magnitudes.

- `1` for `'BPSK'`
- `1/sqrt(2)` for `'QPSK'`
- `[1 3]/sqrt(10)` for `'16QAM'`
- `[1 3 5 7]/sqrt(42)` for `'64QAM'`
- `[1 3 5 7 9 11 13 15]/sqrt(170)` for `'256QAM'`

Data Types: `double`

References

[1] Tosato, F., and Bisaglia, P. "Simplified soft-output demapper for binary interleaved COFDM with application to HIPERLAN/2." *IEEE International Conference on Communications (ICC) 2002, Vol. 2*. pp. 664-668.

[2] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteLayerDemap` | `lteSymbolModulate` | `lteULDescramble`

Introduced in R2014a

lteSymbolModulate

Symbol modulation

Syntax

```
out = lteSymbolModulate(in,mod)
```

Description

`out = lteSymbolModulate(in,mod)` maps the bit values, `in`, to complex modulation symbols with the modulation scheme specified in `mod`.

Examples

Generate QPSK Modulated Symbols

Map bit values to QPSK modulated symbols.

```
out = lteSymbolModulate([0; 1; 1; 0], 'QPSK')
```

```
out =

   0.7071 - 0.7071i
  -0.7071 + 0.7071i
```

Input Arguments

`in` — Input bits

column vector | cell array

Input bits, specified as a column vector, where each bit is either 0 or 1. The vector length must be a multiple of 2 for QPSK modulation, 4 for 16-QAM modulation, 6 for 64-QAM modulation and 8 for 256-QAM modulation. The bit values must be 0 or 1.

Alternatively, specify `in` as a cell array containing one bit vector or a cell array containing two bit vectors.

Data Types: `double` | `cell`

`mod` — Modulation scheme

`'BPSK'` | `'QPSK'` | `'16QAM'` | `'64QAM'` | `'256QAM'` | cell array

Modulation scheme, specified as `'BPSK'`, `'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`.

Alternately, you can specify `mod` as a cell array of one or two modulation schemes. The number of modulation schemes in `mod` cannot exceed the number of bit vectors specified by `in`. If `in` specifies two bit vectors and `mod` specifies one modulation scheme, the same modulation is used for both bit vectors.

Data Types: `char` | `cell`

Output Arguments

`out` — Complex modulated output symbols

column vector

Complex modulated output symbols, returned as a column vector. The symbols use the modulation scheme specified in `mod`.

Data Types: `double`
Complex Number Support: Yes

See Also

See Also

`lteDLPrecode` | `lteLayerMap` | `lteSymbolDemodulate` | `lteULScramble`

Introduced in R2014a

lteTBS

Transport block size lookup

Use `lteTBS` to look up transport block sizes as defined in TS 36.213 [1], Section 7.1.7.2 tables. The tables are Release 12 compliant and contain 34 TBS values for each of the 111 number of physical resource blocks entries. The first 27 table entries are the Release 8–Release 11 compatible TBSs.

Syntax

```
tbs = lteTBS(nprb)
tbs = lteTBS(nprb,itbs)
tbs = lteTBS(nprb,itbs,smnlayer)
```

Description

`tbs = lteTBS(nprb)` returns the column of TS 36.213 [1], Table 7.1.7.2.1-1 for the number of physical resource blocks, `nprb`, specified. Table 7.1.7.2.1-1 is for transport blocks not mapped to two or more spatial multiplexing layers. The returned column vector, `tbs`, has 34 elements, corresponding to transport block size indices from 0 to 33.

`tbs = lteTBS(nprb,itbs)` uses an additional input, `itbs` (a vector of transport block size indices from 0 to 33) to restrict returned vector of values. A value in the `itbs` vector equal to –1, indicates a discontinuous transmission (DTX) and `lteTBS` produces a corresponding `tbs` value of 0.

`tbs = lteTBS(nprb,itbs,smnlayer)` uses an additional input, `smnlayer` to indicate the number of spatial multiplexing layers to which the transport block is mapped. This combines TS 36.213 [1], Table 7.1.7.2.1-1 with the appropriate spatial layer TBS translation table:

- For 2-layer spatial multiplexing, the function follows the rules in TS 36.213 [1], Section 7.1.7.2.2.
- For 3-layer spatial multiplexing, the function follows the rules in TS 36.213 [1], Section 7.1.7.2.4.
- For 4-layer spatial multiplexing, the function follows the rules in TS 36.213 [1], Section 7.1.7.2.5.

For transmission schemes that do not support spatial multiplexing (`'Port0','TxDiversity','Port5','Port8'`), set `smnlayer = 1`.

Examples

Generate Transport Block Sizes for Release 12

Generate the set of 34 transport block sizes from TS 36.213, Table 7.1.7.2.1-1 (Release 12) that are valid for a single PRB allocation.

```
tbs = lteTBS(1)
```

```
tbs =

  34×1 int32 column vector

    16
    24
    32
    40
    56
    72
   328
   104
   120
   136
   144
   176
   208
   224
   256
   280
   328
   336
   376
   408
   440
   488
   520
   552
   584
   616
```

```
   712
   648
   680
   712
   776
   808
   840
   968
```

Generate Transport Block Sizes for Three Spatial Layers

Generate the set of 27 Release 8-Release 11 transport block sizes for a single PRB allocation and 3 spatial layers.

```
nprb = 1;
itbs = 0:26;
smnlayer = 3;

tbs = lteTBS(nprb, itbs, smnlayer)
```

```
tbs =

  27×1 int32 column vector

    56
    88
   144
   176
   208
   224
   256
   328
   392
   456
   504
   584
   680
   744
   840
   904
   968
  1064
  1160
```

```
1288
1384
1480
1608
1736
1800
1864
2216
```

Input Arguments

`nprb` — Number of physical resource blocks

1,...,110

Number of physical resource blocks, specified as a positive scalar integer from 1 to 110.

Data Types: `double`

`itbs` — Transport block size indices

numeric vector

Transport block size indices, specified as a numeric vector.

Data Types: `double`

`smnlayer` — Number of spatial multiplexing layers to which transport block is mapped

1,...,4

Number of spatial multiplexing layers to which transport block is mapped, specified as a positive scalar integer from 1 to 4.

Data Types: `double`

Output Arguments

`tbs` — Transport block size or sizes

column vector | nonnegative integer

Transport block size or sizes, returned as a column vector of nonnegative integers from the transport block size table in TS 36.213, Section 7.1.7.2 [1]. This vector contains up to 34 rows, corresponding to TBS indices from 0 to 33.

Data Types: `int32`

References

[1] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteDLSCH` | `lteMCS` | `ltePDSCH` | `ltePUSCH` | `lteULSCH`

Introduced in R2014a

lteTestModel

Downlink test model configuration structure

Syntax

```
tm = lteTestModel(tmn,bw)
tm = lteTestModel(tmn,bw,ncellid,duplexmode)
tm = lteTestModel(tmcfg)
```

Description

`tm = lteTestModel(tmn,bw)` returns the E-UTRA test model (E-TM) configuration structure for given test model number and bandwidth. The output structure, `tm`, contains the configuration parameters required to generate a given downlink E-TM waveform using the generator tool, `lteTestModelTool`. The field names and default values align with those defined in TS 36.141 [1], Section 6.1.

The `PDSCH` is a substructure relating to the physical channel configuration and contains the fields `NLayers`, `TxScheme`, and `Modulation`.

`tm = lteTestModel(tmn,bw,ncellid,duplexmode)` controls the configuration of the physical cell identity, `ncellid`, and duplex mode, `duplexmode`.

`tm = lteTestModel(tmcfg)` returns `tm`, a configuration structure for the test model partially (or wholly) defined by the input structure `tmcfg`. The input structure `tmcfg` can define any (or all) of the parameters or substructure parameters and the output structure `tm` retains the defined parameters. The undefined fields are given appropriate default values.

The `tm` structure can be used with the E-TM generator tool to generate a waveform.

Examples

Create Downlink E-TM Configuration Structure

Create the configuration structure for Test Model TS 36.141 E-TM 3.2, 20MHz.

Specify an E-TM 3.2 test model number and 20-MHz channel bandwidth. Create a test model configuration structure and view the contents.

```
tmn = '3.2';
bw  = '20MHz';

tm = lteTestModel(tmn, bw)
tm.PDSCH
```

```
tm =

  struct with fields:

                    TMN: '3.2'
                     BW: '20MHz'
                  NDLRB: 100
                CellRefP: 1
                 NCellID: 1
            CyclicPrefix: 'Normal'
                    CFI: 1
                     Ng: 'Sixth'
           PHICHDuration: 'Normal'
               NSubframe: 0
            TotSubframes: 10
               Windowing: 0
              DuplexMode: 'FDD'
                   PDSCH: [1×1 struct]
             CellRSPower: 0
                PSSPower: 2.4260
                SSSPower: 2.4260
               PBCHPower: 2.4260
             PCFICHPower: 0
      NAllocatedPDCCHREG: 180
              PDCCHPower: 1.1950
       PDSCHPowerBoosted: 2.4260
     PDSCHPowerDeboosted: -3


ans =

  struct with fields:

      TxScheme: 'Port0'
    Modulation: {'16QAM'  'QPSK'}
```

```
NLayers: 1
```

Input Arguments

`tmn` — Test model number

`'1.1'` | `'1.2'` | `'2'` | `'2a'` | `'3.1'` | `'3.1a'` | `'3.2'` | `'3.3'`

Test model number, specified as a character vector. See TS 36.141 [1] for information on the test models.

Data Types: `char`

`bw` — Channel bandwidth

`'1.4MHz'` | `'3MHz'` | `'5MHz'` | `'10MHz'` | `'15MHz'` | `'20MHz'` | `'9RB'` | `'11RB'` | `'27RB'` | `'45RB'` | `'64RB'` | `'91RB'`

Channel bandwidth, specified as a character vector. You can set the nonstandard bandwidths, `'9RB'`, `'11RB'`, `'27RB'`, `'45RB'`, `'64RB'`, and `'91RB'`, only when `tmn` is `'1.1'`. These nonstandard bandwidths specify custom test models.

Data Types: `char`

`ncellid` — Physical layer cell identity

1 for standard bandwidths and 10 for non-standard bandwidths (default) | optional | integer from 0 to 503

Physical layer cell identity, specified as a integer from 0 to 503. If not specified, defaults to 1 for standard bandwidths and 10 for non-standard bandwidths.

Data Types: `double`

`duplexmode` — Duplex mode

`'FDD'` (default) | `'TDD'` | optional

Duplex mode, specified as `'FDD'` or `'TDD'`.

Data Types: `char`

`tmcfg` — Test model configuration

scalar structure

Test model configuration, specified as a scalar structure. Refer to the output `tm` for structure fields. Define any or all listed parameters or substructure parameters in the input structure, `tmcfg`. The output structure, `tm`, retains the defined parameters and appropriate defaults are assigned for undefined fields.

Data Types: `struct`

Output Arguments

`tm` — E-UTRA test model (E-TM) configuration

scalar structure

E-UTRA test model (E-TM) configuration, returned as a scalar structure. `tm` contains the following fields.

Parameter Field	Values	Description
`TMN`	`'1.1'`, `'1.2'`, `'2'`, `'2a'`, `'3.1'`, `'3.1a'`, `'3.2'`, `'3.3'`	Test model number
`BW`	`'1.4MHz'`, `'3MHz'`, `'5MHz'`, `'10MHz'`, `'15MHz'`, `'20MHz'`, `'9RB'`, `'11RB'`, `'27RB'`, `'45RB'`, `'64RB'`, `'91RB'`,	Channel bandwidth, in MHz, returned as a character vector. Non-standard bandwidths, `'9RB'`, `'11RB'`, `'27RB'`, `'45RB'`, `'64RB'`, and `'91RB'`, specify custom test models.
`NDLRB`	Nonnegative integer	Number of downlink resource blocks. ($N_{\mathrm{RB}}^{\mathrm{DL}}$)
`CellRefP`	1	Number of cell-specific reference signal antenna ports. This argument is for informational purposes and is read-only.
`NCellID`	Integer from 0 to 503	Physical layer cell identity
`CyclicPref`	`'Normal'`	Cyclic prefix length. This argument is for informational purposes and is read-only.
`CFI`	1, 2, or 3	Control format indicator value
`Ng`	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier

Parameter Field	Values	Description
PHICHDurat	`'Normal'`, `'Extended'`	PHICH duration
NSubframe	0 (default), nonnegative scalar integer	Subframe number This argument is for informational purposes and is read-only.
TotSubfram	Nonnegative scalar integer	Total number of subframes to generate
Windowing	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied
DuplexMode	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
CellRSPowe	Numeric value	Cell-specific reference symbol power adjustment, in dB
PDSCH	Scalar structure	PDSCH transmission configuration substructure
PSSPower	Numeric value	Primary synchronization signal (PSS) symbol power adjustment, in dB
SSSPower	Numeric value	Secondary synchronization signal (SSS) symbol power adjustment, in dB
PBCHPower	Numeric value	PBCH symbol power adjustment, in dB
PCFICHPowe	Numeric value	PCFICH symbol power adjustment, in dB
NAllocated	Nonnegative integer	Number of allocated PDCCH REGs. This argument is derived from `tmn` and `bw`.
PDCCHPower	Numeric value	PDCCH symbol power adjustment, in dB
PDSCHPower	Numeric value	PDSCH symbol power adjustment, in dB, for the boosted physical resource blocks (PRBs)
PDSCHPower	Numeric value	PDSCH symbol power adjustment, in dB, for the de-boosted physical resource blocks (PRBs)
These fields are present only when `DuplexMode` is set to `'TDD'`.		

Parameter Field	Values	Description
SSC	Integer from 0 to 9 8 (default)	Special subframe configuration (SSC) `SSC` enumerates the special subframe configuration. TS 36.211 [2], Section 4.2 specifies the special subframe configurations (lengths of DwPTS, GP, and UpPTS).
TDDConfi	Integer from 1 to 6 3 (default)	Uplink–downlink configuration `TDDConfig` enumerates the subframe uplink-downlink configuration to be used in this frame. TS 36.211 [2], Section 4.2 specifies uplink-downlink configurations (uplink, downlink, and special subframe combinations).

PDSCH substructure

The substructure PDSCH relates to the physical channel configuration and contains these fields:

Parameter Field	Values	Description
NLayers	1	Number of transmission layers, returned as 1. This argument is for informational purposes and is read-only.
TxScheme	`'Port0'`	Transmission scheme. The E-TMs have a single antenna port. This argument is for informational purposes and is read-only.
Modulation	Cell array of these one or two character vectors. (`'QPSK'`, `'16QAM'`, `'64QAM'`, `'256QAM'`)	Modulation formats, specifying the modulation formats for boosted and deboosted PRBs. This argument is for informational purposes and is read-only.

Data Types: `struct`

References

[1] 3GPP TS 36.141. "Base Station (BS) conformance testing." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical channels and modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteRMCDL` | `lteRMCUL` | `lteTestModelTool`

Introduced in R2014a

lteTestModelTool

Downlink test model waveform generation

Syntax

```
[waveform,grid,tm] = lteTestModelTool
[waveform,grid,tm] = lteTestModelTool(tmn,bw,ncellid,duplexmode)
[waveform,grid,tm] = lteTestModelTool(tm)
```

Description

`[waveform,grid,tm] = lteTestModelTool` starts a user interface for the parameterization and generation of the E-UTRA test model (E-TM) waveforms. The main function outputs can be configured in the user interface or assigned to variables in a function call. The E-TM time-domain waveform, plus associated resource element grid and test model configuration structure are output.

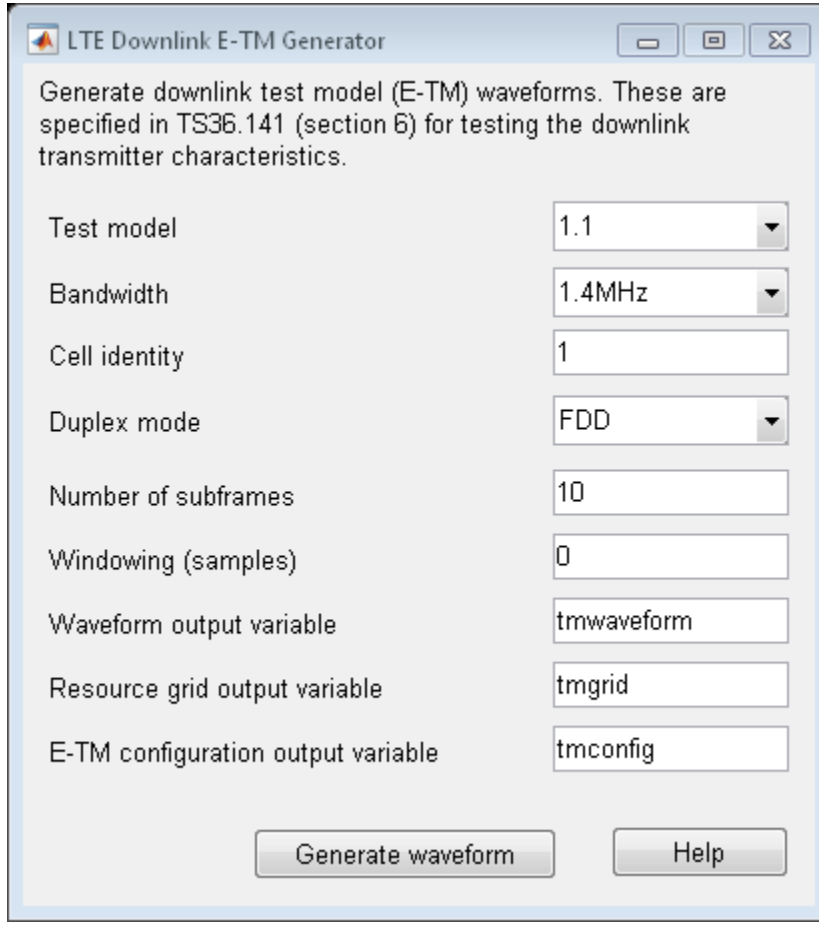
`[waveform,grid,tm] = lteTestModelTool(tmn,bw,ncellid,duplexmode)` accepts inputs for the test model number and channel bandwidth for the generated waveform. Optionally, accepts inputs for the physical cell identity and duplex mode.

`[waveform,grid,tm] = lteTestModelTool(tm)` where a user-defined test model configuration structure is provided as an input.

Examples

Open LTE Test Model Generator App

```
lteTestModelTool
```



The LTE Downlink E-TM Generator user interface opens. Adjust settings and output varable names as desired.

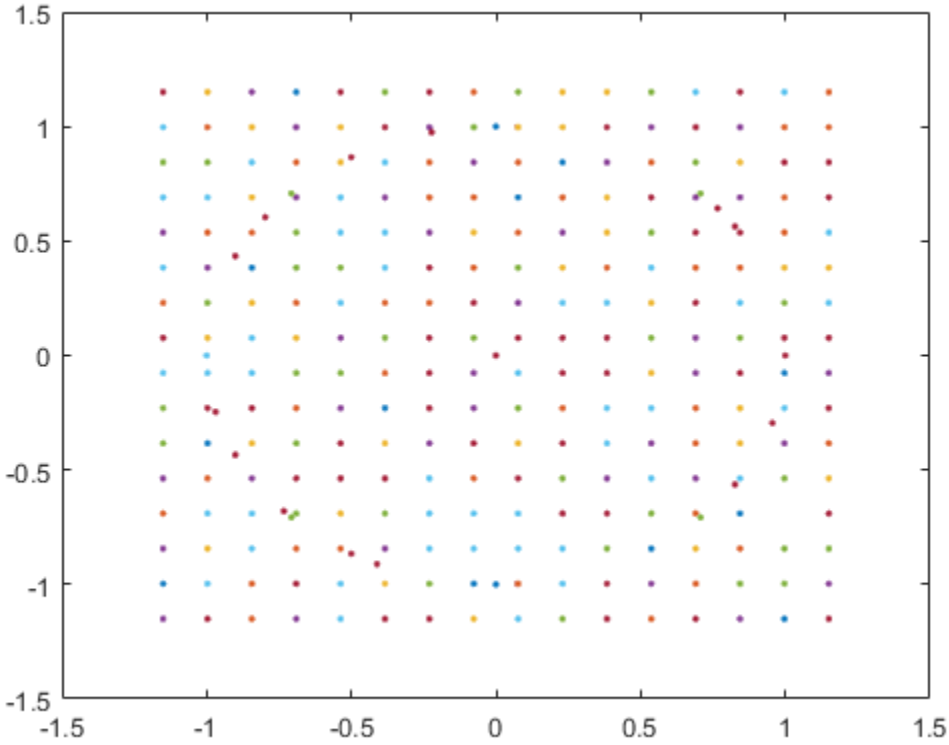
After you click the *Generate waveform* button the specifed waveform, resource grid, and configuration variables will be available in the workspace.

Generate Downlink E-TM 2a Waveform

Generate a time domain signal, `txWaveform`, and a 2-dimensional array of the Resource Elements, `txGrid`, for Test Model TS 36.141 E-TM 2a with 10MHz bandwidth. This is a 256QAM E-TM.

Specify test model number and bandwidth. Generate `txWaveform`. Plot the `txGrid` output.

```
[txWaveform,txGrid,tm] = lteTestModelTool('2a','10MHz');
plot(txGrid,'.')
```



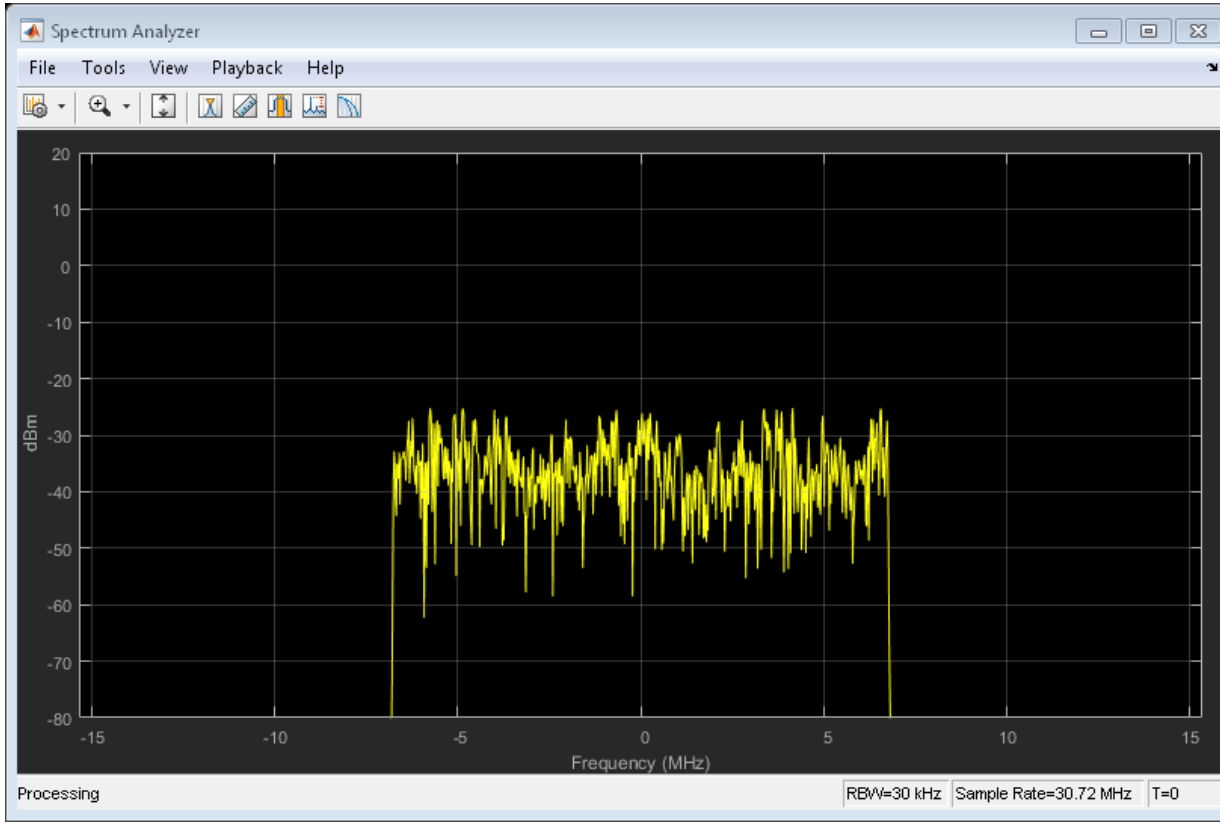
The plot of all the complex resource element symbols in the frame is dominated by the 256QAM PDSCH constellation.

Generate Downlink Waveform Using Full E-TM Configuration Structure

Generate a time domain signal, `txWaveform`, and a 2-dimensional array of the Resource Elements, `txGrid`, for Test Model TS 36.141 E-TM 3.2 with 15MHz bandwidth.

Specify test model number and bandwidth for `tmCfg` configuration structure and create it. Generate `txWaveform`. View the waveform with a spectrum anaylzer.

```
tmn = '3.2';
bw = '15MHz';
tmCfg = lteTestModel(tmn,bw);

[txWaveform,txGrid,tm] = lteTestModelTool(tmCfg);

saScope = dsp.SpectrumAnalyzer('SampleRate', tm.SamplingRate);
saScope(txWaveform)
```



- “Generate a Test Model”

- “Generate LTE Test Model Waveforms”

Input Arguments

`tmn` — Test model number

`'1.1' | '1.2' | '2a' | '2' | '3.1' | '3.1a' | '3.2' | '3.3'`

Test model number, specified as a character vector. For more information on these test model numbers, see TS 36.141 [1], Section 6.1.

Example: `'3.2'`

Data Types: `char`

`bw` — Channel bandwidth

`'1.4MHz' | '3MHz' | '5MHz' | '10MHz' | '15MHz' | '20MHz' | '9RB' | '11RB' | '27RB' | '45RB' | '64RB' | '91RB'`

Channel bandwidth, specified as a character vector. You can set the nonstandard bandwidths, `'9RB'`,`'11RB'`,`'27RB'`,`'45RB'`,`'64RB'`, and `'91RB'`, only when `tmn` is `'1.1'`. These nonstandard bandwidths specify custom test models.

Example: `'15MHz'`

Data Types: `char`

`ncellid` — Physical layer cell identity

1 or 10 (default) | optional | integer

Physical layer cell identity, specified as a integer. If you do not specify this argument, the default is 1 for standard bandwidths and 10 for non-standard bandwidths.

Example: 1

Data Types: `double`

`duplexmode` — Duplex mode of the generated waveform

`'FDD'` (default) | optional | `'TDD'`

Duplex mode of the generated waveform, specified as `'FDD'` or `'TDD'`. Optional.

Example: `'FDD'`

Data Types: `char`

`tm` — User-defined test model configuration

scalar structure

User-defined test model configuration, specified as a scalar structure. You can use `lteTestModel` to generate the various `tm` configuration structures as per TS 36.141, Section 6 [1]. This configuration structure then can be modified as per requirements and used to generate the `waveform`.

Data Types: `struct`

Output Arguments

`waveform` — Generated E-TM time-domain waveform

numeric matrix

Generated E-TM time-domain waveform, returned as a T-by-P numeric matrix, where P is the number of antennas and T is the number of time-domain samples. TS 36.141 [1], Section 6 fixes $P = 1$, making `waveform` a T-by-1 column vector.

Data Types: `double`
Complex Number Support: Yes

`grid` — Resource grid

2-D numeric array

Resource grid, returned as a 2-D numeric array of resource elements for a number of subframes across a single antenna port. The number of subframes (10 for FDD and 20 for TDD), start from subframe zero, across a single antenna port, as specified in TS 36.141 [1], Section 6.1. Resource grids are populated as described in “Data Structures”.

Data Types: `double`
Complex Number Support: Yes

`tm` — Test model configuration

scalar structure

E-UTRA test model (E-TM) configuration, returned as a scalar structure. `tm` contains the following fields.

Test model configuration, returned as a scalar structure containing information about the OFDM modulated waveform as described in `lteOFDMInfo` and test model specific

configuration parameters as described in `lteTestModel`. These fields are included in the output structure:

Parameter Field	Values	Description
TMN	`'1.1'`, `'1.2'`, `'2'`, `'2a'`, `'3.1'`, `'3.1a'`, `'3.2'`, `'3.3'`	Test model number
BW	`'1.4MHz'`, `'3MHz'`, `'5MHz'`, `'10MHz'`, `'15MHz'`, `'20MHz'`, `'9RB'`, `'11RB'`, `'27RB'`, `'45RB'`, `'64RB'`, `'91RB'`,	Channel bandwidth type, in MHz, returned as a character vector. Non-standard bandwidths, `'9RB'`, `'11RB'`, `'27RB'`, `'45RB'`, `'64RB'`, and `'91RB'`, specify custom test models.
NDLRB	Nonnegative integer	Number of downlink resource blocks. (N_{RB}^{DL})
CellRefP	1	Number of cell-specific reference signal antenna ports. This argument is for informational purposes and is read-only.
NCellID	Integer from 0 to 503	Physical layer cell identity
CyclicPref	`'Normal'`	Cyclic prefix length. This argument is for informational purposes and is read-only.
CFI	1, 2, or 3	Control format indicator value
Ng	`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
PHICHDurat	`'Normal'`, `'Extended'`	PHICH duration
NSubframe	0 (default), nonnegative scalar integer	Subframe number This argument is for informational purposes and is read-only.
TotSubfram	Nonnegative scalar integer	Total number of subframes to generate
Windowing	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied

Parameter Field	Values	Description
DuplexMode	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
CellRSPowe	Numeric value	Cell-specific reference symbol power adjustment, in dB
PDSCH	Scalar structure	PDSCH transmission configuration substructure
PSSPower	Numeric value	Primary synchronization signal (PSS) symbol power adjustment, in dB
SSSPower	Numeric value	Secondary synchronization signal (SSS) symbol power adjustment, in dB
PBCHPower	Numeric value	PBCH symbol power adjustment, in dB
PCFICHPowe	Numeric value	PCFICH symbol power adjustment, in dB
NAllocated	Nonnegative integer	Number of allocated PDCCH REGs. This argument is derived from `tmn` and `bw`.
PDCCHPower	Numeric value	PDCCH symbol power adjustment, in dB
PDSCHPower	Numeric value	PDSCH symbol power adjustment, in dB, for the boosted physical resource blocks (PRBs)
PDSCHPower	Numeric value	PDSCH symbol power adjustment, in dB, for the de-boosted physical resource blocks (PRBs)
These fields are present only when `DuplexMode` is set to `'TDD'`.		
SSC	Integer from 0 to 9 8 (default)	Special subframe configuration (SSC) `SSC` enumerates the special subframe configuration. TS 36.211 [2], Section 4.2 specifies the special subframe configurations (lengths of DwPTS, GP, and UpPTS).

Parameter Field	Values	Description
TDDConfi	Integer from 1 to 6 3 (default)	Uplink–downlink configuration `TDDConfig` enumerates the subframe uplink-downlink configuration to be used in this frame. TS 36.211 [2], Section 4.2 specifies uplink-downlink configurations (uplink, downlink, and special subframe combinations).
AllocatedP	Numeric array	Allocated physical resource block list
SamplingRa	Numeric value	Sampling rate of the time-domain waveform
Nfft	Positive integer	Number of fast *Fourier* transform (FFT) points

PDSCH substructure

The substructure PDSCH relates to the physical channel configuration and contains these fields:

Parameter Field	Values	Description
NLayers	1	Number of transmission layers, returned as 1. This argument is for informational purposes and is read-only.
TxScheme	`'Port0'`	Transmission scheme. The E-TMs have a single antenna port. This argument is for informational purposes and is read-only.
Modulation	Cell array of these one or two character vectors. (`'QPSK'`, `'16QAM'`, `'64QAM'`, `'256QAM'`)	Modulation formats, specifying the modulation formats for boosted and deboosted PRBs. This argument is for informational purposes and is read-only.

Data Types: `struct`

References

[1] 3GPP TS 36.141. “Base Station (BS) conformance testing.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

[2] 3GPP TS 36.211. "Physical channels and modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

Apps

LTE Test Model Generator

Functions

`lteDLConformanceTestTool` | `lteRMCDLTool` | `lteRMCULTool` | `lteTestModel`

Topics

“Generate a Test Model”
“Generate LTE Test Model Waveforms”

Introduced in R2014a

lteTurboDecode

Turbo decoding

Syntax

```
out = lteTurboDecode(in)
out = lteTurboDecode(in,nturbodecits)
```

Description

`out = lteTurboDecode(in)` returns the result of turbo decoding the input data `in`. The function can decode single data vectors or cell arrays of data vectors. In the case of cell array input, the output is a cell array containing the separately decoded input array vectors. The input data is assumed to be soft bit data that has been encoded with the parallel concatenated convolutional code (PCCC), as defined in TS 36.212 [1], Section 5.1.3.2. Each input data vector is assumed to be structured as three encoded parity streams concatenated in a block-wise fashion, `[S P1 P2]`, where `S` is the vector of systematic bits, `P1` is the vector of encoder 1 bits, and `P2` is the vector of encoder 2 bits. The decoder uses a default value of 5 iteration cycles. It returns the decoded bits in output vector `out` after performing turbo decoding using a sub-log-MAP (Max-Log-MAP) algorithm.

`out = lteTurboDecode(in,nturbodecits)` provides control over the number of turbo decoding iteration cycles via parameter `nturbodecits`. The `nturbodecits` is an optional parameter. If it is not provided, it uses the default value of 5 iteration cycles.

Examples

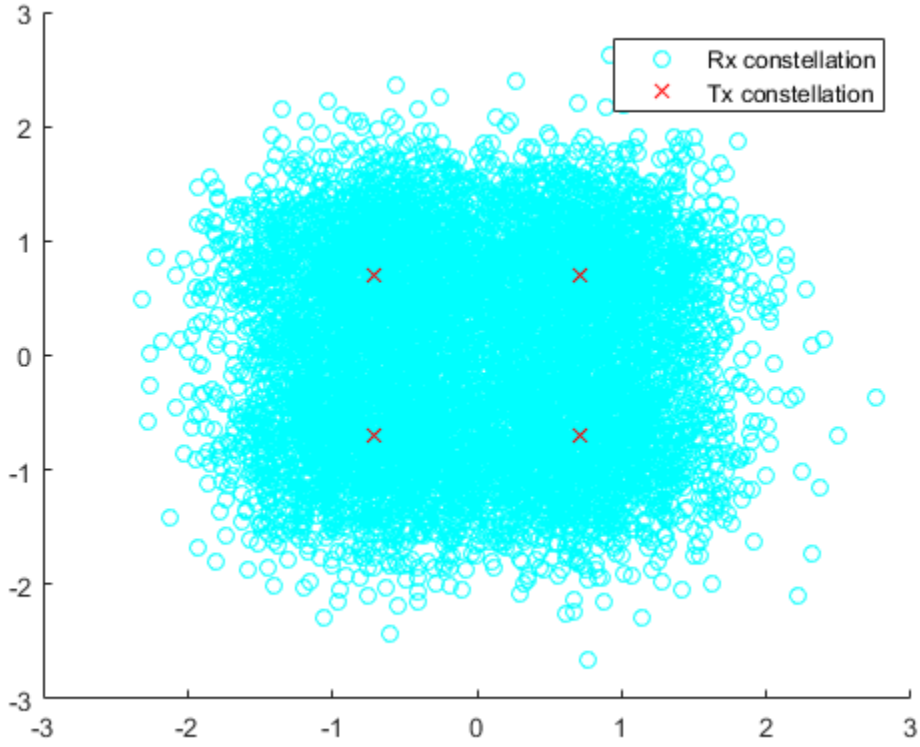
Turbo Decode Input Data

Perform turbo decoding of soft bits obtained from a noisy constellation.

Create a bit stream, turbo encode the bit stream, and modulate it. Create noise, add it to the modulated symbols. Display the transmitted and received symbols on a scatter plot.

```
txBits = randi([0 1],6144,1);
codedData = lteTurboEncode(txBits);
```

```
txSymbols = lteSymbolModulate(codedData,'QPSK');
noise = 0.5*complex(randn(size(txSymbols)),randn(size(txSymbols)));
rxSymbols = txSymbols + noise;

scatter(real(rxSymbols),imag(rxSymbols),'co');
hold on;

scatter(real(txSymbols),imag(txSymbols),'rx')
legend('Rx constellation','Tx constellation')
```



Demodulate the symbols and turbo decode soft bits. Compare the transmitted and recovered bits.

```
softBits = lteSymbolDemodulate(rxSymbols,'QPSK','Soft');
```

```
rxBits = lteTurboDecode(softBits);
numberErrors = sum(rxBits ~= int8(txBits))


numberErrors =

     0
```

Input Arguments

`in` — Soft bit input data

numeric vector | numeric cell array of vectors

Soft bit input data, specified as a numeric vector or a cell array of vectors. The decoder expects the input bits to be encoded with the parallel concatenated convolutional code (PCCC), as defined in TS 36.212 [1], Section 5.1.3.

Data Types: `int8` | `double` | `cell`

`nturbodecits` — Number of turbo decoding iteration cycles

5 (default) | optional | positive scalar integer (1...30)

Number of turbo decoder iteration cycles, specified as a positive scalar integer between 1 and 30. Optional.

Data Types: `double`

Output Arguments

`out` — Turbo decoded bits

integer column vector | cell array of integer column vectors

Turbo decoded bits, returned as an integer column vector or a cell array of integer column vectors.

Data Types: `int8` | `cell`

References

[1] 3GPP TS 36.212. “Multiplexing and channel coding.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCodeBlockDesegment` | `lteConvolutionalDecode` | `lteDLSCHDecode` | `lteRateRecoverTurbo` | `lteTurboEncode` | `lteULSCHDecode`

Introduced in R2014a

lteTurboEncode

Turbo encoding

Syntax

```
out = lteTurboEncode(in)
```

Description

`out = lteTurboEncode(in)` returns the result of turbo encoding the input data, `in`. Only a finite number of acceptable data vector lengths can be coded. For more information, see TS 36.212 [1], Table 5.1.3-3. Filler bits are supported through negative input values.

The encoder is a parallel concatenated convolutional code (PCCC) with two 8-state constituent encoders and a contention-free interleaver. The coding rate of turbo encoder is 1/3. The three encoded parity streams are concatenated block-wise to form the encoded output, `[S P1 P2]`, where `S` is the vector of systematic bits, `P1` is the vector of encoder 1 bits, and `P2` is the vector of encoder 2 bits. To support the correct processing of filler bits, negative input bit values are specially processed. They are treated as logical 0 at the input to both encoders but their negative values are passed directly through to the associated output positions in subblocks `S` and `P1`.

Examples

Turbo Encode Input Data

Perform turbo encoding for a cell array input.

```
bits = lteTurboEncode({ones(40,1),ones(6144,1)})
```

```
bits =

  1×2 cell array
```

```
    [132×1 int8]    [18444×1 int8]
```

Input Arguments

`in` — Input data

numeric vector | numeric cell array of vectors

Input data, specified as a numeric vector or a cell array of vectors.

Data Types: `int8` | `double` | `cell`

Output Arguments

`out` — Turbo encoded bits

integer column vector | cell array of integer column vectors

Turbo encoded bits, returned as an integer column vector or a cell array of integer column vectors. If the input is a cell array, the output is a cell array containing the separately encoded input array vectors.

Data Types: `int8` | `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`lteCodeBlockSegment` | `lteConvolutionalEncode` | `lteDLSCH` | `lteRateMatchTurbo` | `lteTurboDecode` | `lteULSCH`

Introduced in R2014a

lteTransmitDiversityDecode

Orthogonal space frequency block code decoding

Syntax

```
[out,csi] = lteTransmitDiversityDecode(in,hest)
```

Description

`[out,csi] = lteTransmitDiversityDecode(in,hest)` performs orthogonal space frequency block code (OSFBC) decoding of received symbols, `in`, and channel estimate, `hest`, returning the result in `out`.

Examples

Perform OSFBC decoding of PDSCH symbols

This example shows orthogonal space frequency block code (OSFBC) decoding of PDSCH symbols, using ideal channel estimates.

Generate a resource grid using multiple antennas to transmit a single PDSCH codeword.

```
enb = lteRMCDL('R.11');
enb.TotSubframes = 1;
[~,txGrid] = lteRMCDLTool(enb,[1;0;0;1]);
```

Extract the PDSCH symbols from this transmit grid

```
[ind,indInfo] = ltePDSCHIndices(enb,enb.PDSCH,enb.PDSCH.PRBSet);
pdschSym = txGrid(ind);
```

Create an ideal (identity) channel estimate

```
hest = permute(repmat(eye(enb.CellRefP),[1 1 indInfo.Gd]),[3 1 2]);
```

Deprecode the PDSCH symbols using the channel estimates

```
[out,csi] = lteTransmitDiversityDecode(pdschSym,hest);
```

Input Arguments

`in` — Received input symbols

numeric matrix

Received input symbols, specified as a numeric matrix. It has size *M*-by-*NRxAnts*, where *M* is the number of received symbols for each of *NRxAnts* receive antennas.

Data Types: `double`
Complex Number Support: Yes

`hest` — Channel estimate

3-D numeric array

Channel estimate, specified as a 3-D numeric array. It has size *M*-by-*NRxAnts*-by-*CellRefP*. *M* is the number of received symbols in `in`. *NRxAnts* is the number of receive antennas. *CellRefP* is the number of cell-specific reference signal antenna ports.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`out` — Decoded received symbols

complex-valued numeric column vector

Decoded received symbols, returned as a complex-valued numeric column vector. It has size *M*-by-1, where *M* is the number of received symbols for each receive antenna.

Data Types: `double`
Complex Number Support: Yes

`csi` — Soft channel state information

numeric column vector

Soft channel state information (CSI), returned as a numeric column vector. It has size *M*-by-1, where *M* is the number of received symbols for each receive antenna. `csi` provides an estimate of the received RE gain for each received RE.

Data Types: `double`

See Also

See Also

`lteDLDeprecode`

Introduced in R2014a

lteUCI3Decode

PUCCH format 3 transmission UCI decoding

Syntax

```
ucibits = lteUCI3Decode(cw,n)
```

Description

`ucibits = lteUCI3Decode(cw,n)` returns a column vector of decoded UCI bits, `ucibits`, resulting from decoding the soft bit column vector, `cw`. Where the output vector `ucibits` is expected to contain `n` bits. `ucibits` is empty if no HARQ-ACK bits are detected.

The decoder uses a maximum likelihood (ML) approach, assuming that `cw` has been demodulated using `ltePUCCH3Decode`, whose input had already been equalized to best restore the originally transmitted complex values. Specifically, this function assumes that `cw` is properly scaled to reflect a QPSK constellation (± sqrt(2)/2 amplitude for real and imaginary parts). If multiple decoded UCI bit vectors have a likelihood equal to the maximum, `ucibits` is a matrix where each column represents one of the equally likely bit vectors. If a minimum likelihood threshold is not met, `ucibits` is empty.

Examples

Encoding and decoding HARQ-ACK feedback for PUCCH Format 3

This example shows how to encode and decode an ACK using PUCCH format 3 transmission UCI decoding.

Create a Tx ACK vector. Encode the vector using PUCCH format 3. Convert the logical bits into soft data.

```
txAck = [1;0;0;1];

cw = lteUCI3Encode(txAck);
```

```
cw = (double(cw)-0.5)*sqrt(2.0);
```

Decode the received data using the PUCCH format 3 UCI decoder. Verify that the Rx ACK vector matches the Tx ACK vector.

```
rxAck = lteUCI3Decode(cw,length(txAck))
```

```
rxAck =

  4×1 logical array

   1
   0
   0
   1
```

Input Arguments

cw — Soft bits to decode

numeric column vector

Soft bits to decode, specified as a numeric column vector.

Data Types: `int8` | `double`

n — Number of bits to return

positive scalar integer (1...22)

Number of bits to return, specified as a positive scalar integer from 1 through 22.

Data Types: `double`

Output Arguments

ucibits — Concatenated HARQ-ACK bits, periodic CSI bits, and Scheduling Request (SR) bit

logical column vector

Concatenated HARQ-ACK bits, periodic CSI bits, and Scheduling Request (SR) bit, returned as a logical column vector. `ucibits` represents the [a_0, a_1, ... a_{N-1}] bit sequence

as described in TS 36.212 [1], Section 5.2.3.1. The number of bits returned, *N*, is defined by the input argument `n`.

`ucibits` is empty if no UCI bits are detected.

Data Types: `logical`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH3Decode` | `lteUCI3Encode`

Introduced in R2014a

lteUCI3Encode

PUCCH format 3 transmission UCI encoding

Syntax

```
cw = lteUCI3Encode(ucibits)
```

Description

`cw = lteUCI3Encode(ucibits)` returns a column vector of coded UCI bits, `cw`, resulting from processing of control information, `ucibits` for PUCCH format 3. The `ucibits` is a vector of concatenated HARQ-ACK bits and any appended periodic CSI bits and/or scheduling request (SR) bits.

The UCI processing is defined in TS 36.212 [1], Section 5.2.3.1, and consists of a (32,*O*) block code, where *O* is the number of bits in `ucibits`. The coded bit vector, `cw`, is 48 bits long.

Examples

Encode HARQ-ACK Feedback for PUCCH Format 3

Encode and decode HARQ-ACK feedback for PUCCH format 3.

Create a Tx ACK vector. Encode the vector using PUCCH format 3. Turn logical bits into 'LLR' data.

```
txAck = [1;0;0;1];
cw = lteUCI3Encode(txAck);
cw(cw == 0) = -1;
```

Decode the received data using the PUCCH format 3 UCI decoder. Verify that the Rx ACK vector matches the Tx ACK vector.

```
rxAck = lteUCI3Decode(cw,length(txAck))
```

```
rxAck =
```

```
4×1 logical array

  1
  0
  0
  1
```

Input Arguments

`ucibits` — Concatenated HARQ-ACK bits, periodic CSI bits, and Scheduling Request (SR) bit

logical vector of length 1–22

Concatenated HARQ-ACK bits, periodic CSI bits, and Scheduling Request (SR) bit, specified as a logical vector containing from 1 to 22 bits. `ucibits` represents the [a_0, a_1, ... a_{N-1}] bit sequence as described in TS 36.212 [1], Section 5.2.3.1.

Data Types: `logical` | `double`

Output Arguments

`cw` — Coded UCI bits

48-by-1 integer column vector

Coded UCI bits, returned as a 48-by-1 integer column vector. This coded bit vector is 48 bits long.

Data Types: `int8`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH3` | `lteUCI3Decode`

Introduced in R2014a

lteUCIDecode

PUCCH format 2, 2a, and 2b transmission UCI decoding

Syntax

```
ucibits = lteUCIDecode(cw,n)
```

Description

`ucibits = lteUCIDecode(cw,n)` returns a vector of decoded UCI bits, `ucibits`, resulting from decoding the soft bit column vector, `cw`, where the output vector, `ucibits`, is expected to contain `n` bits. `ucibits` is a column vector of CQI/PMI or RI bits (UCI), representing the CQI/PMI or RI information fields described in TS 36.212, Section 5.2.3.3 [1]. `n` must be between 1 and 13. The decoder uses a maximum likelihood approach assuming that `cw` has been demodulated using `ltePUCCH2Decode` whose input had already been equalized to best restore the originally transmitted complex values. If multiple decoded UCI bit vectors have a likelihood equal to the maximum, UCIBITS will be a matrix where each column represents one of the equally likely bit vectors

Examples

Decode UCI Bits

Decode UCI bits representing RI=3 using N=2 bits. According to TS 36.212, Table 5.2.2.6-6 this maps to the set of input bits `[1;0]`.

```
cw = lteUCIEncode([1;0])
softBits = double(cw)/sqrt(2);
decodedUciBits = lteUCIDecode(softBits, 2)
```

```
cw =

  20×1 int8 column vector

   1
   1
```

```
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1

decodedUciBits =

  2×1 logical array

   1
   0
```

The decoded UCI bits match the input bits.

Input Arguments

cw — Codeword of soft bits

numeric column vector

Codeword of soft bits, specified as a numeric column vector.

Data Types: `logical` | `double`

n — Number of bits

1...11

Number of bits, specified as a scalar integer from 1 to 11.

Data Types: `double`

Output Arguments

`ucibits` — Decoded UCI bits

logical column vector

Decoded UCI bits, returned as a logical column vector. UCI bits are CQI/PMI or RI information.

Data Types: `logical`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH2Decode` | `lteUCI3Encode` | `lteUCIEncode`

Introduced in R2014a

lteUCIEncode

PUCCH format 2, 2a, and 2b transmission UCI encoding

Syntax

```
cw = lteUCIEncode(ucibits)
```

Description

`cw = lteUCIEncode(ucibits)` returns a column vector of coded UCI bits, `cw`, resulting from processing of control information, `ucibits`. `ucibits` is a column vector of CQI/PMI or RI bits (UCI), representing the CQI/PMI or RI information fields described in TS 36.212, Section 5.2.3.3 [1]. `ucibits` should be a vector containing up to 13 bits. For PUCCH formats 2a and 2b with extended cyclic prefix, this vector should also contain the appended 1 or 2 HARQ-ACK bits for joint encoding.

The UCI processing is defined in TS 36.212, Section 5.2.3 [1], and consists of a (20,*A*) block code, where *A* is the number of bits in `ucibits`. The coded bit vector, `cw`, is 20 bits long.

Examples

Encode UCI Bits

Encode UCI bits representing RI=3 using two bits. According to TS 36.212, Table 5.2.2.6-6 this maps to the set of input bits [1; 0].

```
cw = lteUCIEncode([1;0])
```

```
cw =

  20×1 int8 column vector

   1
   1
```

```
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
```

Input Arguments

`ucibits` — Control information bits

logical vector of length 1 to 13

Control information bits, specified as a logical vector of length 1 to 13. This vector contains the CQI/PMI or RI logical bits (UCI), representing the CQI/PMI or RI information fields. It should be up to 13 bits in length. For PUCCH formats 2a and 2b with extended cyclic prefix, this vector should also contain the appended 1 or 2 HARQ-ACK bits for joint encoding.

Data Types: `logical`

Output Arguments

`cw` — Coded UCI bits

20-by-1 integer column vector

Coded UCI bits, returned as a 20-by-1 integer column vector. The coded bit vector is 20 bits long.

Data Types: `int8`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUCCH2` | `lteUCI3Decode` | `lteUCIDecode`

Introduced in R2014a

lteULChannelEstimate

PUSCH uplink channel estimation

Syntax

```
[hest, noiseest] = lteULChannelEstimate(ue,chs,rxgrid)
[hest, noiseest] = lteULChannelEstimate(ue,chs,cec,rxgrid)
[hest, noiseest] = lteULChannelEstimate(ue,chs,cec,rxgrid,refgrid)
[hest, noiseest] = lteULChannelEstimate(ue,chs,rxgrid,refgrid)
```

Description

`[hest, noiseest] = lteULChannelEstimate(ue,chs,rxgrid)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these estimates across the allocated resource elements within the time frequency grid. It returns the estimated channel between each transmit and receive antenna and an estimate of the noise power spectral density. See "Algorithms" on page 1-1345.

`[hest, noiseest] = lteULChannelEstimate(ue,chs,cec,rxgrid)` returns the estimated channel using the method and parameters defined by the user in the channel estimator configuration `cec` structure.

`[hest, noiseest] = lteULChannelEstimate(ue,chs,cec,rxgrid,refgrid)` returns the estimated channel using the method and parameters defined by the channel estimation configuration structure and the additional information about the transmitted symbols found in `refgrid`.

When `cec.InterpType` is set to `'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` contains non-zero values in their locations.

`[hest, noiseest] = lteULChannelEstimate(ue,chs,rxgrid,refgrid)` returns the estimated channel using the estimation method as described in TS 36.101 [1], Annex F4. The method described utilizes extra channel information obtained through information of the transmitted symbols found in `refgrid`. This additional information allows for an improved estimate of the channel and is required for accurate EVM measurements. `rxgrid` and `refgrid` must only contain a whole subframe worth of SC-FDMA symbols.

Examples

Estimate Channel Characteristics for PUSCH

Use `lteULChannelEstimate` to estimate the channel characteristics for a received resource grid.

Initialize a UE configuration structure to RMC `A3-2`. Initialize the channel estimation configuration structure. Generate a transmission waveform. For the purpose of this example, we bypass the channel stage of the system model and copy `txWaveform` to `rxWaveform`.

```
ue = lteRMCUL('A3-2');
ue.TotSubframes = 1;
cec = struct('FreqWindow',7,'TimeWindow',1,'InterpType','cubic');
txWaveform = lteRMCULTool(ue,[1;0;0;1]);
rxWaveform = txWaveform;
```

Demodulate the SC-FDMA waveform and perform channel estimation operation on `rxGrid`.

```
rxGrid = lteSCFDMADemodulate(ue,rxWaveform);
hest = lteULChannelEstimate(ue,ue.PUSCH,cec,rxGrid);
```

Input Arguments

ue — UE-specific configuration

structure

UE-specific configuration, specified as a structure. `ue` can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	6, 15, 25, 50, 75, 100	Number of uplink resource blocks. (N_{RB}^{UL})
`NCellID`	Required	Nonnegative scalar integer	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number

Parameter Field	Required or Optional	Values	Description
CyclicPre	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length for uplink.
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.
Hopping	Optional	`'Off'` (default), `'Group'`, or `'Sequence'`	Frequency hopping method.
SeqGroup	Optional	0 (default), integer from 0 to 29	PUSCH sequence group assignment (Δ_{SS}). Only used if `NDMRSID` or `NPUSCHID` is absent
CyclicShi	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for PUSCH DM-RS (yields $n_{DMRS}^{(1)}$).
NPUSCHID	Optional	0 (default), nonnegative scalar integer from 0 to 509	PUSCH virtual cell identity. If this field is not present, `NCellID` is used for group hopping sequence-shift pattern initialization. See footnote 1
NDMRSID	Optional	0 (default), nonnegative scalar integer from 0 to 509	DM-RS identity for cyclic shift hopping ($n_{ID}^{csh\_DMRS}$). If this field is not present, `NCellID` is used for cyclic shift hopping initialization. See footnote 1
1 The pseudorandom sequence generator for cyclic shift hopping is initialized according to `NDMRSID`, if present — otherwise it is initialized according to the cell identity `NCellID` and the sequence group assignment `SeqGroup`. Similarly, the sequence-shift pattern for group hopping is initialized according to `NPUSCHID`, if present — otherwise it is initialized according to `NCellID` and `SeqGroup`.			

Data Types: `struct`

chs — PUSCH channel settings

structure

PUSCH channel settings, specified as a structure that can contain the following fields. The parameter field `PMI` is only required if `ue.NTxAnts` is set to 2 or 4.

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	Physical resource block set, specified as a 1-column or 2-column matrix. This parameter field contains the zero-based physical resource block (PRB) indices corresponding to the slot-wise resource allocations for this PUSCH. If `PRBSet` is a column vector, the resource allocation is the same in both slots of the subframe. To specify differing PRBs for each slot in a subframe, use a 2-column matrix. The PRB indices are zero based.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers
`DynCyclicSh`	Optional	0 (default), integer from 0 to 7	Cyclic shift for DM-RS (yields $n_{\mathrm{DMRS}}^{(2)}$).
`OrthoCover`	Optional	`'Off'` (default), `'On'`	Applies (`'On'`), or does not apply (`'Off'`), orthogonal cover sequence w (*Activate-DMRS-with OCC*).
The following field is required only when `ue.NTxAnts` is set to 2 or 4.			
`PMI`	Optional	nonnegative scalar integer (0,...,23) 0 (default)	Scalar precoder matrix indication (PMI) to be used during precoding of the DRS reference symbols

Data Types: `struct`

rxgrid — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols.

- N_{SC} is the number of subcarriers
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_R is the number of receive antennas

Data Types: `double`
Complex Number Support: Yes

`cec` — Channel estimator configuration

structure

Channel estimator configuration, specified as a structure with these fields.

Parameter Field	Required or Optional	Values	Description
`FreqWindow`	Required	Nonnegative scalar integer	Size of window in resource elements used to average over frequency during channel estimation The window size must be either an odd number or a multiple of 12.
`TimeWindow`	Required	Nonnegative scalar integer	Size of window in resource elements used to average over time during channel estimation The window size must be an odd number.
`InterpType`	Required	`'nearest'`, `'linear'`, `'natural'`,	Type of 2-D interpolation used during interpolation. For details, see `griddata`. Supported choices are shown in the following table.

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>'cubic', 'v4', 'none'

See footnote 1</td><td><table><tr><th>Value</th><th>Description</th></tr><tr><td>'nearest'</td><td>Nearest neighbor interpolation</td></tr><tr><td>'linear'</td><td>Linear interpolation</td></tr><tr><td>'natural'</td><td>Natural neighbor interpolation</td></tr><tr><td>'cubic'</td><td>Cubic interpolation</td></tr><tr><td>'v4'</td><td>MATLAB 4 griddata method</td></tr><tr><td>'none'</td><td>Disables interpolation</td></tr></table></td></tr>
<tr><td>PilotAverag</td><td>Optional</td><td>'UserDefined' 'TestEVM'

See footnote 2</td><td>Type of pilot averaging</td></tr>
<tr><td>Reference</td><td>Optional</td><td>'Antennas' (default), 'Layers', 'None'

See footnote 3</td><td>Specifies point of reference (signals to internally generate) for channel estimation</td></tr>
<tr><td colspan="4">The following field is required only when rxgrid contains more than one subframe.

See footnote 4</td></tr>
<tr><td>Window</td><td>Optional</td><td>'Left', 'Right', 'Centred', 'Centered'</td><td>If more than one subframe is input this parameter is required to indicate the position of the subframe from rxgrid and refgrid containing the desired channel estimate. Only channel estimates for this subframe will be returned. For the 'Centred' and 'Centered' settings, the window size must be odd.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
1	For `cec.InterpType` = `'none'`, no interpolation is performed between pilot symbols and no virtual pilots are created. `hest` will contain channel estimates in the locations of transmitted reference symbols for each received antenna and all other elements of `hest` are zero. The averaging of pilot symbols estimates described by `cec.TimeWindow` and `cec.FreqWindow` are still performed.		
2	The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation upon the pilots. Pilots near the edge of the resource grid are averaged less as they have no neighbors outside of the grid. For `cec.FreqWindow` = 12×*X* (i.e. any multiple of 12) and `cec.TimeWindow` = 1 the estimator enters a special case where an averaging window of (12×*X*)-in-frequency is used to average the pilot estimates; the averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges; therefore the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. This provides the appropriate despreading operation required for the case multi-antenna transmission where the DM-RS signals associated with each antenna occupy the same time/frequency locations but use different orthogonal cover codes to allow them to be differentiated at the receiver. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and follows the method described in TS 36.101, Annex F for the purposes of transmitter EVM testing.		
3	Setting `cec.Reference` to `'Antennas'` uses the PUSCH DMRS after precoding onto the transmission antennas as the reference for channel estimation. In this case, the precoding matrix indicated in `chs.PMI` is used to precode the DMRS layers onto antennas, and the channel estimate, `hest`, is a matrix of size *M*-by-*N*-by-`NRxAnts`-by-`chs.NTxAnts`. Setting `cec.Reference` to `'Layers'` uses the PUSCH DMRS without precoding as the reference for channel estimation. The channel estimate, `hest`, is of size *M*-by-*N*-by-`NRxAnts`-by-`chs.NLayers`. Setting `cec.Reference` to `'None'` generates no internal reference signals, and the channel estimation can be performed on arbitrary known REs as given by the `refgrid` argument. This approach can be used to provide a `refgrid` containing the SRS signals created on all `NTxAnts`, allowing for full-rank channel estimation for the purposes of PMI selection when the PUSCH is transmitted with less than full rank.		
4	When `rxgrid` contains more than one subframe, `cec.Window` provides control of the location of the subframe for which channel estimation is performed. This allows channel estimation for the subframe of interest to be aided by the presence of pilot symbols occupying the same resource block in subframes before and/or after that subframe. For example, if `rxgrid` contains five subframes, `'Left'` estimates the last first subframe in `rxgrid`,		

Parameter Field	Required or Optional	Values	Description
			`'Centred'`/`'Centered'` estimates the third (middle) subframe, and `'Right'` estimates the last subframe. The parameter `ue.NSubframe` corresponds to the chosen subframe. So, with three subframes and `cec.Window` = `'Right'`, `rxgrid` corresponds to subframes (`ue.NSubframe-2`, `ue.NSubframe-1`, `ue.NSubframe`). The `hest` output will be the same size as `rxgrid` and will correspond to the same subframe numbers. All locations other than the estimated subframe will contain zeros.

Data Types: `struct`

`refgrid` — Reference array of known transmitted data symbols in their correct locations
3-D numeric array

Reference array of known transmitted data symbols in their correct locations, specified as an N_{SC}-by-N_{Sym}-by-N_T array of complex symbols. All other locations, such as DM-RS Symbols and unknown data symbol locations, should be represented by a `NaN`. `rxgrid` and `refgrid` must have the same dimensions.

- N_{SC} is the number of subcarriers.
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_T is the number of transmit antennas, `ue.NTxAnts`

For `cec.InterpType` = `'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` will contain non-zero values in their locations. A typical use for `refgrid` is to provide values of the SRS transmitted at some point during the time span of `rxgrid`. The SRS values can be used to enhance the channel estimation.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

4-D array

Channel estimate between each transmit and receive antenna, returned as an N_{SC}-by-N_{Sym}-by-N_R-by-N_T array of complex symbols.

- N_{SC} is the number of subcarriers.
- N_{Sym} is the number of SC-FDMA symbols.
- N_R is the number of receive antennas.
- N_T is the number of transmit antennas, `ue.NTxAnts`.

Optionally, the channel estimator can be configured to use the DM-RS layers as the reference signal. In this case, the 4-D array is an N_{SC}-by-N_{Sym}-by-N_R-by-N_{Layers} array of complex symbols, where N_{Layers} is the number of transmission layers.

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. This output is the power spectral density of the noise present on the estimated channel response coefficients.

Algorithms

The channel estimation algorithm is described in the following steps.

1. Extract the demodulation reference signals, or pilot symbols, for a transmit-receive antenna pair from the allocated physical resource blocks within the received subframe.
2. Average the least-squares estimates to reduce any unwanted noise from the pilot symbols.
3. Using the cleaned pilot symbol estimates, interpolate to obtain an estimate of the channel for the entire number of subframes passed into the function.

Least-Squares Estimation

The least-squares estimates of the reference signals are obtained by dividing the received pilot symbols by their expected value. The least-squares estimates are affected by

any system noise. This noise needs to be removed or reduced to achieve a reasonable estimation of the channel at pilot symbol locations.

Noise Reduction and Interpolation

To minimize the effects of noise on the pilot symbol estimates, the least-squares estimates are averaged. This simple method produces a substantial reduction in the level of noise found on the pilot symbols. The pilot symbol averaging method uses an averaging window defined by the user. The averaging window size is measured in resource elements; any pilot symbols located within the window are used to average the value of the pilot symbol found at the center of the window.

Then, the averaged pilot symbol estimates are used to perform a 2-D interpolation across allocated physical resource blocks. The location of pilot symbols within the subframe is not ideally suited to interpolation. To account for this positioning, virtual pilots are created and placed out with the area of the current subframe. This placement allows complete and accurate interpolation to be performed.

Note: The PUSCH channel estimator is only able to deal with contiguous allocation of resource blocks in time and frequency.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`griddata` | `lteEqualizeMIMO` | `lteEqualizeMMSE` | `lteEqualizeULMIMO` | `lteEqualizeZF` | `lteSCFDMADemodulate` | `lteULFrameOffset` | `lteULPerfectChannelEstimate`

Introduced in R2013b

lteULChannelEstimatePUCCH1

PUCCH format 1 uplink channel estimation

Syntax

```
[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,rxgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,cec,rxgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,cec,rxgrid,
refgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,rxgrid,refgrid)
```

Description

`[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,rxgrid)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these across the allocated resource elements within the time frequency grid. `lteULChannelEstimatePUCCH1` returns `hest`, the estimated channel between each transmit and receive antenna and `noiseest`, an estimate of the noise power spectral density.

`[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,cec,rxgrid)` returns the estimated channel using the method and parameters defined by the user in the channel estimator configuration structure, `cec`.

`[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,cec,rxgrid, refgrid)` returns the estimated channel using the method and parameters defined by the channel estimation configuration structure and the additional information about the transmitted symbols found in `refgrid`. The `rxgrid` and `refgrid` inputs must have the same dimensions. For `cec.InterpType = 'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` will contain non-zero values in their locations.

`[hest,noiseest] = lteULChannelEstimatePUCCH1(ue,chs,rxgrid,refgrid)` returns the estimated channel using the estimation method as described in TS 36.101, Annex F4 [1]. The method described utilizes extra channel information obtained through information of the transmitted symbols found in `refgrid`. This additional information allows for an improved estimate of the channel and is required for accurate EVM

measurements. `rxgrid` and `refgrid` must only contain a whole subframe worth of SC-FDMA symbols.

Examples

Estimate Channel Characteristics for PUCCH Format 1

Use the lteULChannelEstimatePUCCH1 function to estimate channel characteristics for PUCCH Format 1

Initialize a UE configuration structure, PUCCH settings, and create a resource grid.

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
pucch1.ResourceIdx  = 0;
pucch1.DeltaShift   = 1;
pucch1.CyclicShifts = 0;
reGrid = lteULResourceGrid(ue);
reGrid(ltePUCCH1DRSIndices(ue,pucch1)) = ltePUCCH1DRS(ue,pucch1);
```

For the purpose of this example, we skip SC-FDMA modulation, channel and SC-FDMA demodulation stages of the system model and use `reGrid` as the received resource grid. Initialize the channel estimation configuration structure and perform channel estimation operation on `reGrid`.

```
cec = struct('FreqWindow',12,'TimeWindow',1,'InterpType','Cubic');
hest = lteULChannelEstimatePUCCH1(ue,pucch1,cec,reGrid);
```

Input Arguments

ue — UE-specific configuration settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CyclicPrefixUL	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.
Hopping	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
NPUCCHID	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

chs — PUCCH settings

structure

PUCCH channel settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
ResourceIdx	Optional	0 (default), integer from 0 to 2047 or vector of integers.	PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used for transmission. ($n_{PUCCH}^{(1)}$). Define one index for each transmission antenna.

Parameter Field	Required or Optional	Values	Description
`ResourceSize`	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N_{RB}^{(2)}$)
`DeltaShift`	Optional	1 (default), 2, 3	Delta shift, specified as 1, 2, or 3. (Δ_{shift})
`DeltaOffset`	Optional	0 (default), 1, 2	(Δ_{offset}). Warning: The use of this parameter field is not advised. It applies only to 3GPP releases preceding v8.5.0. This parameter will be removed in a future release.
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{cs}^{(1)}$)

Data Types: `struct`

`rxgrid` — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols.

- N_{SC} is the number of subcarriers
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.

- N_R is the number of receive antennas

Data Types: `double`
Complex Number Support: Yes

`cec` — Channel estimator configuration

structure

Channel estimator configuration, specified as a structure with these fields.

Parameter Field	Required or Optional	Values	Description
`FreqWindow`	Optional	Odd scalar integer or a multiple of 12	Size of window used to average over frequency, in resource elements (REs), specified as a scalar integer.
`TimeWindow`	Optional	Odd scalar integer	Size of window used to average over time, in resource elements (REs), specified as a scalar integer.
`InterpType`	Optional	`'nearest'`, `'linear'`, `'natural'`, `'cubic'`, `'v4'`, `'none'` See footnote 1	Type of 2-D interpolation used during interpolation. For details, see `griddata`. Supported choices are shown in the following table.

Value	Description
`'neares`	Nearest neighbor interpolation
`'linear`	Linear interpolation
`'natura`	Natural neighbor interpolation
`'cubic'`	Cubic interpolation
`'v4'`	MATLAB 4 `griddata` method
`'none'`	Disables interpolation

Parameter Field	Required or Optional	Values	Description
`PilotAverage`	Optional	`'UserDefined'` (default), `'TestEVM'` See footnote 2	Type of pilot averaging
The following parameter is required only if `rxgrid` contains more than one subframe. See footnote 3			
`Window`	Optional	`'Left'`, `'Right'`, `'Centred'`, `'Centered'`	If more than one subframe is input this parameter is required to indicate the position of the subframe from *rxgrid* and *refgrid* containing the desired channel estimate. Only channel estimates for this subframe will be returned. For the `'Centred'` and `'Centered'` settings, the window size must be odd.

Parameter Field	Required or Optional	Values	Description
1	For `cec.InterpType` = `'none'`, no interpolation is performed between pilot symbols and no virtual pilots are created. `hest` will contain channel estimates in the locations of transmitted reference symbols for each received antenna and all other elements of `hest` are zero. The averaging of pilot symbols estimates described by `cec.TimeWindow` and `cec.FreqWindow` are still performed.		
2	The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation upon the pilots. Pilots near the edge of the resource grid are averaged less as they have no neighbors outside of the grid. For `cec.FreqWindow` = 12×*X* (i.e. any multiple of 12) and `cec.TimeWindow` = 1 the estimator enters a special case where an averaging window of (12×*X*)-in-frequency is used to average the pilot estimates; the averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges; therefore the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. This provides the appropriate despreading operation required for the case multi-antenna transmission where the DM-RS signals associated with each antenna occupy the same time/frequency locations but use different orthogonal cover codes to allow them to be differentiated at the receiver. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and follows the method described in TS 36.101, Annex F for the purposes of transmitter EVM testing.		
3	When `rxgrid` contains more than one subframe, `cec.Window` provides control of the location of the subframe for which channel estimation is performed. This allows channel estimation for the subframe of interest to be aided by the presence of pilot symbols occupying the same resource block in subframes before and/or after that subframe. For example, if `rxgrid` contains five subframes, `'Left'` estimates the last first subframe in `rxgrid`, `'Centred'`/`'Centered'` estimates the third (middle) subframe, and `'Right'` estimates the last subframe. The parameter `ue.NSubframe` corresponds to the chosen subframe. So, with three subframes and `cec.Window` = `'Right'`, `rxgrid` corresponds to subframes (`ue.NSubframe-2`, `ue.NSubframe-1`, `ue.NSubframe`). The `hest` output will be the same size as `rxgrid` and will correspond to the same subframe numbers. All locations other than the estimated subframe will contain zeros.		

Data Types: `struct`

`refgrid` — Reference array of known transmitted data symbols in their correct locations
3-D numeric array

Reference array of known transmitted data symbols in their correct locations, specified as an N_{SC}-by-N_{Sym}-by-N_T array of complex symbols. All other locations, such as DM-RS Symbols and unknown data symbol locations, should be represented by a `NaN`. `rxgrid` and `refgrid` must have the same dimensions.

- N_{SC} is the number of subcarriers.
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_T is the number of transmit antennas, `ue.NTxAnts`

For `cec.InterpType = 'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` will contain non-zero values in their locations. A typical use for `refgrid` is to provide values of the SRS transmitted at some point during the time span of `rxgrid`. The SRS values can be used to enhance the channel estimation.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

3-D array

Channel estimate between each transmit and receive antenna, returned as a N_{SC}-by-N_{Sym}-by-N_R. array of complex symbols. N_{SC} is the total number of subcarriers, N_{Sym} is the number of SC-FDMA symbols, and N_R is the number of receive antennas.

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. This output is the power spectral density of the noise present on the estimated channel response coefficients.

Algorithms

The channel estimation algorithm functions as described in the following steps.

1. Extract the PUCCH format 1 demodulation reference signals (DM-RS), or pilot symbols, for a transmit-receive antenna pair from the allocated physical resource blocks within the received subframe.
2. Average the least-squares estimates to reduce any unwanted noise from the pilot symbols.
3. Using the cleaned pilot symbol estimates, interpolate to obtain an estimate of the channel for the allocated subframe slot passed into the function.

Least-Squares Estimation

The least-squares estimates of the reference signals are obtained by dividing the received pilot symbols by their expected value. The least-squares estimates are affected by any system noise. This noise needs to be removed or reduced to achieve a reasonable estimation of the channel at pilot symbol locations.

Noise Reduction and Interpolation

To minimize the effects of noise on the pilot symbol estimates, the least-squares estimates are averaged. This simple method produces a substantial reduction in the level of noise found on the pilot symbols. The pilot symbol averaging method uses an averaging window defined by the user. The averaging window size is measured in resource elements; any pilot symbols located within the window are used to average the value of the pilot symbol found at the center of the window.

Then, the averaged pilot symbol estimates are used to perform a 2-D interpolation across the slot of the subframe that was allocated to the PUCCH format 1 data. The location of pilot symbols within the subframe is not ideally suited to interpolation. To account for this positioning, virtual pilots are created and placed out with the area of the current subframe. This placement allows complete and accurate interpolation to be performed.

References

[1] 3GPP TS 36.101. “User Equipment (UE) Radio Transmission and Reception.” *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

`griddata` | `lteSCFDMADemodulate` | `lteULChannelEstimate` | `lteULFrameOffsetPUCCH1` | `lteULPerfectChannelEstimate`

Introduced in R2013b

lteULChannelEstimatePUCCH2

PUCCH format 2 uplink channel estimation

Syntax

```
[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,rxgrid,rxack2)
[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,cec,rxgrid,
rxack2)
[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,cec,rxgrid,
rxack2,refgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,rxgrid,rxack2,
refgrid)
```

Description

`[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,rxgrid,rxack2)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these across the allocated resource elements within the time frequency grid. It returns `hest`, the estimated channel between each transmit and receive antenna and `noiseest`, an estimate of the noise power spectral density.

`[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,cec,rxgrid, rxack2)` returns the estimated channel using the method and parameters defined by the user in the channel estimator configuration structure, `cec`.

`[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,cec,rxgrid, rxack2,refgrid)` returns the estimated channel using the method and parameters defined by the channel estimation configuration structure (`cec`), and the additional information about the transmitted symbols found in `refgrid`. The `rxgrid` and `refgrid` inputs must have the same dimensions. For `cec.InterpType = 'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` contains non-zero values in their locations.

`[hest,noiseest] = lteULChannelEstimatePUCCH2(ue,chs,rxgrid,rxack2, refgrid)` returns the estimated channel using the estimation method, as described in TS 36.101, Annex F4 [1]. The method described utilizes extra channel information

obtained through information of the transmitted symbols found in `refgrid`. This additional information allows for an improved estimate of the channel and is required for accurate EVM measurements.

Examples

Estimate Channel Characteristics for PUCCH Format 2

Use the lteULChannelEstimatePUCCH2 function to estimate channel characteristics for PUCCH Format 2

Initialize a UE configuration structure, PUCCH settings, and create a resource grid. For the purpose of this example, we bypass the SC-FDMA modulation, channel and SC-FDMA demodulation stages of the system model and copy the `txGrid` to an `rxGrid`.

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
pucch2.ResourceIdx = 0;
pucch2.ResourceSize = 0;
pucch2.CyclicShifts = 0;
txGrid = lteULResourceGrid(ue);
txAck = [1;1];
drsIndices = ltePUCCH2DRSIndices(ue,pucch2);

txGrid(drsIndices) = ltePUCCH2DRS(ue,pucch2,txAck);
rxGrid = txGrid;
```

The channel estimator uses the PUCCH Format 2 DRS to estimate the channel, so decode the hybrid ARQ indicators from the PUCCH Format 2 DM-RS. Initialize the channel estimation configuration structure and perform channel estimation operation on `rxGrid`.

```
rxAck = ltePUCCH2DRSDecode(ue,pucch2,length(txAck),rxGrid(drsIndices));
cec = struct('FreqWindow',12,'TimeWindow',1,'InterpType','cubic');
hest = lteULChannelEstimatePUCCH2(ue,pucch2,cec,rxGrid,rxAck);
```

Input Arguments

ue — UE-specific configuration settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`NPUCCHID`	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

`chs` — PUCCH channel settings

structure

PUCCH channel settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 1185 or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission. ($n_{PUCCH}^{(2)}$). Define one index for each transmission antenna.

Parameter Field	Required or Optional	Values	Description
`ResourceSize`	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N_{RB}^{(2)}$)
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{cs}^{(1)}$)

Data Types: `struct`

`rxgrid` — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols.

- N_{SC} is the number of subcarriers
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_R is the number of receive antennas

Data Types: `double`
Complex Number Support: Yes

`rxack2` — Hybrid ARQ indicators

logical value

Hybrid ARQ indicators, specified as a row vector of either 1 or 2 indicators, decoded from the PUCCH Format 2 DRS. This is required as the channel estimator uses the PUCCH Format 2 DM-RS to estimate the channel. `rxack2` can be obtained for example by using the `lteULFrameOffsetPUCCH2` function.

Data Types: `logical`

`cec` — Channel estimator configuration

structure

Channel estimator configuration, specified as a structure with these fields.

Parameter Field	Required or Optional	Values	Description
`FreqWindow`	Optional	Odd scalar integer or a multiple of 12	Size of window used to average over frequency, in resource elements (REs), specified as a scalar integer.
`TimeWindow`	Optional	Odd scalar integer	Size of window used to average over time, in resource elements (REs), specified as a scalar integer.
`InterpType`	Optional	`'nearest'`, `'linear'`, `'natural'`, `'cubic'`, `'v4'`, `'none'` See footnote 1	Type of 2-D interpolation used during interpolation. For details, see `griddata`. Supported choices are shown in the following table.

Value	Description
`'neares`	Nearest neighbor interpolation
`'linear`	Linear interpolation
`'natura`	Natural neighbor interpolation
`'cubic'`	Cubic interpolation
`'v4'`	MATLAB 4 `griddata` method

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table><tr><th>Value</th><th>Description</th></tr><tr><td>'none'</td><td>Disables interpolation</td></tr></table></td></tr>
<tr><td>PilotAverage</td><td>Optional</td><td>'UserDefined' (default), 'TestEVM'

See footnote 2</td><td>Type of pilot averaging</td></tr>
<tr><td colspan="4">The following parameter is required only if rxgrid contains more than one subframe.

See footnote 3</td></tr>
<tr><td>Window</td><td>Optional</td><td>'Left', 'Right', 'Centred', 'Centered'</td><td>If more than one subframe is input this parameter is required to indicate the position of the subframe from rxgrid and refgrid containing the desired channel estimate. Only channel estimates for this subframe will be returned. For the 'Centred' and 'Centered' settings, the window size must be odd.</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
1	For `cec.InterpType` = `'none'`, no interpolation is performed between pilot symbols and no virtual pilots are created. `hest` will contain channel estimates in the locations of transmitted reference symbols for each received antenna and all other elements of `hest` are zero. The averaging of pilot symbols estimates described by `cec.TimeWindow` and `cec.FreqWindow` are still performed.		
2	The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation upon the pilots. Pilots near the edge of the resource grid are averaged less as they have no neighbors outside of the grid. For `cec.FreqWindow` = 12×*X* (i.e. any multiple of 12) and `cec.TimeWindow` = 1 the estimator enters a special case where an averaging window of (12×*X*)-in-frequency is used to average the pilot estimates; the averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges; therefore the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. This provides the appropriate despreading operation required for the case multi-antenna transmission where the DM-RS signals associated with each antenna occupy the same time/frequency locations but use different orthogonal cover codes to allow them to be differentiated at the receiver. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and follows the method described in TS 36.101, Annex F for the purposes of transmitter EVM testing.		
3	When `rxgrid` contains more than one subframe, `cec.Window` provides control of the location of the subframe for which channel estimation is performed. This allows channel estimation for the subframe of interest to be aided by the presence of pilot symbols occupying the same resource block in subframes before and/or after that subframe. For example, if `rxgrid` contains five subframes, `'Left'` estimates the last first subframe in `rxgrid`, `'Centred'`/`'Centered'` estimates the third (middle) subframe, and `'Right'` estimates the last subframe. The parameter `ue.NSubframe` corresponds to the chosen subframe. So, with three subframes and `cec.Window` = `'Right'`, `rxgrid` corresponds to subframes (`ue.NSubframe-2`, `ue.NSubframe-1`, `ue.NSubframe`). The `hest` output will be the same size as `rxgrid` and will correspond to the same subframe numbers. All locations other than the estimated subframe will contain zeros.		

Data Types: `struct`

`refgrid` — Reference array of known transmitted data symbols in their correct locations
3-D numeric array

Reference array of known transmitted data symbols in their correct locations, specified as an N_{SC}-by-N_{Sym}-by-N_T array of complex symbols. All other locations, such as DM-RS Symbols and unknown data symbol locations, should be represented by a `NaN`. `rxgrid` and `refgrid` must have the same dimensions.

- N_{SC} is the number of subcarriers.
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_T is the number of transmit antennas, `ue.NTxAnts`

For `cec.InterpType = 'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` will contain non-zero values in their locations. A typical use for `refgrid` is to provide values of the SRS transmitted at some point during the time span of `rxgrid`. The SRS values can be used to enhance the channel estimation.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

3-D array

Channel estimate between each transmit and receive antenna, returned as an N_{SC}-by-N_{Sym}-by-N_R array of complex symbols. N_{SC} is the total number of subcarriers, N_{Sym} is the number of SC-FDMA symbols, and N_R is the number of receive antennas.

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. This output is the power spectral density of the noise present on the estimated channel response coefficients.

Algorithms

The channel estimation algorithm functions as described in the following steps.

1. Extract the PUCCH format 2 demodulation reference signals (DM-RS), or pilot symbols, for a transmit-receive antenna pair from the allocated physical resource blocks within the received subframe.
2. Average the least-squares estimates to reduce any unwanted noise from the pilot symbols.
3. Using the cleaned pilot symbol estimates, interpolate to obtain an estimate of the channel for the allocated subframe slot.

Least-Squares Estimation

The least-squares estimates of the reference signals are obtained by dividing the received pilot symbols by their expected value. The least-squares estimates are affected by any system noise. This noise needs to be removed or reduced to achieve a reasonable estimation of the channel at pilot symbol locations.

Noise Reduction and Interpolation

To minimize the effects of noise on the pilot symbol estimates, the least-squares estimates are averaged. This simple method produces a substantial reduction in the level of noise found on the pilot symbols. The pilot symbol averaging method uses an averaging window defined by the user. The averaging window size is measured in resource elements; any pilot symbols located within the window are used to average the value of the pilot symbol found at the center of the window.

Then, the averaged pilot symbol estimates are used to perform a 2-D interpolation across the slot of the subframe that was allocated to the PUCCH format 2 data. The location of pilot symbols within the subframe is not ideally suited to interpolation. To account for this positioning, virtual pilots are created and placed out with the area of the current subframe. This placement allows complete and accurate interpolation to be performed.

References

[1] 3GPP TS 36.101. “User Equipment (UE) Radio Transmission and Reception.” *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

`griddata` | `lteSCFDMADemodulate` | `lteULChannelEstimate` | `lteULFrameOffsetPUCCH2` | `lteULPerfectChannelEstimate`

Introduced in R2013b

lteULChannelEstimatePUCCH3

PUCCH format 3 uplink channel estimation

Syntax

```
[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,rxgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,cec,rxgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,cec,rxgrid,
refgrid)
[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,rxgrid,refgrid)
```

Description

`[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,rxgrid)` returns an estimate for the channel by averaging the least squares estimates of the reference symbols across time and copying these across the allocated resource elements within the time frequency grid. It returns `hest`, the estimated channel between each transmit and receive antenna and `noiseest`, an estimate of the noise power spectral density.

`[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,cec,rxgrid)` returns the estimated channel using the method and parameters defined by the user in the channel estimator configuration structure, `cec`.

`[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,cec,rxgrid, refgrid)` returns the estimated channel using the method and parameters defined by the channel estimation configuration structure and the additional information about the transmitted symbols found in `refgrid`. `rxgrid` and `refgrid` must have the same dimensions. For `cec.InterpType = 'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` contains non-zero values in their locations.

`[hest,noiseest] = lteULChannelEstimatePUCCH3(ue,chs,rxgrid,refgrid)` returns the estimated channel using the estimation method, as described in TS 36.101, Annex F4 [1]. The method described utilizes extra channel information obtained through information of the transmitted symbols found in `refgrid`. This additional information allows for an improved estimate of the channel and is required for accurate EVM measurements. `rxgrid` and `refgrid` must have the same dimensions. `rxgrid` and `refgrid` must only contain a whole subframe worth of SC-FDMA symbols.

Examples

Estimate Channel Characteristics for PUCCH Format 3

Use the lteULChannelEstimatePUCCH3 function to estimate channel characteristics for PUCCH Format 3

Initialize a UE configuration structure, PUCCH settings, and create a resource grid. For the purpose of this example, we bypass the SC-FDMA modulation, channel and SC-FDMA demodulation stages of the system model and copy the `txGrid` to an `rxGrid`.

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
pucch3 = struct('ResourceIdx',0);
txGrid = lteULResourceGrid(ue);
txGrid(ltePUCCH3DRSIndices(ue,pucch3)) = ltePUCCH3DRS(ue,pucch3);
rxGrid = txGrid;
```

```
Warning: Using default value for parameter field Shortened (0)
```

Initialize the channel estimation configuration structure and perform channel estimation operation on `rxGrid`.

```
cec = struct('FreqWindow',12,'TimeWindow',1,'InterpType','Cubic');
hest = lteULChannelEstimatePUCCH3(ue,pucch3,cec,rxGrid);
```

```
Warning: Using default value for parameter field PilotAverage ('UserDefined')
Warning: Using default value for parameter field Shortened (0)
```

Input Arguments

ue — UE-specific cell-wide settings

structure

UE-specific cell-wide settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})

Parameter Field	Required or Optional	Values	Description
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.
`NPUCCHID`	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

`chs` — PUCCH channel settings

structure

PUCCH channel settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 549, or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for

Parameter Field	Required or Optional	Values	Description
			transmission ($n_{\mathrm{PUCCH}}^{(3)}$). Define one index for each transmission antenna.

Data Types: `struct`

`rxgrid` — Received resource element grid

3-D array

Received resource element grid, specified as an N_{SC}-by-N_{Sym}-by-N_{R} array of complex symbols.

- N_{SC} is the number of subcarriers
- $N_{\mathrm{Sym}} = N_{\mathrm{SF}} \times N_{\mathrm{SymPerSF}}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - N_{SymPerSF} is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_{R} is the number of receive antennas

Data Types: `double`
Complex Number Support: Yes

`cec` — Channel estimator configuration

structure

Channel estimator configuration, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`FreqWindow`	Optional	Odd scalar integer or a multiple of 12	Size of window used to average over frequency, in resource

<table>
<tr><th>Parameter Field</th><th>Required or Optional</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td>elements (REs), specified as a scalar integer.</td></tr>
<tr><td><code>TimeWindow</code></td><td>Optional</td><td>Odd scalar integer</td><td>Size of window used to average over time, in resource elements (REs), specified as a scalar integer.</td></tr>
<tr><td><code>InterpType</code></td><td>Optional</td><td><code>'nearest'</code>, <code>'linear'</code>, <code>'natural'</code>, <code>'cubic'</code>, <code>'v4'</code>, <code>'none'</code>

See footnote 1</td><td>Type of 2-D interpolation used during interpolation. For details, see <code>griddata</code>. Supported choices are shown in the following table.
<table>
<tr><th>Value</th><th>Description</th></tr>
<tr><td><code>'neares</code></td><td>Nearest neighbor interpolation</td></tr>
<tr><td><code>'linear</code></td><td>Linear interpolation</td></tr>
<tr><td><code>'natura</code></td><td>Natural neighbor interpolation</td></tr>
<tr><td><code>'cubic'</code></td><td>Cubic interpolation</td></tr>
<tr><td><code>'v4'</code></td><td>MATLAB 4 <code>griddata</code> method</td></tr>
<tr><td><code>'none'</code></td><td>Disables interpolation</td></tr>
</table></td></tr>
<tr><td><code>PilotAverage</code></td><td>Optional</td><td><code>'UserDefined'</code>(default), <code>'TestEVM'</code>

See footnote 2</td><td>Type of pilot averaging</td></tr>
<tr><td colspan="4">The following parameter is required only if <code>rxgrid</code> contains more than one subframe.

See footnote 3</td></tr>
</table>

Parameter Field	Required or Optional	Values	Description
`Window`	Optional	`'Left'`, `'Right'`, `'Centred'`, `'Centered'`	If more than one subframe is input this parameter is required to indicate the position of the subframe from *rxgrid* and *refgrid* containing the desired channel estimate. Only channel estimates for this subframe will be returned. For the `'Centred'` and `'Centered'` settings, the window size must be odd.

Parameter Field	Required or Optional	Values	Description
1	For `cec.InterpType` = `'none'`, no interpolation is performed between pilot symbols and no virtual pilots are created. `hest` will contain channel estimates in the locations of transmitted reference symbols for each received antenna and all other elements of `hest` are zero. The averaging of pilot symbols estimates described by `cec.TimeWindow` and `cec.FreqWindow` are still performed.		
2	The `'UserDefined'` pilot averaging uses a rectangular kernel of size `cec.FreqWindow`-by-`cec.TimeWindow` and performs a 2-D filtering operation upon the pilots. Pilots near the edge of the resource grid are averaged less as they have no neighbors outside of the grid. For `cec.FreqWindow` = 12×*X* (i.e. any multiple of 12) and `cec.TimeWindow` = 1 the estimator enters a special case where an averaging window of (12×*X*)-in-frequency is used to average the pilot estimates; the averaging is always applied across (12×*X*) subcarriers, even at the upper and lower band edges; therefore the first (6×*X*) symbols at the upper and lower band edge have the same channel estimate. This operation ensures that averaging is always done on 12 (or a multiple of 12) symbols. This provides the appropriate despreading operation required for the case multi-antenna transmission where the DM-RS signals associated with each antenna occupy the same time/frequency locations but use different orthogonal cover codes to allow them to be differentiated at the receiver. The `'TestEVM'` pilot averaging ignores other structure fields in `cec`, and follows the method described in TS 36.101, Annex F for the purposes of transmitter EVM testing.		
3	When `rxgrid` contains more than one subframe, `cec.Window` provides control of the location of the subframe for which channel estimation is performed. This allows channel estimation for the subframe of interest to be aided by the presence of pilot symbols occupying the same resource block in subframes before and/or after that subframe. For example, if `rxgrid` contains five subframes, `'Left'` estimates the last first subframe in `rxgrid`, `'Centred'`/`'Centered'` estimates the third (middle) subframe, and `'Right'` estimates the last subframe. The parameter `ue.NSubframe` corresponds to the chosen subframe. So, with three subframes and `cec.Window` = `'Right'`, `rxgrid` corresponds to subframes (`ue.NSubframe-2`, `ue.NSubframe-1`, `ue.NSubframe`). The `hest` output will be the same size as `rxgrid` and will correspond to the same subframe numbers. All locations other than the estimated subframe will contain zeros.		

Data Types: `struct`

`refgrid` — Reference array of known transmitted data symbols in their correct locations
3-D numeric array

Reference array of known transmitted data symbols in their correct locations, specified as an N_{SC}-by-N_{Sym}-by-N_T array of complex symbols. All other locations, such as DM-RS Symbols and unknown data symbol locations, should be represented by a `NaN`. `rxgrid` and `refgrid` must have the same dimensions.

- N_{SC} is the number of subcarriers.
- $N_{Sym} = N_{SF} \times N_{SymPerSF}$
  - N_{SF} is the total number of subframes. If N_{SF} is greater than one, the correct region is extracted from the returned `hest` array. The location of the estimated subframe within `hest` is specified using the parameter field `cec.Window`.
  - $N_{SymPerSF}$ is the number of SC-FDMA symbols per subframe.
    - For normal cyclic prefix, each subframe contains 14 SC-FDMA symbols.
    - For extended cyclic prefix, each subframe contains 12 SC-FDMA symbols.
- N_T is the number of transmit antennas, `ue.NTxAnts`

For `cec.InterpType = 'None'`, values in `refgrid` are treated as reference symbols and the resulting `hest` will contain non-zero values in their locations. A typical use for `refgrid` is to provide values of the SRS transmitted at some point during the time span of `rxgrid`. The SRS values can be used to enhance the channel estimation.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`hest` — Channel estimate between each transmit and receive antenna

3-D array

Channel estimate between each transmit and receive antenna, returned as a N_{SC}-by-N_{Sym}-by-N_R. array of complex symbols. N_{SC} is the total number of subcarriers, N_{Sym} is the number of SC-FDMA symbols, and N_R is the number of receive antennas.

`noiseest` — Noise estimate

numeric scalar

Noise estimate, returned as a numeric scalar. This output is the power spectral density of the noise present on the estimated channel response coefficients.

Algorithms

The channel estimation algorithm functions as described in the following steps.

1. Extract the PUCCH format 3 demodulation reference signals (DM-RS), or pilot symbols, for a transmit-receive antenna pair from the allocated physical resource blocks within the received subframe.
2. Average the least-squares estimates to reduce any unwanted noise from the pilot symbols.
3. Using the cleaned pilot symbol estimates, interpolate to obtain an estimate of the channel for the allocated subframe slot.

Least-Squares Estimation

The least-squares estimates of the reference signals are obtained by dividing the received pilot symbols by their expected value. The least-squares estimates are affected by any system noise. This noise needs to be removed or reduced to achieve a reasonable estimation of the channel at pilot symbol locations.

Noise Reduction and Interpolation

To minimize the effects of noise on the pilot symbol estimates, the least-squares estimates are averaged. This simple method produces a substantial reduction in the level of noise found on the pilot symbols. The pilot symbol averaging method uses an averaging window defined by the user. The averaging window size is measured in resource elements; any pilot symbols located within the window are used to average the value of the pilot symbol found at the center of the window.

Then, the averaged pilot symbol estimates are used to perform a 2-D interpolation across the slot of the subframe that was allocated to the PUCCH format 3 data. The location of pilot symbols within the subframe is not ideally suited to interpolation. To account for this positioning, virtual pilots are created and placed out with the area of the current subframe. This placement allows complete and accurate interpolation to be performed.

References

[1] 3GPP TS 36.101. “User Equipment (UE) Radio Transmission and Reception.” *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

`griddata` | `lteSCFDMADemodulate` | `lteULChannelEstimate` | `lteULFrameOffsetPUCCH3` | `lteULPerfectChannelEstimate`

Introduced in R2013b

lteULDeprecode

SC-FDMA deprecoding

Syntax

```
out = lteULDeprecode(in,nrb)
```

Description

`out = lteULDeprecode(in,nrb)` performs SC-FDMA deprecoding of the complex modulation symbols `in` for PUSCH configuration with a bandwidth of `nrb` resource blocks.

Examples

Deprecode Symbols After SC-FDMA Demodulation

Deprecode symbols after SC-FDMA demodulation and symbol extraction from the received resource grid.

Create an UL RMC configuration structure, resource grid, and bit stream.

```
rmc = lteRMCUL('A3-2');
[puschInd, info] = ltePUSCHIndices(rmc,rmc.PUSCH);
ueDim = lteULResourceGridSize(rmc);
bits = randi([0,1],info.G,rmc.PUSCH.NLayers);
```

Scramble bits, create modulated symbols, and perform UL precoding and resource mapping.

```
scrBits = lteULScramble(rmc,bits);
symbols = lteSymbolModulate(scrBits,rmc.PUSCH.Modulation);
precodedSymbols = lteULPrecode(symbols,rmc.NULRB);
grid = lteULResourceGrid(rmc);
grid(puschInd) = precodedSymbols;
```

Perform SC-FDMA modulation and demodulation.

```
[timeDomainSig,infoScfdma] = lteSCFDMAModulate(rmc,grid);
```

```
rxGrid = lteSCFDMADemodulate(rmc,timeDomainSig);
```

Extract PUSCH from grid and perform UL deprecoding.

```
rxPrecoded = rxGrid(puschInd);
dePrecodedSymbols = lteULDeprecode(rxPrecoded,rmc.NULRB);
```

Input Arguments

`in` — Complex modulation symbols

numeric matrix

Complex modulation symbols, specified as an N_{Sym}-by-N_L matrix of complex symbols. N_{Sym} is the number of symbols and N_L is the number of layers.

Data Types: `double`
Complex Number Support: Yes

`nrb` — Number of resource blocks

nonnegative integer

Number of resource blocks, specified as a nonnegative integer.

Data Types: `double`

Output Arguments

`out` — Deprecoded PUSCH output symbols

numeric matrix

Deprecoded PUSCH output symbols, returned as an N_{Sym}-by-N_L matrix of complex symbols. N_{Sym} is the number of symbols, and N_L is the number of layers.

The dimension and size of the input and output symbol matrices are the same.

See Also

See Also

`lteLayerDemap` | `ltePUSCHDecode` | `ltePUSCHDeprecode` | `lteULPrecode`

Introduced in R2014a

lteULDescramble

PUSCH descrambling

Syntax

```
out = lteULDescramble(ue,chs,in)
out = lteULDescramble(ue,in)
out = lteULDescramble(in,nsubframe,cellid,rnti)
```

Description

`out = lteULDescramble(ue,chs,in)` performs PUSCH descrambling of the soft bit vector, `in`, or cell array in case of two codewords, according to UE-specific settings in the `ue` structure and UL-SCH related parameters in the `chs` structure. It performs PUSCH descrambling to undo the processing described in TS 36.212, Section 5.3.1 [1] and returns a soft bit vector or cell array of vectors, `out`. This syntax supports the descrambling of control information bits if they are present in the soft bits `in` in conjunction with information bits. The descrambling of the control information bits is done by establishing the correct locations of placeholder bits with the help of UL-SCH-related parameters present in `chs`. The descrambler skips the *'x'* placeholder bits to undo the processing defined in TS 36.212, Section 5.3.1 [1].

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, 1-by-1, structure. In the latter case, any scalar field values apply to both codewords and a scalar `NLayers` is the total number. For further details, see "UL-SCH Parameterization".

`out = lteULDescramble(ue,in)` performs PUSCH descrambling of the soft bit input, `in`, but takes only the UE-specific settings in the `ue` structure. The `in` input should contain only the scrambled data bits resulting in descrambling of transport data only. The `ue` structure must include the `NCellID`, `NSubframe`, and `RNTI` fields.

`out = lteULDescramble(in,nsubframe,cellid,rnti)` performs PUSCH descrambling of soft bits, `in`, for subframe number, `nsubframe`, cell identity, `cellid`, and specified radio network temporary identifier (RNTI), `rnti`. This syntax performs

only block descrambling and expects the input, `in`, to contain only the scrambled data bits. If the `in` vector contains placeholder bits, they are not descrambled correctly because the placeholder bits are not skipped during the descrambling process. Thus, this function syntax descrambles only the transport data bits.

Examples

Scramble and Descramble PUSCH Vector

Perform scrambling and descrambling of vector `in`. The scrambled bits are modulated to QPSK symbols. Noise is added to these symbols, which are then demodulated to produce soft bits. These soft bits are finally descrambled.

```
in = ones(10,1);
ue = struct('NCellID',100,'NSubframe',0,'RNTI',61);
scrBits = lteULScramble(ue,in);
txSymbols = lteSymbolModulate(scrBits,'QPSK');
noise = 0.01*complex(randn(size(txSymbols)),randn(size(txSymbols)));
rxSymbols = txSymbols + noise;
softBits = lteSymbolDemodulate(rxSymbols,'QPSK','Soft');
descram = lteULDescramble(ue,softBits)
```

```
descram =

    0.7125
    0.7202
    0.7254
    0.7028
    0.6845
    0.7037
    0.7157
    0.7429
    0.7039
    0.6794
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure that can contain the following fields.

`NCellID` — Physical layer cell identity
scalar integer

Physical layer cell identity, specified as a scalar integer.

Data Types: `double`

`NSubframe` — Subframe number
scalar integer

Subframe number, specified as a scalar integer.

Data Types: `double`

`RNTI` — Radio network temporary identifier
numeric scalar

Radio network temporary identifier, 16-bit, specified as a numeric scalar.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length
`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`Shortened` — Shorten subframe flag
0 (default) | optional | 1

Shorten subframe flag, specified as 0 or 1. If 1, the last symbol of the subframe is not used and rate matching is adjusted accordingly. This setting is required for subframes with possible SRS transmission.

Data Types: `logical` | `double`

Data Types: `struct`

`chs` — UL-SCH channel-specific settings
structure

UL-SCH channel-specific settings, specified as a structure that can contain the following fields.

`Modulation` — Modulation scheme associated with each transport block

`'QPSK' | '16QAM' | '64QAM'`

Modulation scheme associated with each transport block, specified as `'QPSK'`, `'16QAM'`, or `'64QAM'`

Data Types: `char`

`NLayers` — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, total or per codeword, specified as 1, 2, 3, or 4.

Data Types: `double`

`ORI` — Number of uncoded RI bits

0 (default) | optional | nonnegative scalar integer

Number of uncoded RI bits, specified as a nonnegative scalar integer.

Data Types: `double`

`OACK` — Number of uncoded HARQ-ACK bits

0 (default) | optional | nonnegative scalar integer

Number of uncoded HARQ-ACK bits, specified as a nonnegative scalar integer.

Data Types: `double`

`QdRI` — Number of coded RI symbols in UL-SCH

0 (default) | optional | nonnegative scalar integer

Number of coded RI symbols in UL-SCH, specified as a nonnegative scalar integer. (*Q'_RI*)

Data Types: `double`

`QdACK` — Number of coded HARQ-ACK symbols in UL-SCH

0 (default) | optional | nonnegative scalar integer

Number of coded HARQ-ACK symbols in UL-SCH, specified as a nonnegative scalar integer. (*Q'_ACK*)

Data Types: `double`

Data Types: `struct`

`in` — Soft bit input data

numeric column vector | cell array of numeric column vectors

Soft bit input data, specified as a numeric column vector or cell array of numeric column vectors. This argument contains one or two vectors corresponding to the number of codewords to be scrambled.

Data Types: `double | cell`

`nsubframe` — Subframe number

scalar integer

Subframe number, specified as a scalar integer.

Data Types: `double`

`cellid` — Physical layer cell identity

scalar integer

Physical layer cell identity, specified as a scalar integer.

Data Types: `double`

`rnti` — Radio network temporary identifier

numeric scalar

Radio network temporary identifier, 16-bit, specified as a numeric scalar.

Data Types: `double`

Output Arguments

`out` — PUSCH descrambled output bits

numeric column vector | cell array of numeric column vectors

PUSCH descrambled output bits, returned as a numeric column vector or cell array of numeric column vectors.

Data Types: `double`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCHDecode` | `lteSymbolDemodulate` | `lteULScramble`

Introduced in R2014a

lteULFrameOffset

PUSCH DM-RS uplink subframe timing estimate

Syntax

```
offset = lteULFrameOffset(ue,chs,waveform)
[offset,corr] = lteULFrameOffset(ue,chs,waveform)
```

Description

`offset = lteULFrameOffset(ue,chs,waveform)` performs synchronization using PUSCH DM-RS signals for the time-domain waveform, `waveform`, given UE-specific settings, `ue`, and PUSCH configuration, `chs`.

The returned value `offset` indicates the number of samples from the start of the waveform, `waveform`, to the position in that waveform where the first subframe containing the DM-RS begins.

`offset` provides subframe timing; frame timing can be achieved by using `offset` with the subframe number, `ue.NSubframe`. This information is consistent with real-world operation, since the base station knows when, or in which subframe, to expect uplink transmissions.

`[offset,corr] = lteULFrameOffset(ue,chs,waveform)` also returns a complex matrix `corr`, which is the signal used to extract the timing offset.

Examples

Synchronize and SCFDMA Demodulate Delayed Transmission

Synchronization and demodulation of transmission which has been delayed by 5 samples.

Initialize waveform and insert a 5 sample delay.

```
ue = lteRMCUL('A3-2');
```

```
waveform = lteRMCULTool(ue,[1;0;0;1]);
tx = [zeros(5,1); waveform];
```

Determine `offset` and demodulate the waveform.

```
offset = lteULFrameOffset(ue,ue.PUSCH,tx)
rxGrid = lteSCFDMADemodulate(ue,tx(1+offset:end));
```

```
offset =

     5
```

View PUSCH Transmission Correlation Peaks

View the correlation peak for a transmission waveform that has been delayed. The transmission contains PUSCH demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

UE Configuration

Create configuration structures for `ue.`

```
ue = lteRMCUL('A3-2');
tx = lteRMCULTool(ue,[1;0;0;1]);
```

Determine Offset

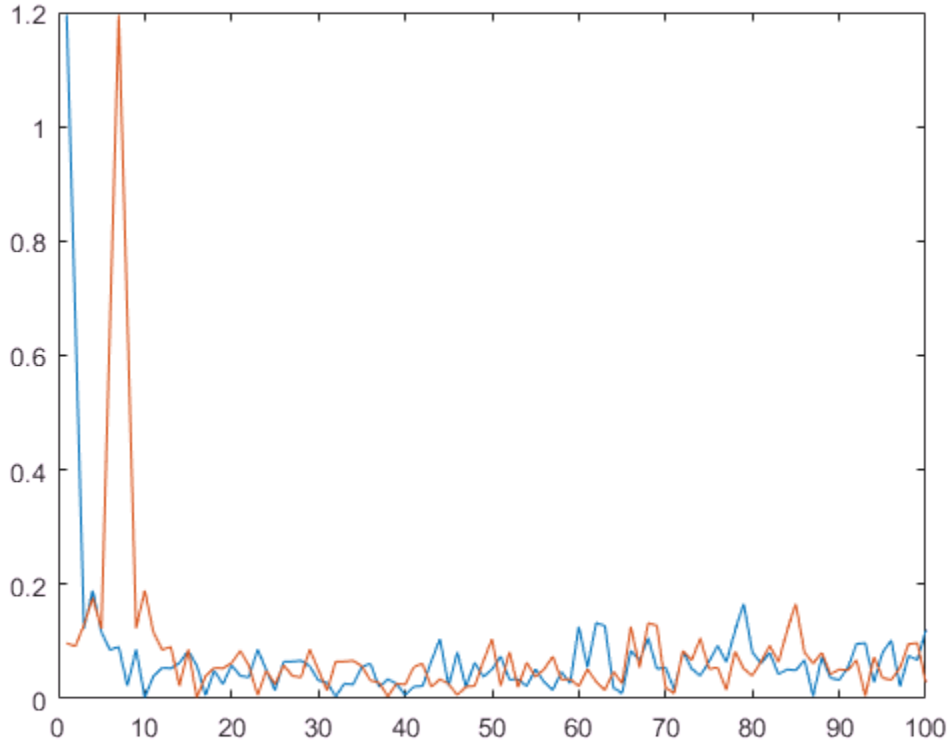
Calculate timing offset and return the correlations for the transmit waveform and for a delayed version of the transmit waveform.

```
[~,corr] = lteULFrameOffset(ue,ue.PUSCH,tx);

txDelayed = [zeros(6,1); tx];
[offset,corrDelayed] = lteULFrameOffset(ue,ue.PUSCH,txDelayed);
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
```

```
hold off
xlim([0 100])
```



Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSCFDMADemodulate(ue,txDelayed(1+offset:end));
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`, or `'Sequence'`	Frequency hopping method.
`SeqGroup`	Optional	0 (default), integer from 0 to 29	PUSCH sequence group assignment (Δ_{SS}). Only used if `NDMRSID` or `NPUSCHID` is absent
`CyclicShift`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for PUSCH DM-RS (yields $n_{DMRS}^{(1)}$).
`NPUSCHID`	Optional	0 (default), nonnegative scalar integer from 0 to 509	PUSCH virtual cell identity. If this field is not present, `NCellID` is used for group hopping sequence-shift pattern initialization. See footnote 1
`NDMRSID`	Optional	0 (default), nonnegative scalar integer from 0 to 509	DM-RS identity for cyclic shift hopping ($n_{ID}^{csh\_DMRS}$). If this field is not present, `NCellID` is used for cyclic shift hopping initialization.

Parameter Field	Required or Optional	Values	Description
			See footnote 1
1 The pseudorandom sequence generator for cyclic shift hopping is initialized according to `NDMRSID`, if present — otherwise it is initialized according to the cell identity `NCellID` and the sequence group assignment `SeqGroup`. Similarly, the sequence-shift pattern for group hopping is initialized according to `NPUSCHID`, if present — otherwise it is initialized according to `NCellID` and `SeqGroup`.			

Data Types: `struct`

chs — PUSCH configuration

scalar structure

PUSCH configuration, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`PRBSet`	Required	Integer column vector or two-column matrix	0-based physical resource block indices (PRBs) for the slots of the current PUSCH resource allocation. As a column vector, the resource allocation is the same in both slots of the subframe. As a two-column matrix, it specifies different PRBs for each slot in a subframe.
`NLayers`	Optional	1 (default), 2, 3, 4	Number of transmission layers.
`DynCyclicShift`	Optional	0 (default), integer from 0 to 7	Cyclic shift for DM-RS (yields $n_{\mathrm{DMRS}}^{(2)}$).
`OrthCover`	Optional	`'Off'` (default), `'On'`	Applies (`'On'`), or does not apply (`'Off'`), orthogonal cover sequence w (*Activate-DMRS-with OCC*).
The following field is required only when `ue.NTxAnts` is set to 2 or 4.			

Parameter Field	Required or Optional	Values	Description
`PMI`	Optional	0 (default), nonnegative scalar integer from 0 to 23.	Scalar precoder matrix indication (PMI) to be used during precoding See `lteULPMIInfo`.

Data Types: `struct`

`waveform` — Time-domain waveform

numeric matrix

Time-domain waveform, specified as a numeric matrix. `waveform` must be a N_S-by-N_R matrix, where N_S is the number of time-domain samples and N_R is the number of receive antennas.

Generate `waveform` by SC-FDMA modulation of a resource matrix using the `lteSCFDMAModulate` function, or by using one of the channel model functions, `lteFadingChannel`, `lteHSTChannel`, or `lteMovingChannel`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`offset` — Offset number of samples

scalar integer

Offset number of samples, returned as a scalar integer. This output is the number of samples from the start of the waveform to the position in that waveform where the first subframe containing the DM-RS begins. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna and the antenna with the strongest correlation is used to compute `offset`.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`corr` — Signal used to extract the timing offset

complex-valued numeric matrix

Signal used to extract the timing offset, returned as a complex-valued numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteFrequencyCorrect` | `lteFrequencyOffset` | `lteHSTChannel` | `lteMovingChannel` | `lteSCFDMADemodulate`

Introduced in R2014a

lteULFrameOffsetPUCCH1

PUCCH format 1 DM-RS uplink subframe timing estimate

Syntax

```
offset = lteULFrameOffsetPUCCH1(ue,chs,waveform)
[offset,corr] = lteULFrameOffsetPUCCH1(ue,chs,waveform)
```

Description

`offset = lteULFrameOffsetPUCCH1(ue,chs,waveform)` performs synchronization using PUCCH format 1 demodulation reference signals (DM-RS) for the time-domain waveform, `waveform`, given UE-specific settings, `ue`, and PUCCH format 1 configuration, `chs`.

The returned value `offset` indicates the number of samples from the start of the waveform `waveform` to the position in that waveform where the first subframe containing the DM-RS begins.

`offset` provides subframe timing. Frame timing can be achieved by using `offset` with the subframe number, `ue.NSubframe`. This behavior is consistent with real-world operation because the base station knows when, or in which subframe, to expect uplink transmissions.

`[offset,corr] = lteULFrameOffsetPUCCH1(ue,chs,waveform)` also returns a complex matrix `corr`, which is the signal used to extract the timing offset.

Examples

Synchronize and Demodulate Using PUCCH Format 1 DM-RS

Synchronizate and demodulate a transmission that has been delayed by four samples using the PUCCH format 1 demodulation reference signal (DM-RS) symbols.

Initialize configuration structures (`ue` and `pucch1`).

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;

pucch1 = struct('ResourceIdx',0);
pucch1.CyclicShifts = 0;
pucch1.DeltaShift = 1;
pucch1.ResourceSize = 0;
```

On the transmit side, populate `reGrid`, generate `waveform`, and insert a delay of four samples.

```
reGrid = lteULResourceGrid(ue);
reGrid(ltePUCCH1DRSIndices(ue,pucch1)) = ltePUCCH1DRS(ue,pucch1);
waveform = lteSCFDMAModulate(ue,reGrid);
tx = [zeros(4,1); waveform];
```

On the receive side, perform synchronization using the PUCCH format 1 DM-RS symbols for the time-domain waveform and demodulate adjusting for the frame timing estimate. Show estimated frame timing offset.

```
fOffset = lteULFrameOffsetPUCCH1(ue,pucch1,tx)
rxGrid = lteSCFDMADemodulate(ue,tx(1+fOffset:end));
```

```
fOffset =

     4
```

View PUCCH Format 1 DM-RS Transmission Correlation Peaks

View the correlation peak for a transmission waveform that has been delayed. The transmission contains PUCCH format 1 demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

UE Configuration

Create configuration structures for `ue` and `pucch1.`

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
```

```
pucch1 = struct('ResourceIdx',0);
pucch1.CyclicShifts = 0;
pucch1.DeltaShift = 1;
pucch1.ResourceSize = 0;
```

Generate Transmission Waveform

On the transmit side, populate a resource grid and generate a waveform containing PUCCH1 DM-RS.

```
reGrid = lteULResourceGrid(ue);
reGrid(ltePUCCH1DRSIndices(ue,pucch1)) = ltePUCCH1DRS(ue,pucch1);

tx = lteSCFDMAModulate(ue,reGrid);
```

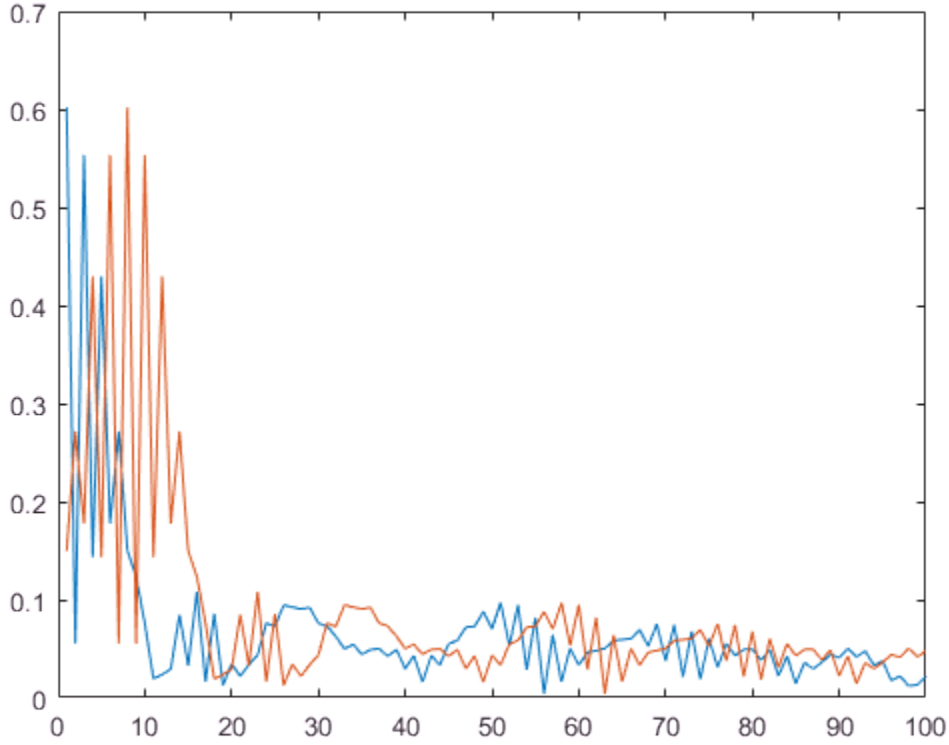
Waveform Reception

On the receive side, calculate timing offset using the PUCCH format 1 DM-RS symbols for the time-domain waveform and return the correlations for the transmit waveform and for a delayed version of the transmit waveform.

```
[~,corr] = lteULFrameOffsetPUCCH1(ue,pucch1,tx);

txDelayed = [zeros(7,1); tx];
[offset,corrDelayed] = lteULFrameOffsetPUCCH1(ue,pucch1,txDelayed);
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
hold off
xlim([0 100])
```



Correct the timing offset and demodulate the received waveform.

```
rrxGrid = lteSCFDMADemodulate(ue,txDelayed(1+offset:end));
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`NPUCCHID`	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

`chs` — PUCCH format 1 configuration

scalar structure

PUCCH format 1 configuration, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 2047 or vector of integers.	PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used for transmission. ($n_{PUCCH}^{(1)}$).

Parameter Field	Required or Optional	Values	Description
			Define one index for each transmission antenna.
`ResourceSize`	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N_{RB}^{(2)}$)
`DeltaShift`	Optional	1 (default), 2, 3	Delta shift, specified as 1, 2, or 3. (Δ_{shift})
`DeltaOffset`	Optional	0 (default), 1, 2	(Δ_{offset}). Warning: The use of this parameter field is not advised. It applies only to 3GPP releases preceding v8.5.0. This parameter will be removed in a future release.
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{cs}^{(1)}$)

Data Types: `struct`

`waveform` — Time-domain waveform

numeric matrix

Time-domain waveform, specified as a numeric matrix. `waveform` must be a N_S-by-N_R matrix, where N_S is the number of time-domain samples and N_R is the number of receive antennas.

Generate `waveform` by SC-FDMA modulation of a resource matrix using `lteSCFDMAModulate` function, or by using one of the channel model functions (`lteFadingChannel`, `lteHSTChannel`, or `lteMovingChannel`).

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`offset` — Number of samples from the start of the waveform to the position in that waveform where the first subframe begins

scalar integer

Number of samples from the start of the waveform to the position in that waveform where the first subframe containing the DM-RS begins, returned as a scalar integer. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna and the antenna with the strongest correlation is used to compute `offset`.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`corr` — Signal used to extract the timing offset

numeric matrix

Signal used to extract the timing offset, returned as a complex numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteHSTChannel` | `lteMovingChannel` | `lteSCFDMADemodulate` | `lteULFrameOffset` | `lteULFrameOffsetPUCCH2` | `lteULFrameOffsetPUCCH3`

Introduced in R2014a

lteULFrameOffsetPUCCH2

PUCCH format 2 DM-RS uplink subframe timing estimate

Syntax

```
offset = lteULFrameOffsetPUCCH2(ue,chs,waveform,oack)
[offset,ack] = lteULFrameOffsetPUCCH2(ue,chs,waveform,oack)
[offset,ack,corr] = lteULFrameOffsetPUCCH2(ue,chs,waveform,oack)
```

Description

`offset = lteULFrameOffsetPUCCH2(ue,chs,waveform,oack)` performs synchronization using PUCCH format 2 demodulation reference signals (DM-RS) for the time-domain waveform, `waveform`, given UE-specific settings, `ue`, PUCCH format 2 configuration `chs`, and the number of Hybrid ARQ indicators `oack`.

The returned value `offset` indicates the number of samples from the start of the waveform `waveform` to the position in that waveform where the first subframe containing the DM-RS begins.

`offset` provides subframe timing; frame timing can be achieved by using `offset` with the subframe number, `ueNSubframe`. This behavior is consistent with real-world operation because the base station knows when, in which subframe, to expect uplink transmissions.

`[offset,ack] = lteULFrameOffsetPUCCH2(ue,chs,waveform,oack)` also returns a vector `ack` of decoded PUCCH format 2 Hybrid ARQ indicators.

`[offset,ack,corr] = lteULFrameOffsetPUCCH2(ue,chs,waveform,oack)` also returns a complex matrix `corr`, which is used to extract the timing offset.

Examples

Synchronize and Demodulate Using PUCCH Format 2 DM-RS

This example performs synchronization and uses the PUCCH format 2 DM-RS when demodulating a transmission that has been delayed by 5 samples.

Initialize ue specific parameter structure, PUCCH2 structure, UL resource grid and txAck parameter.

```
ue.NULRB = 6;
ue.NCellID = 0;
ue.NSubframe = 0;
ue.Hopping = 'Off';
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
pucch2.ResourceIdx = 0;
pucch2.ResourceSize = 0;
pucch2.CyclicShifts = 0;
rgrid = lteULResourceGrid(ue);
txAck = [1;1];
rgrid(ltePUCCH2DRSIndices(ue,pucch2)) = ltePUCCH2DRS(ue,pucch2,txAck);
```

Generate modulated waveform and add a five sample delay.

```
waveform = lteSCFDMAModulate(ue,rgrid);
tx = [zeros(5,1);waveform];
```

Use PUCCH format 2 DM-RS to estimate UL frame offset timing, then demodulate the waveform.

```
offset = lteULFrameOffsetPUCCH2(ue,pucch2,tx,length(txAck))
rxGrid = lteSCFDMADemodulate(ue,tx(1+offset:end));
```

```
offset =

     5
```

View PUCCH Format 2 H-ARQ Indicators

View the Hybrid ARQ indicators for a PUCCH format 2 transmission waveform. The transmission contains PUCCH format 2 demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

UE Configuration

Create configuration structures for `ue` and pucch2.

```
ue.NULRB = 6;
ue.NCellID = 0;
```

```
ue.NSubframe = 0;
ue.Hopping = 'Off';
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;

pucch2.ResourceIdx = 0;
pucch2.ResourceSize = 0;
pucch2.CyclicShifts = 0;
```

Generate Transmission Waveform

On the transmit side, populate a resource grid and generate a waveform containing PUCCH2 DM-RS.

```
reGrid = lteULResourceGrid(ue);
txAck = [0;1];
reGrid(ltePUCCH2DRSIndices(ue,pucch2)) = ltePUCCH2DRS(ue,pucch2,txAck);

tx = lteSCFDMAModulate(ue,reGrid);
```

Waveform Reception

On the receive side, calculate timing offset using the PUCCH2 DM-RS symbols for the time-domain waveform and return decoded PUCCH format 2 Hybrid ARQ indicators.

```
[offset,ack] = lteULFrameOffsetPUCCH2(ue,pucch2,tx,length(txAck));
ack
```

```
ack = 2×1 logical array
   0
   1
```

Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSCFDMADemodulate(ue,tx(1+offset:end));
```

View PUCCH Format 2 DM-RS Transmission Correlation Peaks

View the correlation peak for a transmission waveform that has been delayed. The transmission contains PUCCH format 2 demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

UE Configuration

Create configuration structures for `ue` and pucch2.

```
ue.NULRB = 6;
ue.NCellID = 0;
ue.NSubframe = 0;
ue.Hopping = 'Off';
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;

pucch2.ResourceIdx = 0;
pucch2.ResourceSize = 0;
pucch2.CyclicShifts = 0;
```

Generate Transmission Waveform

On the transmit side, populate a resource grid and generate a waveform containing PUCCH2 DM-RS.

```
reGrid = lteULResourceGrid(ue);
txAck = [1;1];
reGrid(ltePUCCH2DRSIndices(ue,pucch2)) = ltePUCCH2DRS(ue,pucch2,txAck);

tx = lteSCFDMAModulate(ue,reGrid);
```

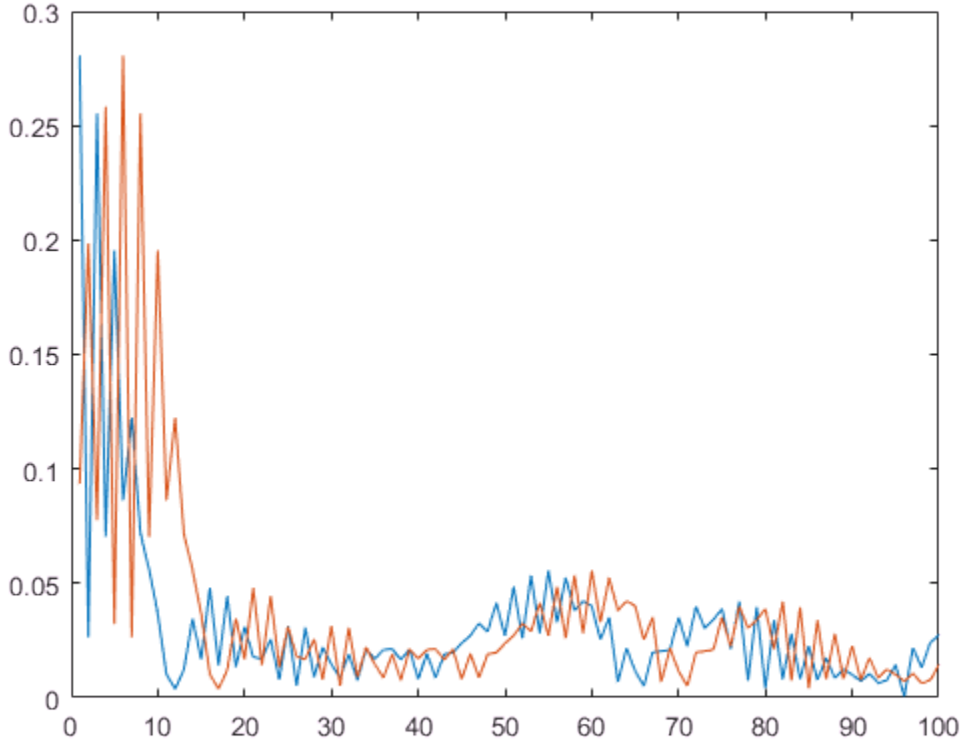
Waveform Reception

On the receive side, calculate timing offset using the PUCCH2 DM-RS symbols for the time-domain waveform and return the correlations for the transmit waveform and for a delayed version of the transmit waveform.

```
[~,ack,corr] = lteULFrameOffsetPUCCH2(ue,pucch2,tx,length(txAck));

txDelayed = [zeros(5,1); tx];
[offset,ack,corrDelayed] = lteULFrameOffsetPUCCH2(ue,pucch2,txDelayed,length(txAck));
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
hold off
xlim([0 100])
```



Correct the timing offset and demodulate the received waveform.

```
rrxGrid = lteSCFDMADemodulate(ue,txDelayed(1+offset:end));
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`NULRB`	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
`NCellID`	Required	Integer from 0 to 503	Physical layer cell identity
`NSubframe`	Required	0 (default), nonnegative scalar integer	Subframe number
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
`NTxAnts`	Optional	1 (default), 2, 4	Number of transmission antennas.
`Hopping`	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
`NPUCCHID`	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

`chs` — PUCCH format 2 configuration

scalar structure

PUCCH format 2 configuration, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`ResourceIdx`	Optional	0 (default), integer from 0 to 1185 or vector of integers.	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission. ($n_{PUCCH}^{(2)}$). Define one index for each transmission antenna.
`ResourceSize`	Optional	0 (default), integer from 0 to 98.	Size of resource allocated to PUCCH format 2 ($N_{RB}^{(2)}$)

Parameter Field	Required or Optional	Values	Description
`CyclicShifts`	Optional	0 (default), integer from 0 to 7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{cs}^{(1)}$)

Data Types: `struct`

`waveform` — Time-domain waveform

numeric matrix

Time-domain waveform, specified as a numeric matrix. `waveform` must be a N_S-by-N_R matrix, where N_S is the number of time-domain samples and N_R is the number of receive antennas.

Generate `waveform` by SC-FDMA modulation of a resource matrix using the `lteSCFDMAModulate` function, or by using one of the channel model functions, `lteFadingChannel`, `lteHSTChannel`, or `lteMovingChannel`.

Data Types: `double`
Complex Number Support: Yes

`oack` — Number of uncoded Hybrid ARQ bits

1 | 2

Number of uncoded Hybrid ARQ bits exbected, 1 (PUCCH format 2a) or 2 (PUCCH format 2b).

Data Types: `double`

Output Arguments

`offset` — Number of samples from the start of the waveform to the position in that waveform where the first subframe begins

scalar integer

Number of samples from the start of the waveform to the position in that waveform where the first subframe containing the DM-RS begins, returned as a scalar integer. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna and the antenna with the strongest correlation is used to compute `offset`. This process is repeated for either one or two Hybrid ARQ indicators combination as specified by the parameter `oack`. This correlation amounts to a maximum likelihood (ML) decoding of the Hybrid ARQ indicators, which are signaled on the PUCCH format 2 DM-RS.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`ack` — Decoded PUCCH format 2 Hybrid ARQ bits

numeric vector or matrix

Decoded PUCCH format 2 Hybrid ARQ bits, returned as a numeric vector or matrix. If multiple decoded Hybrid ARQ indicator vectors have a likelihood equal to the maximum, `ack` is a matrix where each column represents one of the equally likely Hybrid ARQ indicator vectors.

`corr` — Signal used to extract the timing offset

numeric matrix

Signal used to extract the timing offset, returned as a complex numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteHSTChannel` | `lteMovingChannel` | `lteSCFDMADemodulate` | `lteULFrameOffset` | `lteULFrameOffsetPUCCH1` | `lteULFrameOffsetPUCCH3`

Introduced in R2014a

lteULFrameOffsetPUCCH3

PUCCH format 3 DM-RS uplink subframe timing estimate

Syntax

```
offset = lteULFrameOffsetPUCCH3(ue,chs,waveform)
[offset corr] = lteULFrameOffsetPUCCH3(ue,chs,waveform)
```

Description

`offset = lteULFrameOffsetPUCCH3(ue,chs,waveform)` performs synchronization using PUCCH format 3 demodulation reference signals (DM-RS) for the time-domain waveform, `waveform`, given UE-specific settings, `ue`, and PUCCH format 3 configuration, `chs`.

The returned value, `offset`, indicates the number of samples from the start of the waveform, `waveform`, to the position in that waveform where the first subframe containing the DM-RS begins.

`offset` provides subframe timing; frame timing can be achieved by using `offset` with the subframe number, `ue.NSubframe`. This behavior is consistent with real-world operation because the base station knows when, or in which subframe, to expect uplink transmissions.

`[offset corr] = lteULFrameOffsetPUCCH3(ue,chs,waveform)` also returns a complex-valued matrix `corr`, which is the signal used to extract the timing offset.

Examples

Synchronize and Demododulate Using PUCCH Format 3 DM-RS

Synchronize and demodulate a transmission that has been delayed by seven samples using the PUCCH format 3 demodulation reference signal (DM-RS) symbols.

Initialize configuration structures (`ue` and `pucch3`).

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
ue.Shortened = 0;

pucch3 = struct('ResourceIdx',0);
```

On the transmit side, populate `reGrid`, generate `waveform`, and insert a delay of seven samples.

```
reGrid = lteULResourceGrid(ue);
reGrid(ltePUCCH3DRSIndices(ue,pucch3)) = ltePUCCH3DRS(ue,pucch3);
waveform = lteSCFDMAModulate(ue,reGrid);
tx = [zeros(7,1); waveform];
```

On the receive side, perform synchronization using the PUCCH format 3 DM-RS symbols for the time-domain waveform and demodulate adjusting for the frame timing estimate. Show estimated frame timing offset.

```
fOffset = lteULFrameOffsetPUCCH3(ue,pucch3,tx)
rxGrid = lteSCFDMADemodulate(ue,tx(1+fOffset:end));
```

```
fOffset =

     7
```

View PUCCH Format 3 DM-RS Transmission Correlation Peaks

View the correlation peak for a transmission waveform that has been delayed. The transmission contains PUCCH format 3 demodulation reference signal (DM-RS) symbols avaliable for estimating the waveform timing.

UE Configuration

Create configuration structures for `ue` and pucch3.

```
ue = struct('NULRB',6,'NCellID',0,'NSubframe',0,'Hopping','Off');
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 1;
ue.Shortened = 0;

pucch3 = struct('ResourceIdx',0);
```

Generate Transmission Waveform

On the transmit side, populate a resource grid and generate a waveform containing PUCCH3 DM-RS.

```
reGrid = lteULResourceGrid(ue);
reGrid(ltePUCCH3DRSIndices(ue,pucch3)) = ltePUCCH3DRS(ue,pucch3);

tx = lteSCFDMAModulate(ue,reGrid);
```

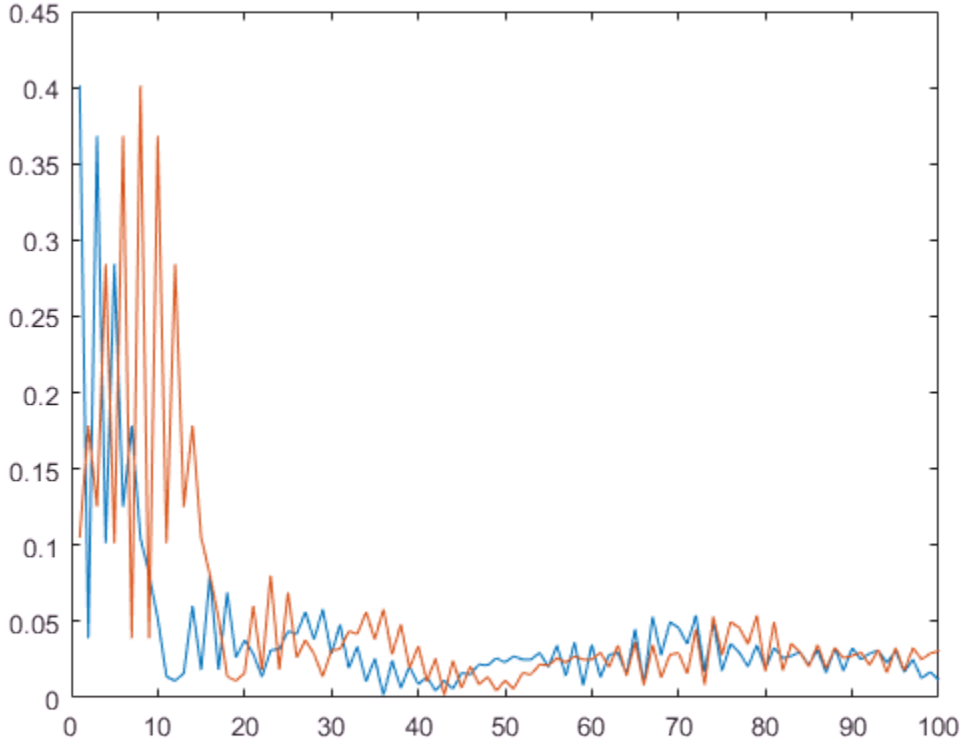
Waveform Reception

On the receive side, calculate timing offset using the PUCCH3 DM-RS symbols for the time-domain waveform and return the correlations for the transmit waveform and for a delayed version of the transmit waveform.

```
[~,corr] = lteULFrameOffsetPUCCH3(ue,pucch3,tx);

txDelayed = [zeros(7,1); tx];
[offset,corrDelayed] = lteULFrameOffsetPUCCH3(ue,pucch3,txDelayed);
```

Plot the correlation data before and after delay is added. Zoom in on the *x*-axis to view correlation peaks.

```
plot(corr)
hold on
plot(corrDelayed)
hold off
xlim([0 100])
```



Correct the timing offset and demodulate the received waveform.

```
rxGrid = lteSCFDMADemodulate(ue,txDelayed(1+offset:end));
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
NCellID	Required	Integer from 0 to 503	Physical layer cell identity
NSubframe	Required	0 (default), nonnegative scalar integer	Subframe number
CyclicPrefixUL	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length
NTxAnts	Optional	1 (default), 2, 4	Number of transmission antennas.
Hopping	Optional	`'Off'` (default), `'Group'`	Frequency hopping method.
Shortened	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If 1, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.
NPUCCHID	Optional	Integer from 0 to 503	PUCCH virtual cell identity. If this field is not present, `NCellID` is used as the identity.

Data Types: `struct`

chs — PUCCH format 3 configuration

scalar structure

PUCCH format 3 configuration, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
ResourceIdx	Optional	0 (default), integer from 0 to 549, or vector of integers.	PUCCH resource indices which determine the physical

Parameter Field	Required or Optional	Values	Description
			resource blocks, cyclic shift, and orthogonal cover used for transmission ($n^{(3)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.

Data Types: `struct`

`waveform` — Time-domain waveform
numeric matrix

Time-domain waveform, specified as a numeric matrix. `waveform` must be a N_S-by-N_R matrix, where N_S is the number of time-domain samples and N_R is the number of receive antennas.

Generate `waveform` by SC-FDMA modulation of a resource matrix using the `lteSCFDMAModulate` function, or by using one of the channel model functions, `lteFadingChannel`, `lteHSTChannel`, or `lteMovingChannel`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

`offset` — Number of samples from the start of the waveform to the position in that waveform where the first subframe begins
scalar integer

Number of samples from the start of the waveform to the position in that waveform where the first subframe begins, returned as a scalar integer. `offset` is computed by extracting the timing of the peak of the correlation between `waveform` and internally generated reference waveforms containing DM-RS signals. The correlation is performed separately for each antenna and the antenna with the strongest correlation is used to compute `offset`.

Note: `offset` is the position of `mod(max(abs(corr),`L_{SF}`))`, where L_{SF} is the subframe length.

`corr` — Signal used to extract the timing offset
numeric matrix

Signal used to extract the timing offset, returned as a numeric matrix. `corr` has the same dimensions as `waveform`.

See Also

See Also

`lteFadingChannel` | `lteHSTChannel` | `lteMovingChannel` | `lteSCFDMADemodulate` | `lteULFrameOffset` | `lteULFrameOffsetPUCCH1` | `lteULFrameOffsetPUCCH2`

Introduced in R2014a

lteULPMIInfo

PUSCH precoder matrix indication reporting information

Syntax

```
info=lteULPMIInfo(ue,chs)
```

Description

`info=lteULPMIInfo(ue,chs)` returns a structure `info` containing information related to precoder matrix indication (PMI) reporting.

You can use `info.NSubbands` to determine the correct size of the vector PMI required for closed-loop spatial multiplexing operation. PMI is a column vector with `info.NSubbands` rows. Currently, only wideband PMI reporting is defined by the standard. Thus, the number of subbands, `info.NSubbands`, is always 1. This field and `info.k` are provided for consistency with the downlink version of this function, `ltePMIInfo`.

Examples

Get PUSCH PMI Reporting Information

```
Get PMI reporting information for FRC A3-2.

ue = lteRMCUL('A3-2');
pmiInfo = lteULPMIInfo(ue, ue.PUSCH)


pmiInfo =

  struct with fields:

           k: 6
    NSubbands: 1
       MaxPMI: 0
```

Input Arguments

ue — UE-specific configuration

structure

UE-specific configuration, specified as a structure. `ue` can contain the following fields.

NULRB — Number of uplink resource blocks

6 | 15 | 25 | 50 | 75 | 100

Number of uplink resource blocks, specified as a positive scalar integer.

Data Types: `double`

NTxAnts — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as a positive scalar integer. Optional. Valid values are 1, 2, and 4.

Data Types: `double`

Data Types: `struct`

chs — PUSCH channel settings

structure

PUSCH channel settings, specified as a structure with the following fields.

NLayers — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, specified as 1, 2, 3, or 4. Optional.

Data Types: `double`

Data Types: `struct`

Output Arguments

`info` — Information related to PMI reporting
structure

Information related to PMI reporting, returned as a structure with these fields.

`k` — Subband size
scalar integer

Subband size, in resource blocks (RBs), returned as a scalar integer. This parameter is equal to `NULRB`.

Data Types: `double`

`NSubbands` — Number of subbands for PMI reporting
scalar integer

Number of subbands for PMI reporting, returned as a scalar integer. This parameter is equal to 1 for wideband PMI.

Data Types: `double`

`MaxPMI` — Maximum permitted PMI value for the given configuration
scalar integer

Maximum permitted PMI value for the given configuration, returned as a scalar integer. Valid PMI values range from 0 to `MaxPMI`.

Data Types: `double`

See Also

See Also
`ltePUSCH` | `ltePUSCHPrecode` | `lteULPMISelect`

Introduced in R2014a

lteULPMISelect

PUSCH precoder matrix indication calculation

Syntax

```
pmi = lteULPMISelect(ue,chs,hest,noiseest)
pmi = lteULPMISelect(ue,chs,hest,noiseest,refgrid)
pmi = lteULPMISelect(ue,chs,hest,noiseest,refgrid,cec)
```

Description

`pmi = lteULPMISelect(ue,chs,hest,noiseest)` performs PUSCH precoder matrix indication (PMI) calculation for given UE-specific settings, `ue`, channel configuration structure, `chs`, channel estimate resource array, `hest`, and receiver noise variance, `noiseest`. The output, `pmi`, is a scalar containing the PMI selected for closed-loop transmission.

`hest` is a 4-D array of size *M*-by-*N*-by-`NRxAnts`-by-`NTxAnts`, where *M* is the number of subcarriers, *N* is the number of SC-FDMA symbols, `NRxAnts` is the number of receive antennas, and `NTxAnts` is the number of transmit antennas.

`noiseest` is a scalar, an estimate of the received noise power spectral density.

`pmi = lteULPMISelect(ue,chs,hest,noiseest,refgrid)` provides an additional input `refgrid`, a 3-D *M*-by-*N*-by-`NTxAnts` array containing known transmitted data symbols in their correct locations. All other locations i.e. DRS Symbols and unknown data symbol locations should be represented by a `NaN`. This is the same array as the additional `refgrid` input described for the `lteULChannelEstimate` function. For PMI selection the symbols in `refgrid` are ignored, but the non-`NaN` RE locations are used as RE locations at which to sample the channel estimate and perform PMI estimation. This approach can be used to provide a `refgrid` containing for example the SRS RE locations created on all `NTxAnts`, allowing for full-rank channel estimation for the purposes of PMI selection when the PUSCH is transmitted with less than full rank.

`pmi = lteULPMISelect(ue,chs,hest,noiseest,refgrid,cec)` accepts channel estimator configuration structure `cec` containing the field `Reference`.

`Reference = 'None'` will generate no internal reference signals, and the PMI estimation can be performed on arbitrary known REs as given by the `refgrid` argument. This approach can be used to provide a `refgrid` containing for example the SRS signals created on all `NTxAnts`, allowing for full-rank PMI estimation for the purposes of PMI selection when the PUSCH is transmitted with less than full rank. `Reference = 'Antennas'` or `Reference = 'Layers'` will use the PUSCH DMRS RE indices as reference locations for PMI estimation; additional references can still be provided in `refgrid`.

Examples

Calculate PUSCH PMI

This example creates an empty resource grid for RMC A3-2 and amend it for MIMO configuration.

Initialize ue specific parameter structure and create an empty resource grid for RMC A3-2 and amend it for MIMO configuration.

```
ue = lteRMCUL('A3-2');
ue.NTxAnts = 4;
ue.PUSCH.NLayers = 2;
rgrid = lteULResourceGrid(ue);
rgrid(ltePUSCHDRSIndices(ue,ue.PUSCH)) = ltePUSCHDRS(ue,ue.PUSCH);
```

Generate modulated waveform.

```
txWaveform = lteSCFDMAModulate(ue,rgrid);
```

Configure a fading channel.

```
chcfg.Seed = 100;
chcfg.DelayProfile = 'EPA';
chcfg.NRxAnts = 2;
chcfg.InitTime = 100;
chcfg.InitPhase = 'Random';
chcfg.ModelType = 'GMEDS';
chcfg.NTerms = 16;
chcfg.NormalizeTxAnts = 'On';
chcfg.NormalizePathGains = 'On';
chcfg.DopplerFreq = 50.0;
chcfg.MIMOCorrelation = 'Low';
```

```
chcfg.SamplingRate = 15360000;
```

Filter the transmit waveform through a fading channel and perform SC-FDMA demodulation.

```
rxWaveform = lteFadingChannel(chcfg,txWaveform);
rxSubframe = lteSCFDMADemodulate(ue,rxWaveform);
```

Estimate the corresponding channel and the noise power spectral density on the reference signal subcarriers.

```
cec = struct('FreqWindow',12,'TimeWindow',1,'InterpType','cubic');
cec.PilotAverage = 'UserDefined';
cec.Reference = 'Antennas';

[hest,noiseEst] = lteULChannelEstimate(ue,ue.PUSCH,cec,rxSubframe);
```

Use this estimate to calculate the precoder matrix indication (PMI).

```
pmi = lteULPMISelect(ue,ue.PUSCH,hest,noiseEst)
```

```
pmi =

     4
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields.

NULRB — Number of uplink (UL) resource blocks (RBs)

scalar integer

Number of uplink (UL) resource blocks (RBs), specified as a scalar integer.

Data Types: `double`

CyclicPrefixUL — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NTxAnts` — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as 1, 2, or 4.

Data Types: `double`

Data Types: `struct`

`chs` — Channel configuration structure

scalar structure

Channel configuration structure, specified as a scalar structure with the following fields.

`PRBSet` — Physical Resource Block indices

numeric column matrix

Physical Resource Block indices, specified as a numeric column matrix. `PRBSet` can be a 1- or 2-column matrix, containing the 0-based Physical Resource Block indices (PRBs) corresponding to the resource allocations for this PUSCH.

Data Types: `double`

`NLayers` — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, specified as 1, 2, 3, or 4.

Data Types: `double`

Data Types: `struct`

`hest` — Channel estimate

4-D numeric array

Channel estimate, specified as a 4-D numeric array of size *M*-by-*N*-by-`NRxAnts`-by-`NTxAnts`. *M* is the number of subcarriers, *N* is the number of SC-FDMA symbols, `NRxAnts` is the number of receive antennas and `NTxAnts` is the number of transmit antennas.

Data Types: `double`
Complex Number Support: Yes

`noiseest` — Receiver noise variance

numeric scalar

Receiver noise variance, specified as a numeric scalar. It is an estimate of the received noise power spectral density.

Data Types: `double`

`refgrid` — Transmitted data symbols

3-D numeric array

Transmitted data symbols, specified as a 3-D numeric array. `refgrid` is an *M*-by-*N*-by-`NTxAnts` array containing known symbols in their correct locations.

Data Types: `double`
Complex Number Support: Yes

`cec` — Channel estimator configuration

scalar structure

Channel estimator configuration, specified as a scalar structure with the following fields.

`Reference` — Point of reference (indices to internally generate) for PMI estimation

`'Antennas'` (default) | optional | `'Layers'` | `'None'`

Point of reference (indices to internally generate) for PMI estimation. `Reference` = `'None'` generates no internal reference signals, and the PMI estimation can be performed on arbitrary known REs as given by the `refgrid` argument. `Reference` = `'Antennas'` or `Reference` = `'Layers'` uses the PUSCH DMRS RE indices as reference locations for PMI estimation; additional references can still be provided in `refgrid`.

Data Types: `char`

Data Types: `struct`

Output Arguments

`pmi` — Precoder matrix indication selected for closed-loop transmission

numeric scalar (0...23)

Precoder matrix indication selected for closed-loop transmission, returned as a numeric scalar between 0 and 23.

See Also

See Also

`ltePUSCH` | `ltePUSCHPrecode` | `lteULPMIInfo`

Introduced in R2014a

lteULPerfectChannelEstimate

Uplink perfect channel estimation

Syntax

```
hest = lteULPerfectChannelEstimate(ue,propchan)
hest = lteULPerfectChannelEstimate(ue,propchan,toffset)
```

Description

`hest = lteULPerfectChannelEstimate(ue,propchan)` performs perfect channel estimation for a system configuration given structures containing the UE-specific settings, and the propagation channel configuration. The perfect channel estimates are only produced for the fading channel model created using the `lteFadingChannel` toolbox function.

This function provides a perfect MIMO channel estimate after SC-FDMA modulation. Perfect channel estimation is achieved by setting the channel with the desired configuration and sending a set of known symbols through it, for each transmit antenna in turn.

`hest = lteULPerfectChannelEstimate(ue,propchan,toffset)` adds the parameter `toffset`, which specifies the timing offset. This parameter allows `hest` to be the precise channel that results when the receiver is precisely synchronized.

Examples

Perform Perfect UL Channel Estimation

Perform perfect channel estimation for a given propagation channel configuration.

Initialize strucutres for UE configuration and propagation channel configuration.

```
ue.NULRB = 6;
```

```
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 2;
ue.TotSubframes = 1;

chs.Seed = 1;
chs.DelayProfile = 'EPA';
chs.NRxAnts = 4;
chs.DopplerFreq = 5.0;
chs.MIMOCorrelation = 'Low';
chs.InitPhase = 'Random';
chs.InitTime = 0.0;
chs.ModelType = 'GMEDS';
chs.NTerms = 16;
chs.NormalizeTxAnts = 'On';
chs.NormalizePathGains = 'On';
```

Perform perfect channel estimation and display dimension of channel estimate array.

```
H = lteULPerfectChannelEstimate(ue, chs);
sizeH = size(H)
```

```
sizeH =

    72    14     4     2
```

Perform Perfect UL Channel Estimation on a Time Offset Waveform

Perform perfect channel estimation on a time offset waveform that has passed through a fading channel.

Configuration initialization

Initialize structures for UE configuration and propagation channel configuration, and timing offset.

```
ue = lteRMCUL('A1-1','FDD',1);
ue.NULRB = 10;
ue.CyclicPrefixUL = 'Normal';
ue.NTxAnts = 4;
ue.TotSubframes = 1;

propchan.Seed = 1;
```

```
propchan.DelayProfile = 'EVA';
propchan.NRxAnts = 2;
propchan.DopplerFreq = 5.0;
propchan.MIMOCorrelation = 'UplinkMedium';
propchan.InitPhase = 'Random';
propchan.InitTime = 0.0;
propchan.ModelType = 'GMEDS';
propchan.NTerms = 16;
propchan.NormalizeTxAnts = 'On';
propchan.NormalizePathGains = 'On';
```

Waveform processing

- Create waveform and add samples for channel delay.
- Pass through a fading channel, generating time-domain receiver samples.

```
[txwave,txgrid,rmcCfg] = lteRMCULTool(ue,[1;0;0;1]);
txwave = [txwave; zeros(25,4)];
propchan.SamplingRate = rmcCfg.SamplingRate;
rxwave = lteFadingChannel(propchan,txwave);
```

Determine timing offset

- Use lteULFrameOffset to estimate time offset.
- Account for timing offset in the received waveform.

```
toffset = lteULFrameOffset(ue,ue.PUSCH,rxwave)
rxwave = rxwave(1+toffset:end,:);
```

```
toffset =

     8
```

Demodulation and perfect channel estimation

- Demodulate `rxwave` to generate frequency-domain receiver data in `rxgrid`.
- Equalize with perfect channel estimate with time offset.
- Plot resource element grids to show impact of fading channel on the transmitted signal and recovery of the signal using the perfect channel estimate.

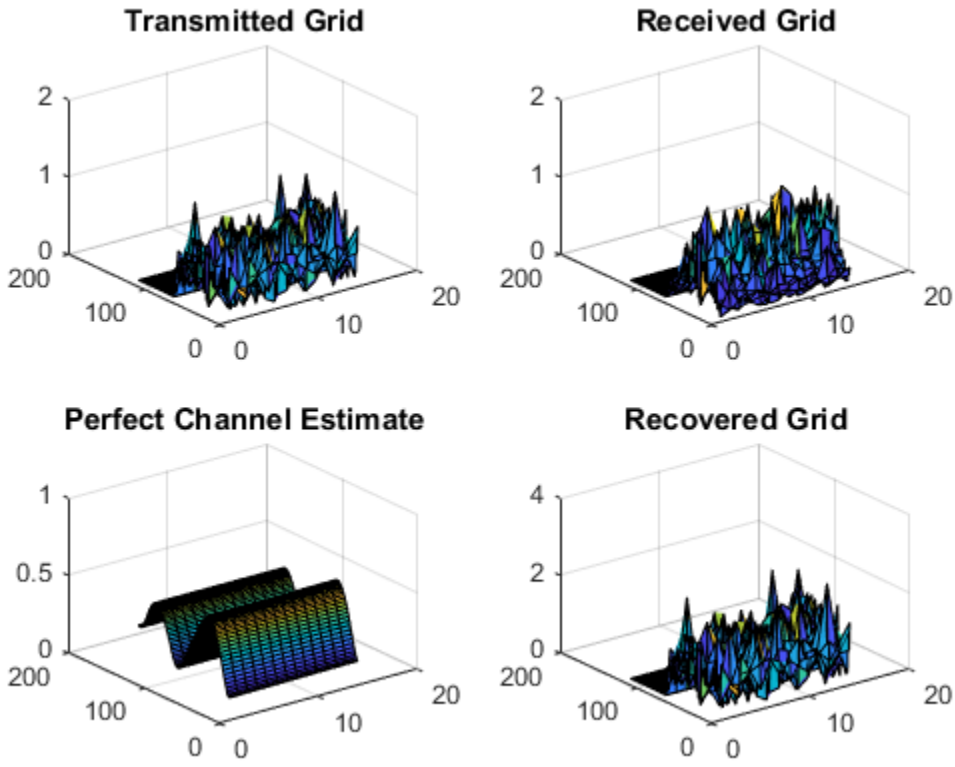
```
rxgrid = lteSCFDMADemodulate(ue,rxwave);
```

```
hest = lteULPerfectChannelEstimate(ue,propchan,toffset);
sizeH = size(hest)
```

```
sizeH =

   120    14     2     4
```

The output channel estimate is a 4D array. The input specified ten resource blocks leading to 120 subcarriers per symbol. Normal cyclic prefix results in 14 symbols per subframe. The third and forth dimensions reflect the 2 receive and 4 transmit antennas specified in the input configuration structures.

```
recoveredgrid = rxgrid./hest;

subplot(2,2,1)
surf(abs(txgrid(:,:,1,1)))
title('Transmitted Grid')
subplot(2,2,2)
surf(abs(rxgrid(:,:,1,1)))
title('Received Grid')
subplot(2,2,3)
surf(abs(hest(:,:,1,1)))
title('Perfect Channel Estimate')
subplot(2,2,4)
surf(abs(recoveredgrid(:,:,1,1)))
title('Recovered Grid')
```



Comparing the transmitted grid to the recovered grid, shows equalization of the received grid with the perfect channel estimate recovers the transmission.

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
NULRB	Required	Scalar integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
CyclicPre	Optional	'Normal' (default), 'Extended'	Cyclic prefix length.
NTxAnts	Required	1, 2, 4	Number of transmission antennas.
TotSubfra	Optional	Nonnegative scalar integer (default 1)	Total number of subframes to generate

Data Types: struct

propchan — Propagation channel configuration structure

scalar structure

Propagation channel configuration structure, specified as a scalar structure. propchan must contain the fields required to parameterize the channel model for lteFadingChannel to be configured.

Note: Before execution of the channel itself, lteULPerfectChannelEstimate sets SamplingRate internally to the sampling rate of the time domain waveform passed to lteFadingChannel for channel filtering. Therefore, the propchan structure does not require the SamplingRate field. If one is included, it is not used.

Parameter Field	Required or Optional	Values	Description
NRxAnts	Required	1, 2, 4	Number of receive antennas
MIMOCorre	Required	'Low', 'Medium', 'UplinkMedium', 'High', 'Custom'	Correlation between UE and eNodeB antennas • 'Low' correlation is equivalent to no correlation between antennas.

Parameter Field	Required or Optional	Values	Description
			• `'Medium'` correlation level is applicable to tests defined in TS 36.101 [1]. • `'UplinkMedium'` correlation level is applicable to tests defined in TS 36.104 [2].
`Normalize`	Optional	`'On'` (default), `'Off'`	Transmit antenna number normalization. • `'On'`, this function normalizes the model output by `1/sqrt(`N_{TX}`)`, where N_{TX} is the number of transmit antennas. Normalization by the number of transmit antennas ensures that the output power per receive antenna is unaffected by the number of transmit antennas. • `'Off'`, normalization is not performed.

Parameter Field	Required or Optional	Values	Description
DelayProf	Required	`'EPA'`, `'EVA'`, `'ETU'`, `'Custom'`, `'Off'`	Delay profile model. For more information, see "Propagation Channel Models". Setting `DelayProfile` to `'Off'` switches off fading completely and implements a static MIMO channel model. In this case, the antenna geometry corresponds to `propchan.MIMOCorrelation`, `propchan.NRxAnts`, and the number of transmit antennas. The temporal part of the model for each link between transmit and receive antennas consists of a single path with zero delay and constant unit gain.
The following fields are applicable when `DelayProfile` is set to a value other than `'Off'`.			
Doppl	Required	Numeric value	Maximum *Doppler* frequency, in Hz.
InitT	Required	Numeric value	Fading process time offset, in seconds.
NTerm	Optional	Positive integer, 16 (default), power of 2	Number of oscillators used in fading path modeling.

Parameter Field	Required or Optional	Values	Description
`ModelT`	Optional	`'GMEDS'` (default), `'Dent'`	Rayleigh fading model type. • `'GMEDS'`, the Rayleigh fading is modeled using the Generalized Method of Exact Doppler Spread (GMEDS), as described in [4]. • `'Dent'`, the Rayleigh fading is modeled using the modified Jakes fading model described in [3]. **Note:** `ModelType = 'Dent'` is not recommended. Use `ModelType = 'GMEDS'` instead.
`Norma`	Optional	`'On'` (default), `'Off'`	Model output normalization. • `'On'`, the model output is normalized such that the average power is unity. • `'Off'`, the average output power is the sum of the powers of the taps of the delay profile.

Parameter Field	Required or Optional	Values	Description
`InitP`	Optional	`'Random'` (default), numeric value (in radians), or N-by-L-by-N_{TX}-by-N_{RX} array	Phase initialization for the sinusoidal components of the model. • `'Random'`, sets the phases randomly initialized according to `Seed`. • A numeric value, assumed to be in radians, is used to initialize the phases of all components. • An N-by-L-by-N_{TX}-by-N_{RX} array used to explicitly initialize the phase in radians of each component. In this case, N is the number of phase initialization values per path, L is the number of paths, N_{TX} is the number of transmit antennas, and N_{RX} is the number of receive antennas (`NRxAnts`). **Note:** • When `ModelType` is set to `'GMEDS'`, $N = 2 \times$ `NTerms`. • When `ModelType` is set to `'Dent'`, $N =$ `NTerms`.
The following field is applicable when `DelayProfile` is set to a value other than `'Off'` and `InitPhase` is set to `'Random'`.			

Parameter Field	Required or Optional	Values	Description
`Seed`	Required	Numeric value	Random number generator seed. To use a random seed, set `Seed` to zero. **Note:** MathWorks recommends using `Seed` values from 0 to $2^{31} - 1 - (K(K-1)/2)$, where $K = N_{TX} \times N_{RX}$, the product of the number of transmit and receive antennas. `Seed` values outside of this range are not guaranteed to give distinct results.
The following fields are applicable when `DelayProfile` is set to `'Custom'`.			
`Avera`	Required	Vector	Average gains of the discrete paths, expressed in dB.
`PathD`	Required	Vector	Delays of the discrete paths, expressed in seconds. This vector must have the same size as `AveragePathGaindB`.
The following fields are applicable when `MIMOCorrelation` is set to `'Custom'`.			
`TxCor`	Required	Matrix	Correlation between each of the transmit antennas, specified as a N_{TX}-by-N_{TX} complex matrix.
`RxCor`	Required	Matrix	Correlation between each of the receive antennas, specified as a complex matrix of size N_{RX}-by-N_{RX}.

Data Types: `struct`

`toffset` — Timing offset

nonnegative integer

Timing offset in samples, specified as a nonnegative integer. The timing offset is specified from the start of the output of the channel to the estimated SC-FDMA demodulation starting point. Specify the timing offset, when known, to obtain the perfect channel

estimate as seen by a synchronized receiver. Use `lteULFrameOffset` to derive `toffset`.

Data Types: `double`

Output Arguments

`hest` — Perfect channel estimate

4-D array

Perfect channel estimate, returned as an N_{SC}-by-N_{SYM}-by-N_{RX}-by-N_{TX} array.

- N_{SC} is the number of subcarriers.
- N_{SYM} is the number of SC-FDMA symbols.
- N_{RX} is the number of receive antennas as specified by `propchan.NRxAnts`.
- N_{TX} is the number of transmit antenna planes, specified by `ue.NTxAnts`.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] Dent, P., G. E. Bottomley, and T. Croft. "Jakes Fading Model Revisited." *Electronics Letters*. Vol. 29, 1993, Number 13, pp. 1162–1163.

[4] Pätzold, Matthias, Cheng-Xiang Wang, and Bjørn Olav Hogstad. "Two New Sum-of-Sinusoids-Based Methods for the Efficient Generation of Multiple Uncorrelated Rayleigh Fading Waveforms." *IEEE Transactions on Wireless Communications*. Vol. 8, 2009, Number 6, pp. 3122–3131.

See Also

See Also

`lteDLPerfectChannelEstimate` | `lteULChannelEstimate` | `lteULChannelEstimatePUCCH1` | `lteULChannelEstimatePUCCH2` | `lteULChannelEstimatePUCCH3`

Introduced in R2014a

lteULPrecode

SC-FDMA precoding

Syntax

```
out = lteULPrecode(in,nrb)
```

Description

`out = lteULPrecode(in,nrb)` performs SC-FDMA precoding of the complex modulation symbols `in` for PUSCH configuration with a bandwidth of `nrb` resource blocks.

Examples

Perform SC-FDMA Precoding on Complex Modulation Symbols

UL precoding is a step in the PUSCH processing chain. The chain includes scrambling, symbol mapping, UL precoding, RE mapping, and SC-FDMA modulation.

Create a UE-specific configuration structure, get PUSCH indices, and generate a bit stream sized according to configuration structure.

```
ue = lteRMCUL('A3-2');
[puschInd, info] = ltePUSCHIndices(ue,ue.PUSCH);
ueDim = lteULResourceGridSize(ue);
bits = randi([0,1],info.G,ue.PUSCH.NLayers);
```

Perform scrambling, symbol modulation, and UL precoding.

```
scrBits = lteULScramble(ue,bits);
symbols = lteSymbolModulate(scrBits,ue.PUSCH.Modulation);
precodedSymbols = lteULPrecode(symbols,ue.NULRB);
```

Generate resource mapping grid, populate the grid with the precoded symbols, and perform SC-FDMA modulation.

```
grid = lteULResourceGrid(ue);
grid(puschInd) = precodedSymbols;
[timeDomainSig,infoScfdma] = lteSCFDMAModulate(ue,grid);
```

Input Arguments

`in` — Complex modulation symbols
numeric matrix

Complex modulation symbols, specified as an N_{Sym}-by-N_L matrix of complex symbols. N_{Sym} is the number of symbols and N_L is the number of layers.

Data Types: `double`
Complex Number Support: Yes

`nrb` — Number of resource blocks
nonnegative integer

Number of resource blocks, specified as a nonnegative integer.

Data Types: `double`

Output Arguments

`out` — Precoded PUSCH output symbols
numeric matrix

Precoded PUSCH output symbols, returned as an N_{Sym}-by-N_L matrix of complex symbols. N_{Sym} is the number of symbols, and N_L is the number of layers.

The dimension and size of the input and output symbol matrices are the same.

See Also

See Also
`lteLayerMap` | `ltePUSCH` | `ltePUSCHPrecode` | `lteULDeprecode`

Introduced in R2014a

lteULResourceGrid

Uplink subframe resource array

Syntax

```
grid = lteULResourceGrid(ue)
grid = lteULResourceGrid(ue,p)
```

Description

`grid = lteULResourceGrid(ue)` returns an empty resource array generated from the UE-specific settings structure `ue`. For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see “Data Structures”.

`grid = lteULResourceGrid(ue,p)` returns a resource array, where `p` directly specifies the number of antenna planes in the array. In this case, `NTxAnts` is not required as a structure field of `ue`.

Examples

Create UL Resource Array

Create an empty resource array representing the resource elements for 10 MHz bandwidth.

```
reGrid = lteULResourceGrid(struct('NULRB',50,'CyclicPrefixUL','Normal','NTxAnts',1));
```

Create Uplink Subframe Resource Array Using Optional Antenna Plane Input

Create an empty resource array that represents the uplink resource elements for 5 MHz bandwidth, one subframe, extended cyclic prefix, and four antenna ports.

```
cfg = struct('NULRB',25,'CyclicPrefixUL','Extended');
p = 4;
gridul = lteULResourceGrid(cfg,p);
```

```
size(gridul)

ans =

   300    12     4
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields.

NULRB — Number of uplink (UL) resource blocks (RBs)

scalar integer from 6 to 110

Number of uplink (UL) resource blocks (RBs), specified as a scalar integer from 6 to 110.

Data Types: `double`

CyclicPrefixUL — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

NTxAnts — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as 1, 2, or 4.

Data Types: `double`

Data Types: `struct`

p — Number of antenna planes in the return array

scalar integer

Number of antenna planes in the return array, specified as a scalar integer.

Data Types: `double`

Output Arguments

`grid` — Empty resource grid

multidimensional numeric array

Empty resource grid, returned as an *N*-by-*M*-by-*P* numeric array. *N* is the number of subcarriers (12×`NULRB`). *M* is the number of SC-FDMA symbols in a subframe, 14 for normal cyclic prefix and 12 for extended cyclic prefix. *P* is the number of transmission antennas. `grid` is used to represent the resource elements for one subframe across all configured antenna ports.

Data Types: `double`

See Also

See Also

`lteDLResourceGrid` | `lteResourceGrid` | `lteSCFDMAModulate` | `lteULResourceGridSize`

Introduced in R2014a

lteULResourceGridSize

Size of uplink subframe resource array

Syntax

```
d = lteULResourceGridSize(ue)
d = lteULResourceGridSize(ue,p)
```

Description

`d = lteULResourceGridSize(ue)` returns a three-element row vector of dimension lengths for the resource array generated from the UE-specific settings structure `ue`. For more information on the resource grid and the multidimensional array used to represent the resource elements for one subframe across all configured antenna ports, see "Data Structures".

`d = lteULResourceGridSize(ue,p)` returns a three-element row vector, where `p` directly specifies the number of antenna planes in the array. In this case, `NTxAnts` is not required as a structure field of `ue`.

Examples

Get Size of Uplink Subframe Resource Array

Use the returned vector to directly create MATLAB® arrays.

```
ue = struct('NULRB',6,'CyclicPrefixUL','Normal','NTxAnts',1);
rgrid = zeros(lteULResourceGridSize(ue));
size(rgrid)
```

```
ans =

    72    14
```

This result is the same matrix as the one obtained using the `lteULResourceGrid` function.

Get Uplink Subframe Resource Array Size Using Optional Antenna Plane Input

Get the uplink subframe resource array size from an uplink configuration structure using the antenna plane input. Then, use the returned vector to directly create a MATLAB™ array.

```
cfgul = struct('NULRB',50,'CyclicPrefixUL','Normal');
p = 2;
gridul = zeros(lteULResourceGridSize(cfgul,p));
size(gridul)
```

```
ans =

   600    14     2
```

The output grid, `gridul`, is a resource array. This resource array size could be obtained in a similar manner using the `lteResourceGridSize` function.

Input Arguments

`ue` — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields.

`NULRB` — Number of uplink (UL) resource blocks (RBs)

scalar integer from 6 to 110

Number of uplink (UL) resource blocks (RBs), specified as a scalar integer from 6 to 110.

Data Types: `double`

`CyclicPrefixUL` — Cyclic prefix length

`'Normal'` (default) | optional | `'Extended'`

Cyclic prefix length, specified as `'Normal'` or `'Extended'`.

Data Types: `char`

`NTxAnts` — Number of transmission antennas

1 (default) | optional | 2 | 4

Number of transmission antennas, specified as 1, 2, or 4.

Data Types: `double`

Data Types: `struct`

p — Number of antenna planes in the return array

scalar integer

Number of antenna planes in the return array, specified as a scalar integer.

Data Types: `double`

Output Arguments

d — Dimension lengths

3-element row vector

Dimension lengths, returned as a three-element row vector [*N M P*]. *N* is the number of subcarriers (12×`NULRB`). *M* is the number of SC-FDMA symbols in a subframe, 14 for normal cyclic prefix and 12 for extended cyclic prefix. *P* is the number of transmission antennas.

Data Types: `double`

See Also

See Also

`lteDLResourceGridSize` | `lteResourceGridSize` | `lteULResourceGrid`

Introduced in R2014a

lteULSCH

Uplink shared channel

Syntax

```
[cwout,chinfo] = lteULSCH(ue,chs,trblkin)
[cwout,chinfo] = lteULSCH(ue,chs,trblkin,opts)
[cwout,chinfo] = lteULSCH(ue,chs,trblkin,cqi,ri,ack,opts)
```

Description

`[cwout,chinfo] = lteULSCH(ue,chs,trblkin)` performs complete UL-SCH transport coding and UCI coding on the input information bits, `trblkin`, and returns the complete codewords in the output, `cwout`. It encodes both a single transport block or pair of blocks, contained in a cell array, for the case of spatial multiplexing schemes transmitting two codewords, represented by input `trblkin` without any UCI data. The lowest order information bit of `trblkin` should be mapped to the most significant bit of the transport block, as defined in TS 36.321 Section 6.1.1 [3]. The encoding process also includes the channel interleaving. It The transport encoding includes type-24A CRC calculation, code block segmentation and type-24B CRC attachment, turbo encoding, rate matching, block concatenation, and channel interleaving. For more information, see TS 36.212 Sections 5.2.2.1 to 5.2.2.5 and 5.2.2.8 [2]. Parameter information relating to the underlying UL-SCH and UCI coding is available in structure `chinfo`.

The output `chinfo` is a structure containing information related to the UL-SCH coding process.

For multiple transport blocks, each structure in the array corresponds to one of the blocks. This output is also available from the `lteULSCHInfo` function.

`[cwout,chinfo] = lteULSCH(ue,chs,trblkin,opts)` allows for the merging of the input `chs` structure fields into `chinfo` at the output.

If the UL-SCH encoding is for a retransmission of a previously sent transport block, use the three “Init” fields, `'InitPRBSet'`, `'InitCyclicPrefixUL'`, and `'InitShortened'`. If any of these fields are absent, their values are assumed to be the same as the values for the associated current subframe fields, `'PRBSet'`, `'CyclicPrefixUL'`, and `'Shortened'`.

`opts` is an optional input parameter which enables the concatenation or merging of the `chs` input structure fields into the fields returned by `chinfo`. This parameter is useful for combining the high-level configuration parameters with the fine-grained ones used in the encoding process.

`opts` allows additional control of the contents and format of the `chinfo` output.

`[cwout,chinfo] = lteULSCH(ue,chs,trblkin,cqi,ri,ack,opts)` encodes and multiplexes the UCI input data, CQI, RI, and ACK, along with the information bits, `trblkin`, in the codeword, `cwout`. For more information, see TS 36.212 Sections 5.2.2.6 to 5.2.2.8 [2]. Any of the `trblkin`, `cqi`, `ri`, or `ack` vectors can be empty if that data is not present. If `trblkin` is empty, only UCI on UL-SCH/PUSCH is processed, according to TS 36.212 Section 5.2.4 [2]. The coding of the UCI can be controlled through the additional fields, `BetaACK`, `BetaCQI`, `BetaRI`, and `NBundled`, in the `chs` input structure. Setting `NBundled` to 0 disables the TDD HARQ-ACK bundling scrambling; therefore, it is off by default.

Examples

Generate UL-SCH Codewords

Create coded information bits for a 3 MHz, Uplink A3-3 FRC.

Create an UL RMC configuration structure. Initialize the optional fields for a ue-specific setting structure. Default settings are used if you don't initial optional fields. Create a transport block bit stream, `trBlk`.

```
rmc = lteRMCUL('A3-3');
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;
trBlk = randi([0,1],rmc.PUSCH.TrBlkSizes(1),1);
```

Generate UL-SCH codewords for the A3-3 FRC.

```
cw = lteULSCH(ue,rmc.PUSCH,trBlk);
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure with the following fields.

Parameter Field	Required or Optional	Values	Description
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Current cyclic prefix length
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

`chs` — Channel-specific transmission configuration

scalar structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or a cell array of these character vectors	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
`NLayers`	Optional	1 (default), 2, 3, 4	Total number of transmission layers associated with the transport block or blocks.
`RV`	Required	Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).	Specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is Read-Only.

Parameter Field	Required or Optional	Values	Description
			This parameter field is not required if `trblkin` is `[]`, which signifies that the UL-SCH is carrying only UCI and no transport data.
`PRBSet`	Required	Integer column vector or two-column matrix	0-based physical resource block indices (PRBs) for the slots of the current PUSCH resource allocation. As a column vector, the resource allocation is the same in both slots of the subframe. As a two-column matrix, it specifies different PRBs for each slot in a subframe.
The following three `'Init'` fields should be used if the UL-SCH encoding is for a retransmission of a previously sent transport block. If any of these fields are absent, its value is assumed to be the same as the value for its associated current subframe field.			
`InitPRBSet`	Optional	1- or 2-column integer matrix, `PRBSet` (default)	PRB indices used in the initial transmission PUSCH allocation. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `PRBSet`.
`InitCyclicPrefixU`	Optional	`'Normal'`, `'Extended'`, `CyclicPrefixUL` (default)	Cyclic prefix length of initial transmit subframe. This is the length used during the first transmission of this transport block. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `CyclicPrefixUL`.

Parameter Field	Required or Optional	Values	Description
`InitShortened`	Optional	0, 1, `Shortened` (default)	Initial transmit subframe shortened flag. If 1, the initial transmit subframe was shortened for possible SRS. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `Shortened`.
The coding of the UCI can be controlled through the following additional fields.			
`BetaCQI`	Optional	numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for CQI and PMI bits
`BetaRI`	Optional	numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for RI bits
`BetaACK`	Optional	numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for HARQ-ACK bits. This field was previously named `BetaHI`; if this field is absent but `BetaHI` is present, it is used as before.
`NBundled`	Optional	0 (default), 1, …, 9	TDD HARQ-ACK bundling scrambling sequence index. When set to 0, the function disables the TDD HARQ-ACK bundling scrambling. Therefore, it is off by default.

`trblkin` — Input transport blocks

numeric vector | cell array of numeric vectors

Input transport blocks, specified as a numeric vector or a cell array of numeric vectors.

Data Types: `double` | `cell`

`opts` — Options to control output contents and format

character vector | cell array of character vectors

Options to control output contents and format, specified as a character vector or a cell array of character vectors. You may choose any of the option listed in this table.

Option	Values	Description
Channel parameter merging	`'nochsconcat'` (default)	Do not concatenate `chs` input structure into `chinfo`.
	`'chsconcat'`	Concatenate `chs` input structure into `chinfo`.
Output structure format	`'cwseparate'` (default)	Information values for each codeword are output in separate elements of the 1-by-*ncodewords* structure array `chinfo`.
	`'cwcombined'`	Information values for each codeword are combined into the fields of a single scalar, or 1-by-1, structure.

Data Types: `char` | `cell`

`cqi` — CQI input data
numeric vector

CQI input data, specified as a numeric vector. Part of the UCI data.

Data Types: `double`

`ri` — RI input data
numeric vector

RI input data, specified as a numeric vector. Part of the UCI data.

Data Types: `double`

`ack` — HARQ-ACK input data
numeric vector

HARQ-ACK input data, specified as a numeric vector. Part of the UCI data.

Data Types: `double`

Output Arguments

`cwout` — Complete output codewords
integer column vector | cell array of integer column vectors

Complete output codewords, returned as an integer column vector or a cell array of integer column vectors.

Data Types: `int8` | `cell`

`chinfo` — Parameter information relating to the underlying UL-SCH and UCI coding

structure | structure array

Parameter information relating to the underlying UL-SCH and UCI coding, returned as a structure or a structure array. If two transport blocks are encoded, `chinfo` is a structure array of two elements, one for each block. Alternatively, you can create code block segmentation fields in this structure independently, by calling the `lteULSCHInfo` function. `chinfo` contains the following fields.

Parameter Field	Description	Values	Data Type
`C`	Total number of code blocks	nonnegative scalar integer	`int32`
`Km`	Lower code block size ($K-$)	nonnegative scalar integer	`int32`
`Cm`	Number of code blocks of size `Km` ($C-$)	nonnegative scalar integer	`int32`
`Kp`	Upper code block size ($K+$)	nonnegative scalar integer	`int32`
`Cp`	Number of code blocks of size `Kp` ($C+$)	nonnegative scalar integer	`int32`
`F`	Number of filler bits in first block	nonnegative scalar integer	`int32`
`L`	Number of segment cyclic redundancy check (CRC) bits	nonnegative scalar integer	`int32`
`Bout`	Total number of bits in all segments	nonnegative scalar integer	`int32`
`G`	Number of coded and rate matched UL-SCH data bits	nonnegative scalar integer	`int32`
`Qm`	Number of bits per symbol	nonnegative scalar integer	`int32`
`Gd`	Number of coded and rate matched UL-SCH data symbols (G')	nonnegative scalar integer	`int32`

Parameter Field	Description	Values	Data Type
OCQI	Number of uncoded channel quality information (CQI) bits	nonnegative scalar integer	int32
ORI	Number of uncoded symbols for RI	nonnegative scalar integer	int32
OACK	Number of uncoded symbols for ACK/NACK	nonnegative scalar integer	int32
QdCQI	Number of coded symbols for CQI (*Q'_CQI*)	nonnegative scalar integer	int32
QdRI	Number of coded symbols for RI (*Q'_RI*)	nonnegative scalar integer	int32
QdACK	Number of coded symbols for ACK/NACK (*Q'_ACK*)	nonnegative scalar integer	int32
NRE	Number of resource elements (REs) used for PUSCH transmission	nonnegative scalar integer	int32
NLayers	Number of layers associated with one codeword	nonnegative scalar integer	int32
Modulation	Modulation scheme associated with one codeword	'QPSK', '16QAM', '64QAM'	char
RV	RV value associated with one codeword	scalar integer	int32

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.321. "Medium Access Control (MAC) protocol specification." *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCH` | `lteULSCHDecode` | `lteULSCHInfo` | `lteULSCHInterleave`

Introduced in R2014a

lteULSCHDecode

Uplink shared channel decoding

Syntax

```
[trblkout,blkcrc,stateout] = lteULSCHDecode(ue,chs,trblklen,cwin,
statein)
```

Description

`[trblkout,blkcrc,stateout] = lteULSCHDecode(ue,chs,trblklen,cwin, statein)` returns the information bits `trblkout` decoded from the input soft LLR codewords data `cwin`. The UL-SCH decoder includes channel deinterleaver, rate recovery, turbo decoding, block concatenation and CRC calculations. The function also returns the type-24A transport block CRC decoding result in `blkcrc` and the HARQ process decoding state in `stateout`. The initial HARQ process state can be input via the optional `statein` parameter. The function is capable of processing both a single codeword or pairs of codewords, contained in a cell array, for the case of spatial multiplexing schemes transmitting two codewords. The type of the return variable `trblkout` is the same as input `cwin`. If `cwin` is a cell array containing one or two codewords, `trblkout` returns a cell array of one or two transport blocks. If `cwin` is a vector of soft data, `trblkout` returns a vector too. If decoding a pair of codewords, pairs of modulation schemes and RV indicators are required to be defined in the associated parameter fields below. This function only decodes the information bits, but supports the presence of UCI data, CQI, RI, and HARQ-ACK, in the input codeword. UCI should be demultiplexed then decoded separately.

Strictly speaking, because all the fields in structure `ue` are optional, it is legal for this parameter to be an empty structure.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for more details.

`trblklen` is an input vector (one or two elements in length) defining the transport block lengths that the input code blocks should be rate recovered and decoded to.

`cwin` is an input parameter containing the floating point soft LLR data of the codewords to be decoded. It can either be a single vector or a cell array containing one or two vectors. If the latter, then all rate matching calculations assume that the pair were transmitting on a single PUSCH, distributed across the total number of layers defined in `chs`, as per TS 36.211 [1].

`statein` is an optional input structure array (empty or one or two elements) which can input the current decoder buffer state for each transport block in an active HARQ process. If `statein` is not an empty array and it contains a non-empty field `CBSBuffers` then this field should contain a cell array of vectors representing the LLR soft buffer states for the set of code blocks at the input to the turbo decoder i.e. after explicit rate recovery. The updated buffer states after decoding are returned in the `CBSBuffers` field in the output parameter `stateout`. The `statein` array would normally be generated and recycled from the `stateout` of previous calls to lteULSCHDecode as part of a sequence of HARQ transmissions.

`trblkout` is the output parameter containing the decoded information bits. It is either a single vector or a cell array containing one or two vectors, depending on the class and dimensionality of `cwin`.

`blkcrc` is an output array (one or two elements) containing the result of the type-24A transport block CRC decoding for the transport blocks.

`stateout`, the final output parameter, is a one element structure array containing the internal state of each transport block decoder in the fields `CBSBuffers`, `CBSCRC`, `blkcrc`.

The `stateout` array would normally be reapplied via the `statein` variable of subsequent `lteULSCHDecode` function calls as part of a sequence of HARQ retransmissions.

Examples

Decode UL-SCH

Generate and decode 2 transmissions (RV=0 then RV=2) as part of a single codeword HARQ process for the A3-3 FRC.

Initialize one subframe of an FRC A3-3 transmission. Create a codeword with RV = 0. Turn logical bits into 'LLR' data. Initialize the decoder states for the first HARQ transmission. The returned `decState` contains the decoder buffer state for each transport block for an active HARQ process.

```
nsf = 1;
frc = lteRMCUL('A3-3');
trBlkLen = frc.PUSCH.TrBlkSizes(nsf);
trBlkData = randi([0,1],trBlkLen,1);

frc.PUSCH.RV = 0;
cw = lteULSCH(frc,frc.PUSCH,trBlkData);

cw(cw == 0) = -1;

decState = [];
[rxTrBlk,~,decState] = lteULSCHDecode(frc,frc.PUSCH,trBlkLen,cw,decState);
```

Create a second retransmitted codeword with RV = 2. Turn logical bits into 'LLR' data. The previous transmission decoder buffer state, `decState`, is used as part of the sequence of active HARQ transmissions.

```
frc.PUSCH.RV = 2;
cWord = lteULSCH(frc,frc.PUSCH,trBlkData);

cWord(cWord == 0) = -1;

rxTrBlk = lteULSCHDecode(frc,frc.PUSCH,trBlkLen,cWord,decState);
```

Input Arguments

ue — UE-specific settings

scalar structure

UE-specific settings, specified as a scalar structure with the following fields. Because all the fields in structure `ue` are optional, this parameter can be an empty structure.

Parameter Field	Required or Optional	Values	Description
`CyclicPre`	Optional	`'Normal'` (default), `'Extended'`	Cyclic prefix length.

Parameter Field	Required or Optional	Values	Description
Shortened	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If 1, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set Shortened to 1 to maintain a standard compliant configuration.

Data Types: `struct`

chs — UL-SCH related parameters

scalar structure

UL-SCH related parameters, specified as a scalar structure with the following fields.

Parameter Field	Required or Optional	Values	Description
Modulatio	Required	'QPSK', '16QAM', '64QAM'	Modulation scheme associated with each transport block, specified as a character vector, or, if there are 2 blocks, as a cell array of character vectors.
NLayers	Optional	1 (default), 2, 3, 4	Number of transmission layers. (total or per codeword)
RV	Required	0, 1, 2, 3	Redundancy version indicators, specified as a vector of 1 or 2 indicators.
QdCQI	Optional	nonnegative scalar integer	Number of coded channel quality information (CQI) symbols (*Q'_CQI*)
QdRI	Optional	Nonnegative scalar integer 0 (default)	Number of coded symbols for RI (*Q'_RI*)
QdACK	Optional	nonnegative scalar integer	Number of coded ACK symbols (*Q'_ACK*)

Parameter Field	Required or Optional	Values	Description
		0 (default)	
`NTurboDec`	Optional	Scalar integer 5 (default)	Number of turbo decoder iteration cycles

Data Types: `struct`

`trblklen` — Transport block length

numeric vector

Transport block length, specified as a numeric vector (one or two elements in length) defining the transport block lengths that the input code blocks should be rate recovered and decoded to.

Data Types: `double`

`cwin` — Soft LLR codeword data

numeric column vector | cell array of one or two column vectors

Soft LLR codeword data, specified as a numeric column vector or a cell array of one or two column vectors. This argument contains the floating point soft LLR data of the codeword or codewords to be decoded. It can either be a single vector or a cell array containing one or two vectors. If a cell array, all rate matching calculations assume that the pair were transmitting on a single PUSCH, distributed across the total number of layers defined in `chs`, as specified in [1].

Data Types: `int8 | cell`

`statein` — Initial HARQ process state

optional | structure array

Initial HARQ process state, specified as a structure array. It can be empty or have one or two elements, which can input the current decoder buffer state for each transport block in an active HARQ process.

Data Types: `double`

Output Arguments

`trblkout` — Decoded information bits

numeric vector | cell array

Decoded information bits, returned as a numeric vector or cell array. `trblkout` contains decoded transport data blocks. It is either a single vector or a cell array containing one or two vectors, depending on the class and dimensionality of `cwin`.

Data Types: `double` | `cell`

`blkcrc` — Type 24A transport block CRC decoding result

0 or 1

Type 24A transport block CRC decoding result, returned as 0 or 1.

Data Types: `logical`

`stateout` — HARQ process decoding state

structure | structure array

HARQ process decoding state, returned as a one-element structure array. It contains the internal state of each transport block decoder. It contains the following parameter fields.

Parameter Field	Description	Values	Data Type
`CBSBuffers`	LLR soft buffer states for the set of code blocks associated with a single transport block. The buffers are positioned at the input to the turbo decoder, or after explicit rate recovery.	Cell array of numeric vectors	`cell`
`CBSCRS`	Type-24B code block set CRC decoding results	Numeric vector	`int8`
`BLKCRC`	Type-24A transport block CRC decoding error	One- or two-element numeric vector	`logical`

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCHDecode` | `lteULSCH` | `lteULSCHDeinterleave` | `lteULSCHInfo`

Introduced in R2014a

lteULSCHDeinterleave

UL-SCH deinterleaving

Syntax

```
[cdata,ccqi,cri,cack] = lteULSCHDeinterleave(ue,chs,in)
```

Description

`[cdata,ccqi,cri,cack] = lteULSCHDeinterleave(ue,chs,in)` returns the deinterleaved data vector `cdata`, encoded UCI vectors, `ccqi`,`cri`, and `cack`, or cell array of vectors, after performing the demultiplexing and UL-SCH channel deinterleaving to undo the processing described in TS 36.212, Sections 5.2.2.7 and 5.2.2.8 [1] for UE-specific settings, `ue`, and UL-SCH channel specific configuration, `chs`.

The function expects the input `in` to be multiplexed and interleaved as per defined in TS 36.212, Sections 5.2.2.7 and 5.2.2.8 [1]. This input can be a vector or a cell array of vectors, deinterleaved and demultiplexed separately, and the outputs are of the same form. The size of the coded CQI symbols and codeword number with it is multiplexed, to correctly perform the demultiplexing, are deduced using the channel specific structure `chs` via the `Modulation` and `QdCQI` parameters. The presence or absence of `ccqi` in the transmission is signaled via `QdCQI` parameter with nonzero (number of coded CQI symbols) or zero value, respectively.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for more details.

Examples

Interleave and Deinterleave UL-SCH

Perform back-to-back interleaving and deinterleaving of a vector of interleaver input bit indices.

Create UE-specific and propagation channel configuration structures.

```
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;
chs.Modulation = 'QPSK';
chs.NLayers = 1;
chs.QdCQI = 0;
chs.QdRI = 0;
chs.QdACK = 0;
```

There are 288 PUSCH QPSK symbols in two RBs and two bits per symbol for QPSK.

```
cdata = randi([0 1],2*288,1);
size(cdata)
interleaved = lteULSCHInterleave(ue,chs,cdata);
deinterleaved = lteULSCHDeinterleave(ue,chs,interleaved);
size(deinterleaved)
```

```
ans =

   576     1


ans =

   576     1
```

The deinterleaved output is the same size as the data prior to interleaving.

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure with the following fields.

CyclicPrefixUL — Cyclic prefix length

'Normal' (default) | optional | 'Extended'

Cyclic prefix length, specified as 'Normal' or 'Extended'.

Data Types: char

`Shortened` — Shorten subframe flag

0 (default) | optional | 1

Shorten subframe flag, specified as 0 or 1. Optional. If 1, the last symbol of the subframe is not used. It should be set if the current subframe contains a possible SRS transmission.

Data Types: `logical` | `double`

Data Types: `struct`

`chs` — UL-SCH related parameters

structure

UL-SCH related parameters, specified as a structure with the following fields.

`Modulation` — Modulation format

`'QPSK'` | `'16QAM'` | `'64QAM'` | cell array of these character vectors

Modulation format. Specified as a character vector or cell array of character vectors.

Data Types: `char`

`NLayers` — Number of transmission layers

1 (default) | optional | 2 | 3 | 4

Number of transmission layers, total or per codeword, specified as a positive scalar integer. Optional.

Data Types: `double`

`QdCQI` — Number of coded symbols for CQI

0 (default) | optional | nonnegative scalar integer

Number of coded symbols for CQI, specified as a nonnegative scalar integer. Optional. (*Q'_CQI*)

Data Types: `double`

`QdRI` — Number of coded symbols for RI

0 (default) | optional | nonnegative scalar integer

Number of coded symbols for RI, specified as a nonnegative scalar integer. Optional. (*Q'_RI*)

Data Types: `double`

`QdACK` — Number of coded symbols for ACK/NACK

0 (default) | optional | nonnegative scalar integer

Number of coded symbols for ACK/NACK, specified as a nonnegative scalar integer. Optional. (*Q'_ACK*)

Data Types: `double`

Data Types: `struct`

`in` — Input data

column vector | cell array of column vectors

Input data specified as a column vector or a cell array of column vectors.

Data Types: `double` | `cell`

Output Arguments

`cdata` — Deinterleaved data

column vector | cell array of column vectors

Deinterleaved data, returned as a column vector or cell array of column vectors.

Data Types: `double` | `cell`

`ccqi` — Encoded UCI

vector | cell array of vectors

Encoded UCI, returned as a vector or cell array of vectors.

Data Types: `double` | `cell`

`cri` — Encoded UCI

vector | cell array of vectors

Encoded UCI, returned as a vector or cell array of vectors.

Data Types: `double` | `cell`

`cack` — Encoded UCI

vector | cell array of vectors

Encoded UCI, returned as a vector or cell array of vectors.

Data Types: `double` | `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteACKDecode` | `lteCQIDecode` | `lteRateRecoverTurbo` | `lteRIDecode` | `lteULSCH` | `lteULSCHInfo` | `lteULSCHInterleave`

Introduced in R2014a

lteULSCHInfo

UL-SCH coding information

Syntax

```
info = lteULSCHInfo(ue,chs,blklen)
info = lteULSCHInfo(ue,chs,blklen,opts)
info = lteULSCHInfo(ue,chs,blklen,ocqi,ori,oack)
info = lteULSCHInfo(ue,chs,blklen,ocqi,ori,oack,opts)
```

Description

`info = lteULSCHInfo(ue,chs,blklen)` provides information related to the entire UL-SCH coding process, for UL-SCH data without UCI. It returns a structure array with fields covering the transport channel (TrCH) encoding and UCI multiplexing. When UCI is present, it includes the coded symbol capacities given UCI sizes, PUSCH resource allocations, and *Beta* offset values, which can be useful in a number of UL-SCH- and PUSCH-related functions. These symbol capacities are calculated from the Q' formulae in TS 36.212, Sections 5.2.2.6 and 5.2.4.1 [1]. The one- or two-element vector, `blklen`, defines the length of the transmitted transport blocks.

By default, in the case of multiple transport blocks or codewords, each structure in the array corresponds to one of the blocks. Note that the `NLayers`, `Modulation`, and `RV` fields at the output contain only the value for the associated codeword and therefore have a different form to those given in the input. In the case of `NLayers` the output returns the number of layers per codeword where the input field represents the total number of transmission layers across all codewords.

If the UL-SCH encoding is for a retransmission of a previously sent transport block, use the three "Init" fields, `'InitPRBSet'`, `'InitCyclicPrefixUL'`, and `'InitShortened'`. If any of these fields are absent, their values are assumed to be the same as the values for the associated current subframe fields, `'PRBSet'`, `'CyclicPrefixUL'`, and `'Shortened'`.

`info = lteULSCHInfo(ue,chs,blklen,opts)` controls the contents and format of the output `info` through a cell array of options, `opts`. The optional parameter `opts` allows for the merging of the input `chs` structure fields into `info` at the output.

`info = lteULSCHInfo(ue,chs,blklen,ocqi,ori,oack)` supports the multiplexing of both transport and UCI data, CQI, RI, and HARQ-ACK, or UCI only. The number of uncoded UCI bits is given by `ocqi`, `ori` and `oack` respectively. Any of the data length parameters can be zero if the associated data is not present. The coding of the UCI can be controlled through the additional `BetaACK`, `BetaCQI`, and `BetaRI` fields in the `chs` input structure.

`info = lteULSCHInfo(ue,chs,blklen,ocqi,ori,oack,opts)` supports the multiplexing of both transport and UCI data (CQI, RI, HARQ-ACK) or UCI only, and controls the contents and format of the output `info` through a cell array of options, `opts`. The optional parameter `opts` allows for the merging of the input `chs` structure fields into `info` at the output.

Examples

Obtain UL-SCH Information for One Transport Block

Obtain information for UL-SCH coding of a single transport block of length 6712 bits.

Create a PUSCH configuration structure. Initialize the optional fields for a ue-specific setting structure. Default settings are used if you don't initial optional fields. View the UL-SCH information.

```
pusch.Modulation = 'QPSK';
pusch.NLayers = 1;
pusch.PRBSet = [0:74].';
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;
blkLen = 6712;
info = lteULSCHInfo(ue,pusch,blkLen)
```

```
info =

  struct with fields:

            C: 2
           Km: 3328
           Cm: 0
           Kp: 3392
           Cp: 2
            F: 0
```

```
           L: 24
        Bout: 6784
           G: 21600
          Qm: 2
          Gd: 10800
        OCQI: 0
         ORI: 0
        OACK: 0
       QdCQI: 0
        QdRI: 0
       QdACK: 0
         NRE: 10800
    NLayers: 1
Modulation: 'QPSK'
```

Obtain ULSCH Info for Transport Blocks in Structure Array

Obtain information for UL-SCH coding of two transport blocks (codewords) with UCI (3 bit RI, 2 bit HARQ-ACK). Each element in the output array corresponds to a codeword.

Create a PUSCH configuration structure and an empty UE structure.

```
pusch.Modulation = {'QPSK' '16QAM'};
pusch.NLayers = 3;
pusch.PRBSet = [0:74].';
ue = struct();
```

Specify the number of CQI, RI, and HARQ-ACK bits

```
OCQI = 0;
ORI = 3;
OACK = 2;
blkLen = [6712 6712];
```

View the UL-SCH information

```
info = lteULSCHInfo(ue,pusch,blkLen ,OCQI,ORI,OACK)
```

```
info =

  1×2 struct array with fields:

    C
    Km
```

```
Cm
Kp
Cp
F
L
Bout
G
Qm
Gd
OCQI
ORI
OACK
QdCQI
QdRI
QdACK
NRE
NLayers
Modulation
```

Obtain ULSCH Info for Transport Blocks in Scalar Structure

Obtain information in a single scalar structure for the UL-SCH coding of two transport blocks with UCI, specifying 3-bit RI and 2-bit HARQ-ACK.

Create a PUSCH configuration structure and an empty UE structure.

```
pusch.Modulation={'QPSK' '16QAM'};
pusch.NLayers = 3;
pusch.PRBSet = [0:74].';
ue = struct();
```

Specify the number of CQI, RI, and HARQ-ACK bits.

```
OCQI = 0;
ORI = 3;
OACK = 2;
blkLen = [6712 6712];
```

View the UL-SCH information. Most fields in the structure contain two elements corresponding to each codeword.

```
info = lteULSCHInfo(ue,pusch,blkLen,OCQI,ORI,OACK,'cwcombined')
```

```
info =

  struct with fields:

           C: [2 2]
          Km: [3328 3328]
          Cm: [0 0]
          Kp: [3392 3392]
          Cp: [2 2]
           F: [0 0]
           L: [24 24]
        Bout: [6784 6784]
           G: [21590 86360]
          Qm: [2 4]
          Gd: [10795 21590]
        OCQI: 0
         ORI: 3
        OACK: 2
       QdCQI: [0 0]
        QdRI: [5 5]
       QdACK: [4 4]
         NRE: [10800 21600]
    NLayers: [1 2]
  Modulation: {'QPSK'  '16QAM'}
```

Input Arguments

ue — UE-specific configuration settings

structure

UE-specific configuration settings, specified as a structure that can contain the following fields.

Parameter Field	Required or Optional	Values	Description
`CyclicPrefixUL`	Optional	`'Normal'` (default), `'Extended'`	Current cyclic prefix length
`Shortened`	Optional	0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1.

Parameter Field	Required or Optional	Values	Description
			If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.

`chs` — Channel-specific transmission configuration

structure

Channel-specific transmission configuration, specified as a structure that can contain the following parameter fields.

Parameter Field	Required or Optional	Values	Description
`Modulation`	Required	`'QPSK'`, `'16QAM'`, `'64QAM'`, or a cell array of these character vectors	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
`NLayers`	Optional	1 (default), 2, 3, 4	Total number of transmission layers associated with the transport block or blocks.
`PRBSet`	Required	Integer column vector or two-column matrix	0-based physical resource block indices (PRBs) for the slots of the current PUSCH resource allocation. As a column vector, the resource allocation is the same in both slots of the subframe. As a two-column matrix, it specifies different PRBs for each slot in a subframe.
`RV`	Required	Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).	Specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field

Parameter Field	Required or Optional	Values	Description
			is only for informational purposes and is Read-Only.
The following three `'Init'` fields should be used if the UL-SCH encoding is for a retransmission of a previously sent transport block. If any of these fields are absent, its value is assumed to be the same as the value for its associated current subframe field.			
`InitPRBSet`	Optional	1- or 2-column integer matrix, `PRBSet` (default)	PRB indices used in the initial transmission PUSCH allocation. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `PRBSet`.
`InitCyclicPrefixU`	Optional	`'Normal'`, `'Extended'`, `CyclicPrefixUL` (default)	Cyclic prefix length of initial transmit subframe. This is the length used during the first transmission of this transport block. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `CyclicPrefixUL`.
`InitShortened`	Optional	0, 1, `Shortened` (default)	Initial transmit subframe shortened flag. If 1, the initial transmit subframe was shortened for possible SRS. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `Shortened`.
The coding of the UCI can be controlled through the following additional fields.			
`BetaCQI`	Optional	numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for CQI and PMI bits
`BetaRI`	Optional	numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for RI bits

Parameter Field	Required or Optional	Values	Description
`BetaACK`	Optional	numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for HARQ-ACK bits. This field was previously named `BetaHI`; if this field is absent but `BetaHI` is present, it is used as before.

`blklen` — Length of transmitted transport blocks

numeric vector

Length of the transmitted transport blocks, specified as a one or two element numeric vector.

Data Types: `double`

`opts` — Format options

character vector | cell array of character vectors

Format options of `chinfo` output, specified as a character vector or a cell array of character vectors.

Option	Values	Description
Channel parameter merging	`'nochsconcat'` (default)	Do not concatenate `chs` input structure into `chinfo`.
	`'chsconcat'`	Concatenate `chs` input structure into `chinfo`.
Output structure format	`'cwseparate'` (default)	Information values for each codeword are output in separate elements of the 1-by-ncodewords structure array `chinfo`.
	`'cwcombined'`	Information values for each codeword are combined into the fields of a single scalar, or 1-by-1, structure.

Data Types: `char | cell`

`ocqi` — Number of uncoded CQI bits

numeric scalar

Number of uncoded CQI bits, specified as a numeric scalar.

Data Types: `double`

`ori` — Number of uncoded RI bits

numeric scalar

Number of uncoded RI bits, specified as a numeric scalar.

Data Types: `double`

`oack` — Number of uncoded HARQ-ACK bits

numeric scalar

Number of uncoded HARQ-ACK bits, specified as a numeric scalar.

Data Types: `double`

Output Arguments

`info` — UL-SCH information

structure | structure array

UL-SCH information, returned as a structure or a structure array. If two transport blocks are encoded, `info` is a structure array of two elements, one for each block. , It contains the following parameter fields.

Parameter Field	Description	Values	Data Type
`C`	Total number of code blocks	nonnegative scalar integer	`int32`
`Km`	Lower code block size ($K–$)	nonnegative scalar integer	`int32`
`Cm`	Number of code blocks of size `Km` ($C–$)	nonnegative scalar integer	`int32`
`Kp`	Upper code block size ($K+$)	nonnegative scalar integer	`int32`
`Cp`	Number of code blocks of size `Kp` ($C+$)	nonnegative scalar integer	`int32`
`F`	Number of filler bits in first block	nonnegative scalar integer	`int32`

Parameter Field	Description	Values	Data Type
`L`	Number of segment cyclic redundancy check (CRC) bits	nonnegative scalar integer	`int32`
`Bout`	Total number of bits in all segments	nonnegative scalar integer	`int32`
`G`	Number of coded and rate matched UL-SCH data bits	nonnegative scalar integer	`int32`
`Qm`	Number of bits per symbol	nonnegative scalar integer	`int32`
`Gd`	Number of coded and rate matched UL-SCH data symbols (G')	nonnegative scalar integer	`int32`
`OCQI`	Number of uncoded channel quality information (CQI) bits	nonnegative scalar integer	`int32`
`ORI`	Number of uncoded symbols for RI	nonnegative scalar integer	`int32`
`OACK`	Number of uncoded symbols for ACK/NACK	nonnegative scalar integer	`int32`
`QdCQI`	Number of coded symbols for CQI (Q'_CQI)	nonnegative scalar integer	`int32`
`QdRI`	Number of coded symbols for RI (Q'_RI)	nonnegative scalar integer	`int32`
`QdACK`	Number of coded symbols for ACK/NACK (Q'_ACK)	nonnegative scalar integer	`int32`
`NRE`	Number of resource elements (REs) used for PUSCH transmission	nonnegative scalar integer	`int32`
`NLayers`	Number of layers associated with one codeword	nonnegative scalar integer	`int32`
`Modulation`	Modulation scheme associated with one codeword	`'QPSK'`, `'16QAM'`, `'64QAM'`	`char`
`RV`	RV value associated with one codeword	scalar integer	`int32`

References

[1] 3GPP TS 36.212. “Multiplexing and channel coding.” *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteACKEncode` | `lteCQIEncode` | `ltePUSCHDecode` | `lteRIEncode` | `lteULSCH` | `lteULSCHDecode` | `lteULSCHInterleave`

Introduced in R2014a

lteULSCHInterleave

UL-SCH interleaving

Syntax

```
out = lteULSCHInterleave(ue,chs,cdata)
out = lteULSCHInterleave(ue,chs,cdata,ccqi,cri,cack)
```

Description

`out = lteULSCHInterleave(ue,chs,cdata)` performs the UL-SCH channel interleaving on input `cdata` containing encoded transport channel (TrCH) data without UCI. It performs the UL-SCH data and UCI multiplexing and interleaving as defined in TS 36.212 Sections 5.2.2.7 and 5.2.2.8 [1]. This input can be a vector or a cell array of vectors, interleaved separately, and the output is of the same form.

Multiple codewords can be parameterized by two different forms of the `chs` structure. Each codeword can be defined by separate elements of a 1-by-2 structure array, or the codeword parameters can be combined together in the fields of a single scalar, or 1-by-1, structure. Any scalar field values apply to both codewords and a scalar `NLayers` is the total number. See “UL-SCH Parameterization” for more details.

`out = lteULSCHInterleave(ue,chs,cdata,ccqi,cri,cack)` is as above except it also supports UL-SCH channel interleaving on both `cdata` and encoded UCI in `ccqi`, `cri` and `cack`. If any of these inputs are cell arrays, the output has the same form and any vector inputs are interleaved into the first cell of the output only. Any of the input cells or arrays can be empty if the associated input is not transmitted on one or more codewords.

Examples

PUSCH Interleave

Interleave two PUSCH RBs worth of bits for QPSK modulation. Considering the REs reserved for PUSCH DM-RS, there are 144 REs available for PUSCH data per RB.

Therefore, two RBs contain 288 PUSCH symbols. This results in 2*288 bits to QPSK modulate after interleaving.

Initialize UE specific and UL-SCH related parameter structures. Generate data for QPSK modulation of PUSCH symbols in two RBs. For QPSK, there are two bits per symbol. Perform interleaving and symbol modulation.

```
ue.CyclicPrefixUL = 'Normal';
ue.Shortened = 0;

chs.Modulation = 'QPSK';
chs.NLayers = 1;

numRB = 2;
numREperRB = 144;
bitsPerSymbol = 2;
numBits = numRB * numREperRB * bitsPerSymbol;
cdata = randi([0 1], numBits, 1);

interleaved = lteULSCHInterleave(ue, chs, cdata);
symbols = lteSymbolModulate(interleaved, 'QPSK');
```

Input Arguments

ue — UE-specific settings

structure

UE-specific settings, specified as a structure with the following fields.

CyclicPrefixUL — Cyclic prefix length

'Normal' (default) | optional | 'Extended'

Cyclic prefix length, specified as 'Normal' or 'Extended'.

Data Types: char

Shortened — Shorten subframe

0 (default) | optional | 1

Shorten subframe, specified as 0 or 1. If 1, the last symbol of the subframe is not used. It should be set if the current subframe contains a possible SRS transmission.

Data Types: logical

Data Types: `struct`

`chs` — UL-SCH related parameters

scalar structure

UL-SCH related parameters, specified as a scalar structure with the following fields.

`Modulation` — Modulation format

`'QPSK'` | `'16QAM'` | `'64QAM'` | cell array of these character vectors.

Modulation format. Specified as a character vector or cell array of character vectors.

Data Types: `char`

`NLayers` — Number of transmission layers (total or per codeword)

1 (default) | optional | 2 | 3 | 4

Number of transmission layers (total or per codeword), specified as 1, 2, 3, or 4.

Data Types: `double`

Data Types: `struct`

`cdata` — Encoded TrCH data

column vector | cell array of column vectors

Encoded TrCH data, specified as a column vector or a cell array of column vectors.

Data Types: `double` | `cell`

`ccqi` — Encoded CQI

vector

Encoded CQI, specified as a vector.

Data Types: `double`

`cri` — Encoded RI

vector

Encoded RI, specified as a vector.

Data Types: `double`

`cack` — Encoded ACK

vector

Encoded ACK, specified as a vector.

Data Types: `double`

Output Arguments

`out` — Interleaved UL-SCH output

numeric column vector | cell array of numeric column vectors

Interleaved UL-SCH output, returned as a numeric column vector or a cell array of numeric column vectors.

Data Types: `double` | `cell`

References

[1] 3GPP TS 36.212. "Multiplexing and channel coding." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

`lteACKEncode` | `lteCQIEncode` | `lteRateMatchTurbo` | `lteRIEncode` | `lteULSCH` | `lteULSCHDeinterleave` | `lteULSCHInfo`

Introduced in R2014a

lteULScramble

PUSCH scrambling

Syntax

```
out = lteULScramble(in,nsubframe,cellid,rnti)
out = lteULScramble(ue,in)
```

Description

`out = lteULScramble(in,nsubframe,cellid,rnti)` performs PUSCH scrambling of bit vector, `in`, for subframe number, `nsubframe`, cell identity, `cellid`, and specified RNTI, `rnti`. It performs PUSCH scrambling according to TS 36.211, Section 5.3.1 [1]. Placeholder bits, denoted by *x*, are represented by –1 in the input vector or cell array of vectors. Repetition placeholder bits, *y*, are represented by –2. This function substitutes these placeholders as part of its scrambling operation.

`in` is a vector or a cell array containing one or two vectors corresponding to the number of codewords to be scrambled.

`out = lteULScramble(ue,in)` performs PUSCH scrambling of the `in` according to UE-specific settings in structure, `ue`.

Examples

Perform PUSCH Scrambling

Perform PUSCH scrambling for NCellID=100 and RNTI=61.

```
in = ones(10,1);
bits = lteULScramble(struct('NCellID',100,'NSubframe',0,'RNTI',61),in)
```

```
bits =

  10×1 int8 column vector
```

```
0
1
0
0
0
1
0
0
1
1
```

Input Arguments

`in` — Bit input data

numeric column vector | cell array of numeric column vectors

Bit input data, specified as a numeric column vector or cell array of numeric column vectors. This argument contains one or two vectors corresponding to the number of codewords to be scrambled.

Data Types: `double | cell`
Complex Number Support: Yes

`nsubframe` — Subframe number

numeric scalar

Subframe number, specified as a numeric scalar.

Data Types: `double`

`cellid` — Physical layer cell identity

numeric scalar

Physical layer cell identity, specified as a numeric scalar.

Data Types: `double`

`rnti` — Radio Network Temporary Identifier (16-bit)

numeric scalar

Radio Network Temporary Identifier (16-bit). specified as a numeric scalar.

Data Types: `double`

`ue` — UE-specific settings
structure

UE-specific settings, specified as a structure with the following fields.

`NCellID` — Physical layer cell identity
numeric scalar

Physical layer cell identity, specified as a numeric scalar.

Data Types: `double`

`NSubframe` — Subframe number
numeric scalar

Subframe number, specified as a numeric scalar.

Data Types: `double`

`RNTI` — Radio Network Temporary Identifier (16-bit)
numeric scalar

Radio Network Temporary Identifier (16-bit). specified as a numeric scalar.

Data Types: `double`

Data Types: `struct`

Output Arguments

`out` — PUSCH scrambled output bits
numeric column vector | cell array of numeric column vectors

PUSCH scrambled output bits, returned as a numeric column vector or a cell array of numeric column vectors.

References

[1] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

`ltePUSCH` | `lteSymbolModulate` | `lteULDescramble`

Introduced in R2014a

lteWarning

Enable and disable warnings for LTE System Toolbox

Syntax

```
lteWarning('OFF',msgname)
lteWarning('ON',msgname)
```

Description

`lteWarning('OFF',msgname)` and `lteWarning('ON',msgname)` disable and enable the display of any warning messages of type `msgname`, specific to the LTE System Toolbox.

Examples

Toggle LTE Function Warnings

Disable and enable default value warnings for optional parameters.

Turn off the warning about default values.

```
lteWarning('off','DefaultValue')
bch = lteBCH(struct('CellRefP',1),ones(24,1));
```

Turn on the warning about default values.

```
lteWarning('on','DefaultValue')
bch = lteBCH(struct('CellRefP',1),ones(24,1));
```

```
Warning: Using default value for parameter field CyclicPrefix (Normal)
```

Notice a warning about default values is displayed when the same command is run to generate a BCH.

Input Arguments

msgname — Message name

`'defaultValue' | 'deprecated'`

Message name, specified as `'defaultValue'` or `'deprecated'`.

Option	Warning Message
`'defaultValue'`	This warning occurs when an optional parameter value or parameter structure field is not defined and the default value is used instead.
`'deprecated'`	This warning occurs for deprecated functionality of the LTE System Toolbox. For example, it occurs when the user calls a function using a deprecated syntax option. This warning indicates that the functionality may be removed in a later release.

Data Types: `char`

See Also

See Also

`warning`

Introduced in R2014a

umtsDownlinkReferenceChannels

UMTS downlink measurement channel definition

Syntax

```
config = umtsDownlinkReferenceChannels(rc)
config = umtsDownlinkReferenceChannels(rc,modulation)
```

Description

`config = umtsDownlinkReferenceChannels(rc)` uses the input reference channel, `rc`, to produce a downlink reference channel definition structure, `config`. The configuration parameters required by `umtsDownlinkWaveformGenerator` to generate a downlink reference channel waveform are included in `config`.

For all syntaxes, `umtsDownlinkReferenceChannels` uses the input, `rc`, to initialize a configuration data structure compliant with one of the reference channels defined in the following 3GPP standards:

- Downlink W-CDMA reference measurement channel (RMC) waveforms, as defined in TS 25.101, Annex A3 [1]
- HSDPA fixed reference channel (FRC) H-Set waveforms, as defined in TS 25.101, Annex A7 [1]
- Downlink test model waveforms, as defined in TS 25.141, Section 6.1.1 [2]

`config = umtsDownlinkReferenceChannels(rc,modulation)` gives you the option of changing the default modulation scheme when `rc` specifies initialization of an FRC H-Set configuration. See the table of valid H-Set/modulation combinations in the description of the `modulation` input.

Examples

UMTS Downlink Reference Channel Initialization

Initialize a `'QPSK' 'RMC12.2kbps'` reference channel.

Generate the configuration structure, `rmcStruct`

```
rc = 'RMC12.2kbps';
modulation = 'QPSK';
rmcStruct = umtsDownlinkReferenceChannels(rc, modulation);
```

The output from `umtsDownlinkReferenceChannels` provides the input required to generate the desired UMTS waveform corresponding to these settings.

Examine the `DPCH` field in `rmcStruct`. This field has a nested structure defining this physical channel for the `'RMC12.2kbps'` reference channel with `'QPSK'` modulation.

```
rmcStruct
rmcStruct.DPCH
rmcStruct.DPCH.CCTrCH
rmcStruct.DPCH.CCTrCH.TrCH(1)
rmcStruct.DPCH.CCTrCH.TrCH(1).DynamicPart
rmcStruct.DPCH.CCTrCH.TrCH(2)
rmcStruct.DPCH.CCTrCH.TrCH(2).DynamicPart
```

```
rmcStruct =

  struct with fields:

              TotFrames: 1
    PrimaryScramblingCode: 0
               FilterType: 'RRC'
        OversamplingRatio: 4
          NormalizedPower: 'Off'
                     DPCH: [1×1 struct]
                   PCCPCH: [1×1 struct]
                   SCCPCH: [1×1 struct]
                   PCPICH: [1×1 struct]
                   SCPICH: [1×1 struct]
                     PSCH: [1×1 struct]
                     SSCH: [1×1 struct]
                     PICH: [1×1 struct]
                    HSDPA: [1×1 struct]
                     OCNS: [1×1 struct]


ans =

  struct with fields:

                     Enable: 'On'
```

```
                SlotFormat: 11
             SpreadingCode: 6
              NMulticodes: 1
    SecondaryScramblingCode: 1
              TimingOffset: 0
                     Power: 0
                   TPCData: 0
                      TFCI: 0
                DataSource: 'CCTrCH'
                    CCTrCH: [1×1 struct]


ans =

  struct with fields:

          Name: 'DCH'
    DTXPosition: 'fixed'
          TrCH: [1×2 struct]


ans =

  struct with fields:

                Name: 'DTCH'
                 CRC: '16'
          CodingType: 'conv3'
                 RMA: 256
                 TTI: 20
          DataSource: 'PN9-ITU'
    ActiveDynamicPart: 1
         DynamicPart: [1×1 struct]


ans =

  struct with fields:

       BlockSize: 244
    BlockSetSize: 244


ans =
```

```
  struct with fields:

                Name: 'DCCH'
                 CRC: '12'
          CodingType: 'conv3'
                 RMA: 256
                 TTI: 40
          DataSource: 'PN9-ITU'
    ActiveDynamicPart: 1
         DynamicPart: [1×1 struct]


ans =

  struct with fields:

      BlockSize: 100
    BlockSetSize: 100
```

Input Arguments

`rc` — Reference channel configuration

char

Reference channel, specified as a character vector that identifies which RMC, H-Set, or test model to configure.

Parameter Field	Required or Optional	Values	Description
`rc`	Required	Reference Measurement Channels: `'RMC0kbps'`, `'RMC12.2kbps'`, `'RMC64kbps'`, `'RMC144kbps'`, `'RMC384kbps'`	Reference channel identifying the W-CDMA downlink RMC configuration, as defined in TS 25.101, Annex A3 [1]. See Note: for details specific to `RMC0kbps`
		Fixed Reference Channel H-Sets:	Reference channel identifying the HSDPA and HSPA+ FRC H-Set

Parameter Field	Required or Optional	Values	Description
		`'H-Set1'`, `'H-Set2'`, `'H-Set3'`, `'H-Set4'`, `'H-Set5'`, `'H-Set6'`, `'H-Set7'`, `'H-Set8'`, `'H-Set10'`, `'H-Set12'`.	configuration, as defined in TS 25.101, Annex A7 [1].
		Test Models: `'TM1_4DPCH'`, `'TM1_8DPCH'`, `'TM1_16DPCH'`, `'TM1_32DPCH'`, `'TM1_64DPCH'`, `'TM2_3DPCH'`, `'TM3_4DPCH'`, `'TM3_8DPCH'`, `'TM3_16DPCH'`, `'TM3_32DPCH'`, `'TM4'`, `'TM5_4DPCH_4HSPDSCH'`, `'TM5_6DPCH_2HSPDSCH'`, `'TM5_14DPCH_4HSPDSCH'`, `'TM5_30DPCH_8HSPDSCH'`, `'TM6_4DPCH_4HSPDSCH'`, `'TM6_30DPCH_8HSPDSCH'`	Reference channel identifying the test model physical channel configuration, as defined in TS 25.141, Section 6.1.1 [2].

Data Types: `char`

`modulation` — Modulation scheme for FRC H-Set being configured

`H-Set dependent` (default) | optional | `'QPSK'` | `'16QAM'` | `'64QAM'`

If `rc` specifies an FRC H-Set configuration, the `modulation` scheme specified as a character vector can be included. The table here identifies valid H-Set/Modulation combinations and the default if `modulation` is not specified.

Valid Combinations	`modulation`			Default modulation (if not specified)
`rc`	`'QPSK'`	`'16QAM'`	`'64QAM'`	
`'H-Set1'`	✓	✓	—	`'QPSK'`
`'H-Set2'`	✓	✓	—	`'QPSK'`
`'H-Set3'`	✓	✓	—	`'QPSK'`
`'H-Set4'`	✓	—	—	`'QPSK'`

Valid Combinations	modulation			Default modulation (if not specified)
rc	'QPSK'	'16QAM'	'64QAM'	
'H-Set5'	✓	—	—	'QPSK'
'H-Set6'	✓	✓	—	'QPSK'
'H-Set7'	✓	—	—	'QPSK'
'H-Set8'	—	—	✓	'64QAM'
'H-Set10'	✓	✓	—	'QPSK'
'H-Set12'	✓	—	—	'QPSK'

Data Types: char

Output Arguments

config — Definition of the channels included for the waveform generator
structure

Top-Level Parameters and Substructures

Definition of the channels included for the waveform generator, returned as a structure.

Parameter Field	Required or Optional	Values	Description
TotFrames	Required	Nonnegative scalar integer	Total number of frames to be generated
PrimaryScrambling	Required	Scalar integer from 0 to 511	Primary scrambling code index
FilterType	Required	'RRC' (default), or 'Off'	Enable the RRC filter
OversamplingRatio	Required	Nonnegative scalar integer	Oversampling ratio
NormalizedPower	Required	Float (-inf to +inf) or 'Off' to disable power normalization	Overall waveform power in dBW relative to 1 ohm

Parameter Field	Required or Optional	Values	Description
DPCH	Optional	Not present, single structure, or structure array	See DPCH Substructure.
PCCPCH	Optional	Not present or single structure	See PCCPCH Substructure.
SCCPCH	Optional	Not present or single structure	See SCCPCH Substructure.
PCPICH	Optional	Not present or single structure	See PCPICH Substructure.
SCPICH	Optional	Not present or single structure	See SCPICH Substructure.
PSCH	Optional	Not present or single structure	See PSCH Substructure.
SSCH	Optional	Not present or single structure	See SSCH Substructure.
PICH	Optional	Not present or single structure	See PICH Substructure.
HSDPA	Optional	Not present or single structure	See HSDPA Substructure
OCNS	Optional	Not present or single structure	See OCNS Substructure.

DPCH Substructure

Include the `DPCH` substructure in the `config` structure to add dedicated physical channels to the output structure. The `DPCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	`'On'`, or `'Off'`	Enable or disable the channel

Parameter Field	Required or Optional	Values	Description
SlotFormat	Required	Scalar integer from 0 to 16	DPCH slot format number
SpreadingCode	Required	Scalar integer from 0 to 511	DPCH spreading code, for multicode transmission it is the first DPCH code
NMulticodes	Required	Scalar integer (1 ,2, 3, 4, 5, 6)	Number of DPCHs
SecondaryScrambli	Required	Scalar integer form 0 to 15	DPCH secondary scrambling code index
TimingOffset	Required	Scalar integer from 0 to 149	The timing offset in terms of the number of chips (x256Tchip)
Power	Required	Float (-inf to +inf)	Channel power in dB
TPCData	Required	0 or 1	Scalar or vector of Transmit Power Control data
TFCI	Required	Scalar integer from 0 to 1023	Transport Format Combination Indicator

Parameter Field	Required or Optional	Values	Description
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using Transport channel: `'CCTrCH'`	DPCH data source. The data source can be defined as a transport channel (which enables transport channel coding), as one of the PN sequences or as a binary scalar or vector.
`CCTrCH`	Optional	Structure	See CCTrCH Substructure.

CCTrCH Substructure

Include a `CCTrCH` substructure instance individually for `DPCH`, `PCCPCH`, and/or `SCCPCH` substructures. Separate instances of a coded composite transport channel are added to the output structures of the DPCH, P-CCPCH, and/or S-CCPCH physical channel definitions. When the `CCTrCH` substructure is included, it contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Name`	Optional	Character vector (default depends on the physical channel specified)	Name assigned to the CCTrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`DTXPosition`	Required	`'fixed'`, or `'flexible'`	Specifies the DTX position
`TrCH`	Required	Structure or structure array	An array of structures that defines multiple transport channels in the CCTrCH
`TrCH.Name`	Required	Character vector, default depends on the physical channel specified.	Name assigned to the TrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`TrCH.CRC`	Required	Character vector `'0'`, `'8'`, `'12'`, `'16'`, `'24'`	Specifies the CRC polynomial
`TrCH.TTI`	Required	Scalar integer (10, 20, 40, 80)	TTI in ms
`TrCH.CodingTy`	Required	`'turbo'`, `'conv2'`, or `'conv3'`	Specifies channel coding type and rate
`TrCH.RMA`	Required	Scalar integer from 1 to 256	Rate matching attribute value

Parameter Field	Required or Optional	Values	Description
`TrCH.DataSour`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	Transport channel data source. The data source can be defined either as one of the standard PN sequences or as a binary scalar or vector.
		Examples for setting the `DataSource` field include: • ...`CCTrCH.TrCh(1).DataSource = [1 0 0 1]` generates a physical channel data block by looping the vector [1 0 0 1]. • ...`CCTrCH.TrCh(1).DataSource = 'PN9'` generates a physical channel data block with random seed = 511. • ...`CCTrCH.TrCh(1).DataSource = {'PN9',5}` generates a physical channel data block with seed = 5. • ...`CCTrCH.TrCh(1).DataSource = 'CCTrCH'` causes the physical channel to carry the transport channel that is defined by the `CCTrCH` substructure.	
`TrCH.ActiveDy`	Required	Scalar integer, in the range 1 through `length(DynamicPart)`	Scalar or vector specifying the active dynamic part

Parameter Field	Required or Optional	Values	Description
		The `ActiveDynamicPart` field indicates the `DynamicPart` array index for the active transport format `(Blockset, BlockSetSize)` from available combinations defined in `DynamicPart`. The selected transport format is used for data transmission in the current TTI.	
`TrCH.DynamicP`	Required	Structure or structure array	Structure specifying size of each transport block
		The `DynamicPart` fields, `BlockSize` and `BlockSetSize`, define the size of each transport block and the total bits per transport block set. As a pair `(BlockSize, BlockSetSize)` describe a transport format set. `DynamicPart` defines one or multiple transport format sets.	
`TrCH.DynamicP`	Required	Positive scalar integer	Transport block length
`TrCH.DynamicP`	Required	Scalar integer, multiple of `BlockSize`	Total number of bits in the transport block set. Implementation does not support multiple transport blocks, so by definition `BlockSet` is equal to `BlockSetSize`.

Note: When configuring the output structure to transmit the RMC 0kbps, as defined in TS 25.101, Section A.3.0 [1], a transport channel CRC is defined for transmission. The standard indicates DTCH transport block size = 0 and transport block set size = 0. Our implementation requires signalling transmission of a transport block to transmit a CRC. In the `umtsDownlinkWaveformGenerator`, one transport block of size zero is signaled by setting either `BlockSize or BlockSetSize` to `'0'`.

In our implementation, setting both `BlockSize` and `BlockSetSize` to zero signals transmission of zero transport blocks and a transport block size of zero and causes a transmission with no CRC.

PCCPCH Substructure

Include the `PCCPCH` substructure in the `config` structure to add the primary common control physical channel to the output structure. The `PCCPCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`Power`	Required	Float (-inf to +inf)	P-CCPCH power in dB
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using transport channel: `'CCTrCH'`	PCCPCH data source. The data source can be defined as a transport channel (which enables BCH transport channel coding), as one of the PN sequences or as a binary scalar or vector
`CCTrCH`	Optional	Structure	See `CCTrCH` Substructure.

SCCPCH Substructure

Include the `SCCPCH` substructure in the `config` structure to add the secondary common control physical channel to the output structure. The `SCCPCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer from 0 to 17	S-CCPCH slot format number
`SpreadingCode`	Required	Scalar integer from 0 to 255 Valid range depends on slot format	S-CCPCH spreading code
`SecondaryScrambl`	Required	Scalar integer from 0 to 15	S-CCPCH secondary scrambling code index
`TimingOffset`	Required	Scalar integer from0 to 149	The timing offset in terms of the number of chips (x256Tchip)
`Power`	Required	Float (-inf to +inf)	S-CCPCH power in dB
`TFCI`	Required	Scalar integer from 0 to 1023	Transport format combination indicator
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`.	S-CCPCH data source. The data source can be defined as a transport channel (which enables PCH/FACH transport channel coding), as one of the PN sequences, or as a binary scalar or vector.

Parameter Field	Required or Optional	Values	Description
		If no seed is specified, the shift register is initialized with all ones. Using Transport channel: `'CCTrCH'`	
`CCTrCH`	Optional	Structure	See `CCTrCH` Substructure.

PCPICH Substructure

Include the `PCPICH` substructure in the `config` structure to add the primary common pilot channel to the output structure. The `PCPICH` substructure contains the following fields.

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`Power`	Required	Float (-inf to +inf)	P-CPICH power in dB

SCPICH Substructure

Include the `SCPICH` substructure in the `config` structure to add the secondary common pilot channel to the output structure. The `SCPICH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SpreadingCode`	Required	Scalar integer from 0 to 255	S-CPICH spreading code

Parameter Field	Required or Optional	Values	Description
SecondaryScrambl	Required	Scalar integer from 0 to 15	S-CPICH secondary scrambling code index
Power	Required	Float (-inf to +inf)	S-CPICH power in dB

PSCH Substructure

Include the PSCH substructure in the config structure to add the physical shared channel to the output structure. The PSCH substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	'On', or 'Off'	Enable or disable the channel
Power	Required	Float (-inf to +inf)	P-SCH power in dB

SSCH Substructure

Include the SSCH substructure in the config structure to add the secondary synchronization channel to the output structure. The SSCH substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	'On', or 'Off'	Eable or disable the channel
Power	Required	Float (-inf to +inf)	S-SCH power in dB

PICH Substructure

Include the PICH substructure in the config structure to add the page indicator channel to the output structure. The PICH substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SpreadingCode`	Required	Scalar integer from 0 to 255	PICH spreading code
`TimingOffset`	Required	Scalar integer from 0 to 149	The timing offset in terms of the number of chips (x256Tchip)
`Power`	Required	Float (-inf to +inf)	PICH power in dB
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using paging data: `'PagingData'`	PICH data source. The data source can be defined as paging data, as one of the PN sequences or as a binary scalar or vector.
`Np`	Required	Scalar integer (18, 36, 72, 144)	Number of paging indicators per frame

HSDPA Substructure

Include the `HSDPA` substructure in the `config` structure to add high-speed downlink protocol access information and channels to the output structure. The `HSDPA` substructure contains the following fields.

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
Enable	Required	'On', or 'Off'	Enable or disable the HSDPA channels (HS-PDSCHs and HS-SCCH)
CodeGroup	Required	Scalar integer from 0 to 16	Number of channelization codes used simultaneously for HS-PDSCHs
CodeOffset	Required	Scalar integer from 0 to 15	Offset to the first channelization code to use for HS-PDSCHs
Modulation	Required	'QPSK', '16QAM', or '64QAM'	Specifies symbol modulation
VirtualBufferCap	Required	Nonnegative scalar integer	Size of virtual IR buffer
InterTTIDistance	Required	Scalar integer from 1 to 8	TTI interval in ms
NHARQProcesses	Required	Scalar integer from 1 to 8	Total number of HARQ Processes
XrvSequence	Required	Scalar integer from 0 to 7	Redundancy and constellation version coding sequence
UEId	Required	Scalar integer from 0 to 65535	UE identifier
TransportBlockSi	Required	Scalar integer from 0 to 63	Transport block size ID
HSSCCHSpreadingC	Required	Scalar integer from 0 to 127	HS-SCCH spreading code
SecondaryScrambl	Required	Scalar integer from 0 to 15	Secondary scrambling code index for HS-PDSCH and HS-SCCH channels
HSPDSCHPower	Required	Float (-inf to +inf)	HS-PDSCH power in dB
HSSCCHPower	Required	Float (-inf to +inf)	HS-SCCH power in dB

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using transport channel: `'HSDSCH'`	HSDPA data source. The data source can be defined as a transport channel (enables HS-DSCH transport channel coding), as one of the PN sequences, or as a binary scalar or vector
`HSDSCH`	Optional	Not present or a structure	
The following fields are required only if the `HSDSCH` substructure is present.			
`HSDSCH.BlockS`	Required	Nonnegative scalar integer	Transport block size

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
HSDSCH.DataSc	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	HSDSCH transport data source. The data source can be defined either as one of the standard PN sequences or as a binary scalar or vector.

OCNS Substructure

Include the `OCNS` substructure in the `config` structure to add orthogonal channel noise source information to the output structure. The `OCNS` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	`'On'`, or `'Off'`	Enable or disable the channel
Power	Required	Float (-inf to +inf)	OCNS overall power in dB
OCNSType	Required	For RMCs and H-Sets: `'RMC_16DPCH'`, `'H-Set_6DPCH'`, `'H-Set_4DPCH'`	If `OCNS` is enabled, `OCNSType` specifies which OCNS configuration to use. The `OCNS` substructure and `OCNSType` field are used to generate

Parameter Field	Required or Optional	Values	Description

		For Test Model DPCH and HS-PDSCH/HS-SCCH sets:
		
		`'TM1_4DPCH'`,
		`'TM1_8DPCH'`,
		`'TM1_16DPCH'`,
		`'TM1_32DPCH'`,
		`'TM1_64DPCH'`,
		`'TM2_3DPCH'`,
		`'TM3_4DPCH'`,
		`'TM3_8DPCH'`,
		`'TM3_16DPCH'`,
		`'TM3_32DPCH'`,
		`'TM5_4DPCH_4HSPDSCH'`,
		`'TM5_6DPCH_2HSPDSCH'`,
		`'TM5_14DPCH_4HSPDSCH'`
		`'TM5_30DPCH_8HSPDSCH'`
		`'TM6_4DPCH_4HSPDSCH'`,
		`'TM6_30DPCH_8HSPDSCH'`
			• DPCHs, defined as OCNS channels in TS 25.101
			• DPCHs, HS-PDSCHs, and HS-SCCHs, defined for test models in TS 25.141, Section 6
			
			For test model generation, set the corresponding channel configuration `Enable` field to `'Off'`.

References

[1] 3GPP TS 25.101. "User Equipment (UE) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

[2] 3GPP TS 25.141. "Base Station (BS) conformance testing (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

See Also

See Also

`umtsDownlinkWaveformGenerator` | `umtsUplinkReferenceChannels` | `umtsUplinkWaveformGenerator`

Topics

"Downlink Reference Channel and Waveform Generation Parameter Structures"

Introduced in R2015a

umtsDownlinkWaveformGenerator

UMTS downlink waveform generation

Syntax

```
waveform = umtsDownlinkWaveformGenerator(config)
```

Description

`waveform = umtsDownlinkWaveformGenerator(config)` returns the UMTS downlink waveform, `waveform`, defined by the configuration structure, `config`. This function supports W-CDMA, HSDPA, and HSPA+ waveform generation. The top-level parameters and lower-level substructures of `config` characterize the waveform and channel properties of the `umtsDownlinkWaveformGenerator` function output. The `config` input is generated using the `umtsDownlinkReferenceChannels` function. `config` includes top-level parameters and substructures to describe the different channels to include in the waveform. The top-level parameters of `config` are: `TotFrames`, `PrimaryScramblingCode`, `FilterType`, `OversamplingRatio`, and `NormalizedPower`. To enable the specific channels, you can add associated substructures: `DPCH`, `PCCPCH`, `SCCPCH`, `PCPICH`, `SCPICH`, `PSCH`, `SSCH`, `PICH`, `HSDPA`, and `OCNS`.

Note: Include an interfering downlink 3GPP technology noise source by initializing the `OCNS` substructure. Specify the orthogonal channel noise source (OCNS) parameters using the appropriate 3GPP definition,

- RMC OCNS channels are defined in TS 25.101, Table C.6 [1]
- H-Set OCNS channels are defined in TS 25.141, Tables C.13, and C.13A [2]
- Test model DPCHs and HS-PDSCH/HS-SCCH channels are defined in TS 25.141, Section 6.1.1 [2]

Examples

UMTS Downlink Waveform Generation

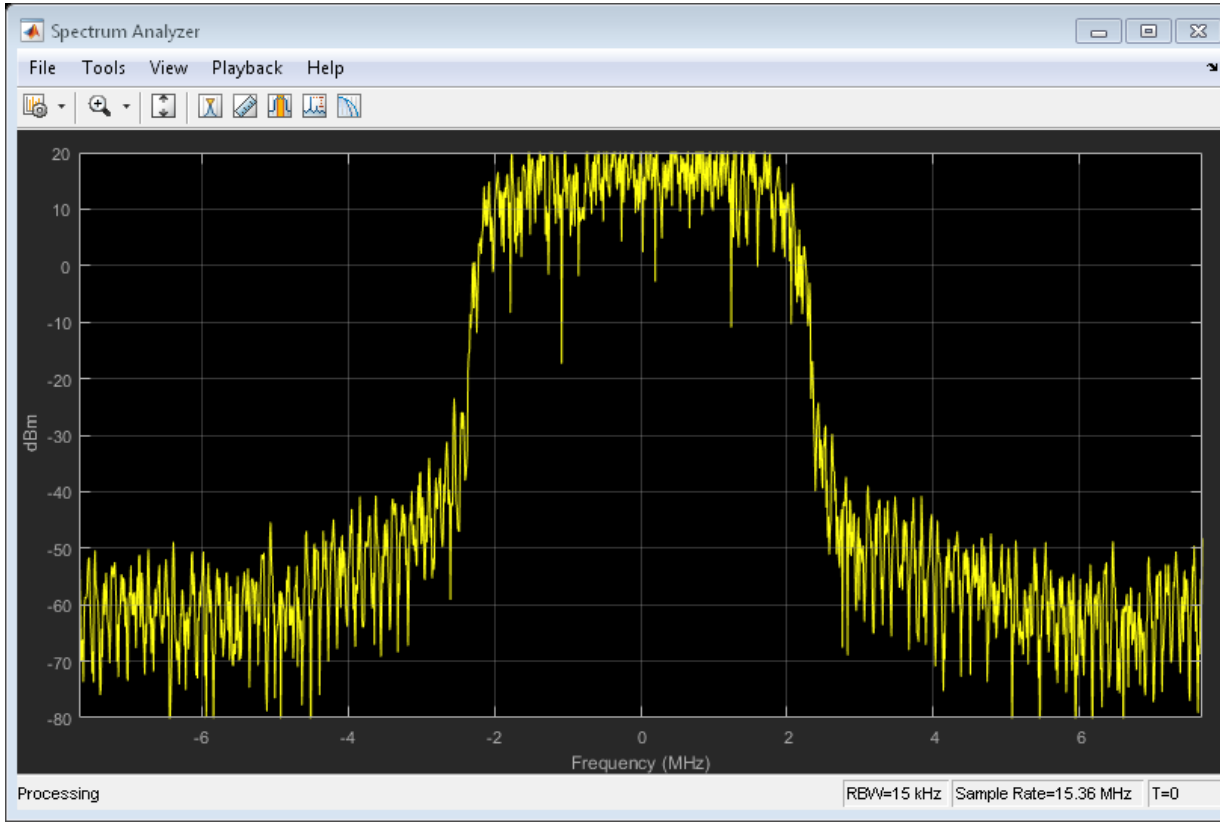
Initialize a `'QPSK'`, `'H-Set1'` FRC reference channel and generate the UMTS waveform that corresponds to these settings.

Generate the configuration structure, `frcStruct`.

```
rc = 'H-Set1';
modulation = 'QPSK';
frcStruct = umtsDownlinkReferenceChannels(rc, modulation);
```

Generate the desired waveform using `frcStruct` as the input to the waveform generation function. Create a spectrum analyzer object sampling at `chiprate` x `OversamplingRatio`. Plot the waveform.

```
waveform = umtsDownlinkWaveformGenerator(frcStruct);
saScope = dsp.SpectrumAnalyzer('SampleRate', 3.84e6*frcStruct.OversamplingRatio);
saScope(waveform);
```



Input Arguments

`config` — Definition of the channels included by waveform generator

structure

Top-Level Parameters and Substructures

Definition of the channels included by the waveform generator, specified as a structure.

Parameter Field	Required or Optional	Values	Description
TotFrames	Required	Nonnegative scalar integer	Total number of frames to be generated
PrimaryScrambling	Required	Scalar integer from 0 to 511	Primary scrambling code index
FilterType	Required	`'RRC'` (default), `'Off'`	Enable the RRC filter
OversamplingRatio	Required	Nonnegative scalar integer	Oversampling ratio
NormalizedPower	Required	Float (-inf to +inf) or `'Off'` to disable power normalization	Overall waveform power in dBW relative to 1 ohm
DPCH	Optional	Not present, structure, or structure array	See DPCH Substructure.
PCCPCH	Optional	Not present or structure	See PCCPCH Substructure.
SCCPCH	Optional	Not present or structure	See SCCPCH Substructure.
PCPICH	Optional	Not present or structure	See PCPICH Substructure.
SCPICH	Optional	Not present or structure	See SCPICH Substructure.
PSCH	Optional	Not present or structure	See PSCH Substructure.
SSCH	Optional	Not present or structure	See SSCH Substructure.
PICH	Optional	Not present or structure	See PICH Substructure.
HSDPA	Optional	Not present or structure	See HSDPA Substructure.
OCNS	Optional	Not present or structure	See OCNS Substructure.

DPCH Substructure

Include the `DPCH` substructure in the `config` structure to add dedicated physical channels to the output structure. The `DPCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer from 0 to 16	DPCH slot format number
`SpreadingCode`	Required	Scalar integer from 0 to 511	DPCH spreading code, for multicode transmission it is the first DPCH code
`NMulticodes`	Required	Scalar integer (1 ,2, 3, 4, 5, 6)	Number of DPCHs
`SecondaryScrambli`	Required	Scalar integer form 0 to 15	DPCH secondary scrambling code index
`TimingOffset`	Required	Scalar integer from 0 to 149	The timing offset in terms of the number of chips (x256Tchip)
`Power`	Required	Float (-inf to +inf)	Channel power in dB
`TPCData`	Required	0 or 1	Scalar or vector of Transmit Power Control data
`TFCI`	Required	Scalar integer from 0 to 1023	Transport Format Combination Indicator

Parameter Field	Required or Optional	Values	Description
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using Transport channel: `'CCTrCH'`	DPCH data source. The data source can be defined as a transport channel (which enables transport channel coding), as one of the PN sequences or as a binary scalar or vector.
`CCTrCH`	Optional	Structure	See CCTrCH Substructure.

CCTrCH Substructure

Include a `CCTrCH` substructure instance individually for `DPCH`, `PCCPCH`, and/or `SCCPCH` substructures. Separate instances of a coded composite transport channel are added to the output structures of the DPCH, P-CCPCH, and/or S-CCPCH physical channel definitions. When the `CCTrCH` substructure is included, it contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Name`	Optional	Character vector (default depends on the physical channel specified)	Name assigned to the CCTrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`DTXPosition`	Required	`'fixed'`, or `'flexible'`	Specifies the DTX position
`TrCH`	Required	Structure or structure array	An array of structures that defines multiple transport channels in the CCTrCH
`TrCH.Name`	Required	Character vector, default depends on the physical channel specified.	Name assigned to the TrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`TrCH.CRC`	Required	Character vector `'0'`, `'8'`, `'12'`, `'16'`, `'24'`	Specifies the CRC polynomial
`TrCH.TTI`	Required	Scalar integer (10, 20, 40, 80)	TTI in ms
`TrCH.CodingTy`	Required	`'turbo'`, `'conv2'`, or `'conv3'`	Specifies channel coding type and rate
`TrCH.RMA`	Required	Scalar integer from 1 to 256	Rate matching attribute value

Parameter Field	Required or Optional	Values	Description
TrCH.DataSour	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	Transport channel data source. The data source can be defined either as one of the standard PN sequences or as a binary scalar or vector.
		Examples for setting the `DataSource` field include: • ...`CCTrCH.TrCh(1).DataSource = [1 0 0 1]` generates a physical channel data block by looping the vector [1 0 0 1]. • ...`CCTrCH.TrCh(1).DataSource = 'PN9'` generates a physical channel data block with random seed = 511. • ...`CCTrCH.TrCh(1).DataSource = {'PN9',5}` generates a physical channel data block with seed = 5. • ...`CCTrCH.TrCh(1).DataSource = 'CCTrCH'` causes the physical channel to carry the transport channel that is defined by the `CCTrCH` substructure.	
TrCH.ActiveDy	Required	Scalar integer, in the range 1 through `length(DynamicPart)`	Scalar or vector specifying the active dynamic part

Parameter Field	Required or Optional	Values	Description
		The `ActiveDynamicPart` field indicates the `DynamicPart` array index for the active transport format `(Blockset, BlockSetSize)` from available combinations defined in `DynamicPart`. The selected transport format is used for data transmission in the current TTI.	
`TrCH.DynamicP`	Required	Structure or structure array	Structure specifying size of each transport block
		The `DynamicPart` fields, `BlockSize` and `BlockSetSize`, define the size of each transport block and the total bits per transport block set. As a pair `(BlockSize, BlockSetSize)` describe a transport format set. `DynamicPart` defines one or multiple transport format sets.	
`TrCH.DynamicP`	Required	Positive scalar integer	Transport block length
`TrCH.DynamicP`	Required	Scalar integer, multiple of `BlockSize`	Total number of bits in the transport block set. Implementation does not support multiple transport blocks, so by definition `BlockSet` is equal to `BlockSetSize`.

Note: When configuring the output structure to transmit the RMC 0kbps as defined in TS 25.101, Section A.3.0 [1], a transport channel CRC is defined for transmission. The standard indicates DTCH transport block size = 0 and transport block set size = 0. Our implementation requires signalling transmission of a transport block to transmit a CRC. In the `umtsDownlinkWaveformGenerator`, one transport block of size zero is signaled by setting either `BlockSize or BlockSetSize` to `'0'`. Setting both `BlockSize` and `BlockSetSize` to `'0'` signals `'0'` transport block of size `'0'` and no CRC is transmitted.

PCCPCH Substructure

Include the `PCCPCH` substructure in the `config` structure to add the primary common control physical channel to the output structure. The `PCCPCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`Power`	Required	Float (-inf to +inf)	P-CCPCH power in dB
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using transport channel: `'CCTrCH'`	PCCPCH data source. The data source can be defined as a transport channel (which enables BCH transport channel coding), as one of the PN sequences or as a binary scalar or vector
`CCTrCH`	Optional	Structure	See `CCTrCH` Substructure.

SCCPCH Substructure

Include the `SCCPCH` substructure in the `config` structure to add the secondary common control physical channel to the output structure. The `SCCPCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer from 0 to 17	S-CCPCH slot format number
`SpreadingCode`	Required	Scalar integer from 0 to 255 Valid range depends on slot format	S-CCPCH spreading code
`SecondaryScrambl`	Required	Scalar integer from 0 to 15	S-CCPCH secondary scrambling code index
`TimingOffset`	Required	Scalar integer from0 to 149	The timing offset in terms of the number of chips (x256Tchip)
`Power`	Required	Float (-inf to +inf)	S-CCPCH power in dB
`TFCI`	Required	Scalar integer from 0 to 1023	Transport format combination indicator
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`.	S-CCPCH data source. The data source can be defined as a transport channel (which enables PCH/FACH transport channel coding), as one of the PN sequences, or as a binary scalar or vector.

Parameter Field	Required or Optional	Values	Description
		If no seed is specified, the shift register is initialized with all ones. Using Transport channel: `'CCTrCH'`	
`CCTrCH`	Optional	Structure	See `CCTrCH` Substructure.

PCPICH Substructure

Include the `PCPICH` substructure in the `config` structure to add the primary common pilot channel to the output structure. The `PCPICH` substructure contains the following fields.

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`Power`	Required	Float (-inf to +inf)	P-CPICH power in dB

SCPICH Substructure

Include the `SCPICH` substructure in the `config` structure to add the secondary common pilot channel to the output structure. The `SCPICH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SpreadingCode`	Required	Scalar integer from 0 to 255	S-CPICH spreading code

Parameter Field	Required or Optional	Values	Description
`SecondaryScrambl`	Required	Scalar integer from 0 to 15	S-CPICH secondary scrambling code index
`Power`	Required	Float (-inf to +inf)	S-CPICH power in dB

PSCH Substructure

Include the `PSCH` substructure in the `config` structure to add the physical shared channel to the output structure. The `PSCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`Power`	Required	Float (-inf to +inf)	P-SCH power in dB

SSCH Substructure

Include the `SSCH` substructure in the `config` structure to add the secondary synchronization channel to the output structure. The `SSCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Eable or disable the channel
`Power`	Required	Float (-inf to +inf)	S-SCH power in dB

PICH Substructure

Include the `PICH` substructure in the `config` structure to add the page indicator channel to the output structure. The `PICH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SpreadingCode`	Required	Scalar integer from 0 to 255	PICH spreading code
`TimingOffset`	Required	Scalar integer from 0 to 149	The timing offset in terms of the number of chips (x256Tchip)
`Power`	Required	Float (-inf to +inf)	PICH power in dB
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using paging data: `'PagingData'`	PICH data source. The data source can be defined as paging data, as one of the PN sequences or as a binary scalar or vector.
`Np`	Required	Scalar integer (18, 36, 72, 144)	Number of paging indicators per frame

HSDPA Substructure

Include the `HSDPA` substructure in the `config` structure to add high-speed downlink protocol access information and channels to the output structure. The `HSDPA` substructure contains the following fields.

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the HSDPA channels (HS-PDSCHs and HS-SCCH)
`CodeGroup`	Required	Scalar integer from 0 to 16	Number of channelization codes used simultaneously for HS-PDSCHs
`CodeOffset`	Required	Scalar integer from 0 to 15	Offset to the first channelization code to use for HS-PDSCHs
`Modulation`	Required	`'QPSK'`, `'16QAM'`, or `'64QAM'`	Specifies symbol modulation
`VirtualBufferCap`	Required	Nonnegative scalar integer	Size of virtual IR buffer
`InterTTIDistance`	Required	Scalar integer from 1 to 8	TTI interval in ms
`NHARQProcesses`	Required	Scalar integer from 1 to 8	Total number of HARQ Processes
`XrvSequence`	Required	Scalar integer from 0 to 7	Redundancy and constellation version coding sequence
`UEId`	Required	Scalar integer from 0 to 65535	UE identifier
`TransportBlockSi`	Required	Scalar integer from 0 to 63	Transport block size ID
`HSSCCHSpreadingC`	Required	Scalar integer from 0 to 127	HS-SCCH spreading code
`SecondaryScrambl`	Required	Scalar integer from 0 to 15	Secondary scrambling code index for HS-PDSCH and HS-SCCH channels
`HSPDSCHPower`	Required	Float (-inf to +inf)	HS-PDSCH power in dB
`HSSCCHPower`	Required	Float (-inf to +inf)	HS-SCCH power in dB

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
DataSource	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: 'PN9-ITU', 'PN9', 'PN11', 'PN15', 'PN23'. If no seed is specified, the shift register is initialized with all ones. Using transport channel: 'HSDSCH'	HSDPA data source. The data source can be defined as a transport channel (enables HS-DSCH transport channel coding), as one of the PN sequences, or as a binary scalar or vector
HSDSCH	Optional	Not present or a structure	
The following fields are required only if the HSDSCH substructure is present.			
HSDSCH.BlockS	Required	Nonnegative scalar integer	Transport block size

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
HSDSCH.DataSc	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	HSDSCH transport data source. The data source can be defined either as one of the standard PN sequences or as a binary scalar or vector.

OCNS Substructure

Include the `OCNS` substructure in the `config` structure to add orthogonal channel noise source information to the output structure. The `OCNS` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	`'On'`, or `'Off'`	Enable or disable the channel
Power	Required	Float (-inf to +inf)	OCNS overall power in dB
OCNSType	Required	For RMCs and H-Sets: `'RMC_16DPCH'`, `'H-Set_6DPCH'`, `'H-Set_4DPCH'`	If `OCNS` is enabled, `OCNSType` specifies which OCNS configuration to use. The `OCNS` substructure and `OCNSType` field are used to generate

Parameter Field	Required or Optional	Values	Description

		For Test Model DPCH and HS-PDSCH/HS-SCCH sets:
		
		`'TM1_4DPCH'`,
		`'TM1_8DPCH'`,
		`'TM1_16DPCH'`,
		`'TM1_32DPCH'`,
		`'TM1_64DPCH'`,
		`'TM2_3DPCH'`,
		`'TM3_4DPCH'`,
		`'TM3_8DPCH'`,
		`'TM3_16DPCH'`,
		`'TM3_32DPCH'`,
		`'TM5_4DPCH_4HSPDSCH'`,
		`'TM5_6DPCH_2HSPDSCH'`,
		`'TM5_14DPCH_4HSPDSCH'`
		`'TM5_30DPCH_8HSPDSCH'`
		`'TM6_4DPCH_4HSPDSCH'`,
		`'TM6_30DPCH_8HSPDSCH'`
			• DPCHs, defined as OCNS channels in TS 25.101
			• DPCHs, HS-PDSCHs, and HS-SCCHs, defined for test models in TS 25.141, Section 6
			
			For test model generation, set the corresponding channel configuration `Enable` field to `'Off'`.

Output Arguments

`waveform` — Modulated baseband waveform containing the UMTS physical channels

complex vector array

Modulated baseband waveform containing the UMTS physical channels, returned as a complex vector array, sampled at (3.84 × `config.OversamplingRatio`) MHz.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 25.101. "User Equipment (UE) Radio Transmission and Reception (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

[2] 3GPP TS 25.141. "Base Station (BS) conformance testing (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

See Also

See Also

`umtsDownlinkReferenceChannels` | `umtsUplinkReferenceChannels` | `umtsUplinkWaveformGenerator`

Topics

"Downlink Reference Channel and Waveform Generation Parameter Structures"

Introduced in R2015a

umtsUplinkReferenceChannels

UMTS uplink measurement channel definition

Syntax

```
config = umtsUplinkReferenceChannels(rc)
```

Description

`config = umtsUplinkReferenceChannels(rc)` returns a structure containing the configuration parameters for the UMTS uplink reference channel defined by `rc`. The output structure, `config`, contains the configuration parameters required by `umtsUplinkWaveformGenerator` to generate an uplink reference channel waveform. `umtsUplinkReferenceChannels` uses, `rc`, to initialize a configuration data structure that is compliant with one of the reference channels defined in the following 3GPP standards:

- Uplink RMC configurations are defined in TS 25.101, Annex A.2 [1].
- Uplink E-DPDCH FRC configurations are as defined in TS 25.141, Annex 10 [2].

Examples

UMTS Uplink Reference Channel Initialization

Initialize a `'RMC12.2kbps'` reference channel.

Generate the configuration structure, `config`.

```
rc = 'RMC12.2kbps';
config = umtsUplinkReferenceChannels(rc);
```

The output from `umtsUplinkReferenceChannels` provides the input required to generate the desired UMTS waveform corresponding to these settings.

Examine the `DPDCH` field in `config`. This field uses a nested structure to define this physical channel for the `'RMC12.2kbps'` reference channel.

```
config
```

```
config.DPDCH
config.DPDCH.CCTrCH
config.DPDCH.CCTrCH.TrCH(1)
config.DPDCH.CCTrCH.TrCH(1).DynamicPart
config.DPDCH.CCTrCH.TrCH(2)
config.DPDCH.CCTrCH.TrCH(2).DynamicPart


config =

  struct with fields:

           TotFrames: 1
       ScramblingCode: 1
           FilterType: 'RRC'
    OversamplingRatio: 4
      NormalizedPower: 'Off'
                DPDCH: [1×1 struct]
                DPCCH: [1×1 struct]
                HSUPA: [1×1 struct]
              HSDPCCH: [1×1 struct]


ans =

  struct with fields:

              Enable: 'On'
          SlotFormat: 2
    CodeCombination: 64
               Power: 0
          DataSource: 'CCTrCH'
              CCTrCH: [1×1 struct]


ans =

  struct with fields:

    Name: 'DCH'
    TrCH: [1×2 struct]


ans =
```

```
  struct with fields:

                Name: 'DTCH'
                 CRC: '16'
          CodingType: 'conv3'
                 RMA: 256
                 TTI: 20
          DataSource: 'PN9-ITU'
    ActiveDynamicPart: 1
          DynamicPart: [1×1 struct]


ans =

  struct with fields:

       BlockSize: 244
    BlockSetSize: 244


ans =

  struct with fields:

                Name: 'DCCH'
                 CRC: '12'
          CodingType: 'conv3'
                 RMA: 256
                 TTI: 40
          DataSource: 'PN9-ITU'
    ActiveDynamicPart: 1
          DynamicPart: [1×1 struct]


ans =

  struct with fields:

       BlockSize: 100
    BlockSetSize: 100
```

Input Arguments

`rc` — Reference channel configuration

char

Reference channel, specified as a character vector that identifies which RMC or E-DPDCH FRC to configure.

Parameter Field	Required or Optional	Values	Description
`rc`	Required	Reference measurement channels: `'RMC12.2kbps'`, `'RMC64kbps'`, `'RMC144kbps'`, `'RMC384kbps'`	Reference channel identifying the W-CDMA uplink RMC configuration set-up as defined in TS 25.101, Annex A.2 [1].
		E-DPDCH Fixed Reference Channels: `'FRC1'`, `'FRC2'`, `'FRC3'`, `'FRC4'`, `'FRC5'`, `'FRC6'`, `'FRC7'`, `'FRC8'`	Reference channel identifying the E-DPDCH FRC configuration as defined in TS 25.141, Annex A.10 [2].

Note: Additional standards-based reference channels can be configured by executing `lteUplinkReferenceChannels` and then adjusting parameters to match configurations defined in TS 25.141 [2]. For example:

- To generate the HS-DPCCH RMC, use `'RMC12.2kbps'` and set `HSDPCCH.Enable = 'On'`.
- To generate the 12.2 kbps RMC defined in TS 25.141 [2], use `'RMC12.2kbps'`. Using this value the function initializes `config` to generate the TS 25.101 [1] 12.2 kbps RMC). After `config` is generated, adjust the DPDCH and DPCCH parameters to align with the settings in TS 25.141 [2].

Output Arguments

`config` — Definition of the channels included for the waveform generator
structure

Top-Level Parameters and Substructures

Definition of the channels included for the waveform generator, returned as a structure.

Parameter Field	Required or Optional	Values	Description
`TotFrames`	Required	Positive scalar integer	Total number of frames to be generated
`ScramblingCode`	Required	Scalar integer $0-\left(2^{24}-1\right)$	Scrambling code index used by UE
`FilterType`	Required	`'RRC'`, or `'Off'`	Enable the RRC filter
`OversamplingRatio`	Required	Positive scalar integer	Oversampling ratio
`NormalizedPower`	Required	Float (-inf to +inf) or `'Off'` to disable power normalization	Overall waveform power in dBW relative to 1 ohm
`DPDCH`	Optional	Not present or single structure	See DPDCH Substructure.
`DPCCH`	Optional	Not present or single structure	See DPCCH Substructure.
`HSUPA`	Optional	Not present or single structure	See HSUPA Substructure.
`HSDPCCH`	Optional	Not present or single structure	See HSDPCCH Substructure.

DPDCH Substructure

Include the `DPDCH` substructure in the `config` structure to add the dedicated physical data channel to the output structure. The `DPDCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer (0, 1, 2, 3, 4, 5, 6)	DPDCH slot format number
`CodeCombination`	Required	Scalar integer or vector (256, 128, 64, 32, 16, 8, 4)	Scalar or vector of valid spreading factors
`Power`	Required	Float (-inf to +inf)	Channel power in dB
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using Transport channel:	DPDCH data source. The data source can be the transport channel (which enables transport channel coding), one of the PN sequences, or a binary scalar or vector.

Parameter Field	Required or Optional	Values	Description
		`'CCTrCH'`	
`CCTrCH`	Optional	Structure	See CCTrCH Substructure.

CCTrCH Substructure

The `CCTrCH` substructure is associated with the DPDCH physical channel definition substructures. The `CCTrCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Name`	Optional	Character vector (default depends on the physical channel specified)	Name assigned to the CCTrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`TrCH`	Required	Structure or structure array	An array of structures that defines multiple transport channels in the CCTrCH
`TrCH.Name`	Required	Character vector (default depends on the physical channel specified)	Name assigned to the TrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`TrCH.CRC`	Required	Character vector `'0'`, `'8'`, `'12'`, `'16'`, `'24'`	Specifies the CRC polynomial
`TrCH.TTI`	Required	Scalar integer (10, 20, 40, 80)	Transmission Time Interval (TTI) in ms
`TrCH.CodingType`	Required	`'turbo'`, `'conv2'`, or `'conv3'`	Specifies channel coding type and rate
`TrCH.RMA`	Required	Scalar integer from 1 to 256	Rate matching attribute value

Parameter Field	Required or Optional	Values	Description
`TrCH.DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	Transport channel data source. The data source can be defined either as one of the standard PN sequences, or as a binary scalar or vector.
		Examples for setting the `DataSource` field include: • ...`CCTrCH.TrCh(1).DataSource = [1 0 0 1]`, generates a physical channel data block by looping the vector [1 0 0 1]. • ...`CCTrCH.TrCh(1).DataSource = 'PN9'`, generates a physical channel data block with random seed = 511. • ...`CCTrCH.TrCh(1).DataSource = {'PN9',5}`, generates a physical channel data block with seed = 5. • ...`CCTrCH.TrCh(1).DataSource = 'CCTrCH'`, causes the physical channel to carry the transport channel that is defined by the `CCTrCH` substructure.	
`TrCH.ActiveDyna`	Required	Scalar integer in the range from 1 to `length(DynamicPart)`	Scalar or vector specifying the active dynamic part

Parameter Field	Required or Optional	Values	Description
		The `ActiveDynamicPart` field indicates the `DynamicPart` array index for the active transport format `(Blockset, BlockSetSize)` from available combinations defined in `DynamicPart`. The selected transport format is used for data transmission in the current TTI.	
`TrCH.DynamicPar`	Required	Structure or structure array	Structure specifying size of each transport block
		The `DynamicPart` fields, `BlockSize` and `BlockSetSize`, define the size of each transport block and the total bits per transport block set. As a pair `(BlockSize, BlockSetSize)` describe a transport format set. `DynamicPart` defines one or multiple transport format sets.	
`TrCH.DynamicPar`	Required	Positive scalar integer	Transport block length
`TrCH.DynamicPar`	Required	Scalar integer, multiple of `BlockSize`	Total number of bits in the transport block set. Implementation does not support multiple transport blocks, so by definition `BlockSet` is equal to `BlockSetSize`.

DPCCH Substructure

Include the `DPCCH` substructure in the `config` structure to add the dedicated physical control channel to the output structure. The `DPCCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer (0, 1, 2 ,3 ,4 ,5)	DPCCH slot format number
`Power`	Required	Float (-inf to +inf)	DPCCH power in dB
`TPCData`	Required	0 or 1	Scalar or vector of transmit power control data

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`TFCI`	Required	Scalar integer from 0 to 1023	Transport format combination indicator
`FBIData`	Required	0 or 1	Scalar or vector of feedback information data

HSUPA Substructure

Include the `HSUPA` substructure in the `config` structure to add the high speed uplink packet access information and channels to the output structure. The `HSUPA` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`CodeCombination`	Required	Scalar integer from 2 to 256	Valid one-code combination: 256, 128, 64, 32, 16, 8, 4 for BPSK modulation Valid two-code combinations: [4 4], [2 2] for BPSK modulation Valid four-code combinations: [2 2 4 4] for BPSK and 4PAM modulation
`EDPDCHPower`	Required	Float (-inf to +inf)	E-DPDCH channel power in dB
`EDPCCHPower`	Required	Float (-inf to +inf)	E-DPCCH channel power in dB
`RSNSequence`	Required	Scalar integer (0, 1, 2 ,3)	Vector of retransmission sequence numbers. The length of this vector determines the number of retransmissions.
`ETFCI`	Required	Scalar integer from 0 to 127	E-TFCI value
`HappyBit`	Required	0 or 1	Happy bit

Parameter Field	Required or Optional	Values	Description
DataSource	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using Transport channel: `'EDCH'`	E-DPDCH data source. The data source can be defined as the transport channel (which enables transport channel coding), as one of the PN sequences, or as a binary scalar or vector.
EDCH	Required		Single structure
EDCH.BlockSize	Required	Nonnegative scalar integer	Transport block size
EDCH.TTI	Required	Scalar integer (2 or 10)	Transmission Time Interval (TTI) in ms
EDCH.Modulation	Required	`'BPSK'` or `'4PAM'`	Specifyies the modulation scheme

Parameter Field	Required or Optional	Values	Description
`EDCH.DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	E-DCH transport data source. The data source can be defined as one of the PN sequences or as a binary scalar or vector.

HSDPCCH Substructure

Include `HSDPCCH` substructure in `config` structure to add the high speed dedicated physical control channel to the output structure. The `HSDPCCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`Power`	Required	Float (-inf to +inf)	HS-DPCCH channel power in dB
`CQI`	Required	Scalar integer or vector from 0 to 30	CQI values
`HARQACK`	Required	Scalar integer or vector (0, 1, 2, 3)	HARQACK messages
`UEMIMO`	Required	0 or 1	Flag to indicate MIMO mode

References

[1] 3GPP TS 25.101. "User Equipment (UE) Radio Transmission and Reception (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

[2] 3GPP TS 25.141. "Base Station (BS) conformance testing (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

See Also

See Also

`umtsDownlinkReferenceChannels` | `umtsDownlinkWaveformGenerator` | `umtsUplinkWaveformGenerator`

Topics

"Uplink Reference Channel and Waveform Generation Parameter Structures"

Introduced in R2015a

umtsUplinkWaveformGenerator

UMTS uplink waveform generation

Syntax

```
waveform = umtsUplinkWaveformGenerator(config)
```

Description

`waveform = umtsUplinkWaveformGenerator(config)` returns the UMTS uplink waveform defined by the configuration structure, `config`. This function supports W-CDMA, HSUPA, and HSPA+ waveform generation. The top-level parameters and lower-level substructures of `config` characterize the waveform and channel properties of the `umtsUplinkWaveformGenerator` function output. The `config` input is generated using the `umtsUplinkReferenceChannels` function. `config` includes top-level parameters and substructures to describe the different channels to include in the waveform. The top-level parameters of `config` are: `TotFrames`, `ScramblingCode`, `FilterType`, `OversamplingRatio`, and `NormalizedPower`. To enable the specific channels, you can add associated substructures: `DPDCH`, `DPCCH`, `HSUPA`, and `HSDPCCH`.

Examples

UMTS Uplink Waveform Generation

Initialize an `'RMC384kbps'` reference channel and generate the UMTS waveform that corresponds to these settings.

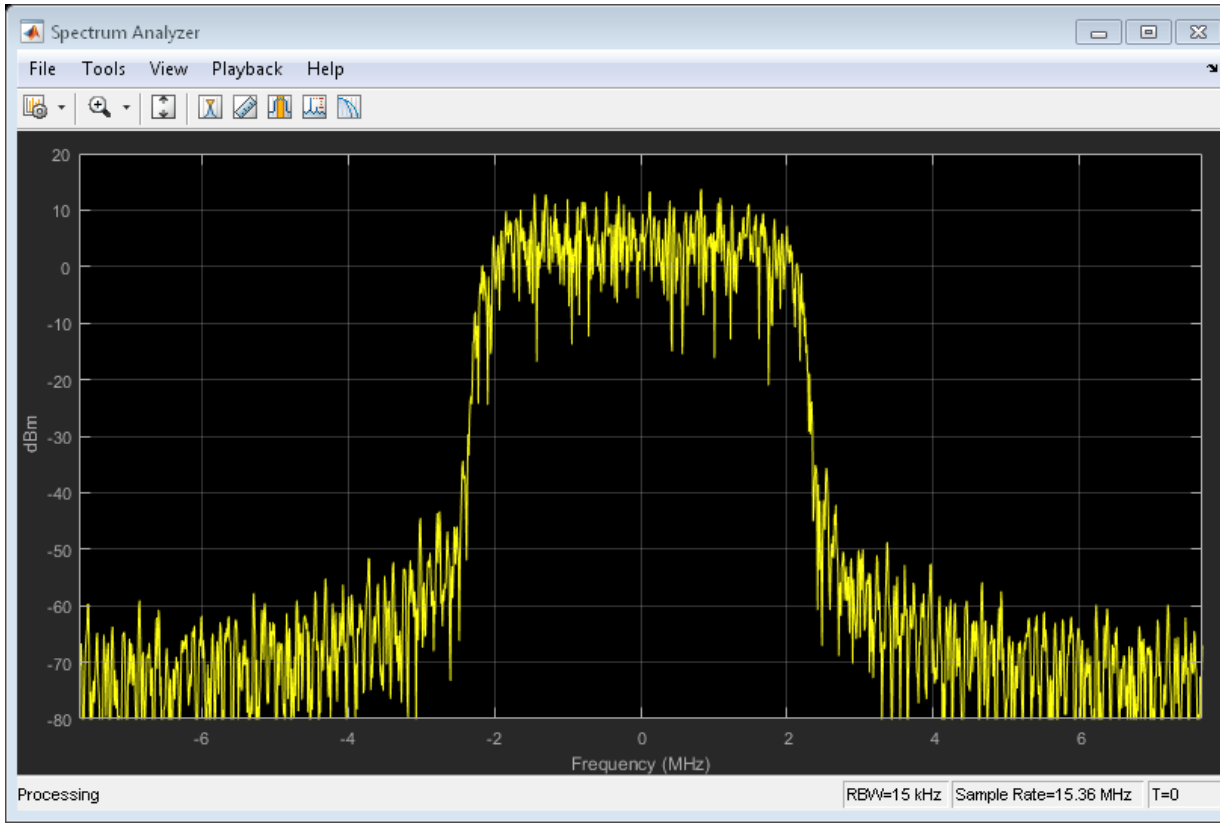
Generate the configuration structure, `config`.

```
rc = 'RMC384kbps';
config = umtsUplinkReferenceChannels(rc);
```

Generate the desired waveform using `config` as the input to the waveform generation function. Create a spectrum analyzer object sampling at `chiprate` x `OversamplingRatio`. Plot the waveform.

```
waveform = umtsUplinkWaveformGenerator(config);
```

```
saScope = dsp.SpectrumAnalyzer('SampleRate', 3.84e6*config.OversamplingRatio);
saScope(waveform);
```



Input Arguments

`config` — Definition of the channels included for the waveform generator

structure

Top-Level parameters and substructures

Definition of the channels included by the waveform generator, specified as a structure.

Parameter Field	Required or Optional	Values	Description
`TotFrames`	Required	Positive scalar integer	Total number of frames to be generated
`ScramblingCode`	Required	Scalar integer $0-\left(2^{24}-1\right)$	Scrambling code index used by UE
`FilterType`	Required	`'RRC'` (default), or `'Off'`	Enable the RRC Filter
`OversamplingRatio`	Required	Positive scalar integer	Oversampling ratio
`NormalizedPower`	Required	Float (-inf to +inf) or `'Off'` to disable power normalization	Overall waveform power in dBW relative to 1 ohm
`DPDCH`	Optional	Not present or structure	See DPDCH Substructure.
`DPCCH`	Optional	Not present or structure	See DPCCH Substructure.
`HSUPA`	Optional	Not present or structure	See HSUPA Substructure.
`HSDPCCH`	Optional	Not present or structure	See HSDPCCH Substructure.

DPDCH Substructure

Include the `DPDCH` substructure in the `config` structure to add the dedicated physical data channel to the output structure. The `DPDCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer (0, 1, 2, 3, 4, 5, 6)	DPDCH slot format number

Parameter Field	Required or Optional	Values	Description
`CodeCombination`	Required	Scalar integer or vector (256, 128, 64, 32, 16, 8, 4)	Scalar or vector of valid spreading factors
`Power`	Required	Float (-inf to +inf)	Channel power in dB
`DataSource`	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones. Using Transport channel: `'CCTrCH'`	DPDCH data source. The data source can be the transport channel (which enables transport channel coding), one of the PN sequences, or a binary scalar or vector.
`CCTrCH`	Optional	Structure	See CCTrCH Substructure.

CCTrCH Substructure

The `CCTrCH` substructure is associated with the DPDCH physical channel definition substructures. The `CCTrCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
`Name`	Optional	Character vector (default depends on the physical channel specified)	Name assigned to the CCTrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`TrCH`	Required	Structure or structure array	An array of structures that defines multiple transport channels in the CCTrCH
`TrCH.Name`	Required	Character vector (default depends on the physical channel specified)	Name assigned to the TrCH. Functions do not use the `Name` field. Therefore, you can redefine the content with no consequence.
`TrCH.CRC`	Required	Character vector `'0'`, `'8'`, `'12'`, `'16'`, `'24'`	Specifies the CRC polynomial
`TrCH.TTI`	Required	Scalar integer (10, 20, 40, 80)	Transmission Time Interval (TTI) in ms
`TrCH.CodingType`	Required	`'turbo'`, `'conv2'`, or `'conv3'`	Specifies channel coding type and rate
`TrCH.RMA`	Required	Scalar integer from 1 to 256	Rate matching attribute value

Parameter Field	Required or Optional	Values	Description
TrCH.DataSource	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	Transport channel data source. The data source can be defined either as one of the standard PN sequences, or as a binary scalar or vector.
		Examples for setting the `DataSource` field include: • ...`CCTrCH.TrCh(1).DataSource = [1 0 0 1]`, generates a physical channel data block by looping the vector [1 0 0 1]. • ...`CCTrCH.TrCh(1).DataSource = 'PN9'`, generates a physical channel data block with random seed = 511. • ...`CCTrCH.TrCh(1).DataSource = {'PN9',5}`, generates a physical channel data block with seed = 5. • ...`CCTrCH.TrCh(1).DataSource = 'CCTrCH'`, causes the physical channel to carry the transport channel that is defined by the `CCTrCH` substructure.	
TrCH.ActiveDyna	Required	Scalar integer in the range from 1 to `length(DynamicPart)`	Scalar or vector specifying the active dynamic part

Parameter Field	Required or Optional	Values	Description
		The `ActiveDynamicPart` field indicates the `DynamicPart` array index for the active transport format `(Blockset, BlockSetSize)` from available combinations defined in `DynamicPart`. The selected transport format is used for data transmission in the current TTI.	
`TrCH.DynamicPar`	Required	Structure or structure array	Structure specifying size of each transport block
		The `DynamicPart` fields, `BlockSize` and `BlockSetSize`, define the size of each transport block and the total bits per transport block set. As a pair `(BlockSize, BlockSetSize)` describe a transport format set. `DynamicPart` defines one or multiple transport format sets.	
`TrCH.DynamicPar`	Required	Positive scalar integer	Transport block length
`TrCH.DynamicPar`	Required	Scalar integer, multiple of `BlockSize`	Total number of bits in the transport block set. Implementation does not support multiple transport blocks, so by definition `BlockSet` is equal to `BlockSetSize`.

DPCCH Substructure

Include the `DPCCH` substructure in the `config` structure to add the dedicated physical control channel to the output structure. The `DPCCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
`Enable`	Required	`'On'`, or `'Off'`	Enable or disable the channel
`SlotFormat`	Required	Scalar integer (0, 1, 2 ,3 ,4 ,5)	DPCCH slot format number
`Power`	Required	Float (-inf to +inf)	DPCCH power in dB
`TPCData`	Required	0 or 1	Scalar or vector of transmit power control data

Parameter Field	Required or Optional	Values / Ranges / Notes	Description
TFCI	Required	Scalar integer from 0 to 1023	Transport format combination indicator
FBIData	Required	0 or 1	Scalar or vector of feedback information data

HSUPA Substructure

Include the HSUPA substructure in the `config` structure to add the high-speed uplink packet access information and channels to the output structure. The HSUPA substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	`'On'`, or `'Off'`	Enable or disable the channel
CodeCombination	Required	Scalar integer from 2 to 256	Valid one-code combination: 256, 128, 64, 32, 16, 8, 4 for BPSK modulation Valid two-code combinations: [4 4], [2 2] for BPSK modulation Valid four-code combinations: [2 2 4 4] for BPSK and 4PAM modulation
EDPDCHPower	Required	Float (-inf to +inf)	E-DPDCH channel power in dB
EDPCCHPower	Required	Float (-inf to +inf)	E-DPCCH channel power in dB
RSNSequence	Required	Scalar integer (0, 1, 2 ,3)	Vector of retransmission sequence numbers. The length of this vector determines the number of retransmissions.
ETFCI	Required	Scalar integer from 0 to 127	E-TFCI value
HappyBit	Required	0 or 1	Happy bit

Parameter Field	Required or Optional	Values	Description
DataSource	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: 'PN9-ITU', 'PN9', 'PN11', 'PN15', 'PN23'. If no seed is specified, the shift register is initialized with all ones. Using Transport channel: 'EDCH'	E-DPDCH data source. The data source can be defined as the transport channel (which enables transport channel coding), as one of the PN sequences, or as a binary scalar or vector.
EDCH	Required		Single structure
EDCH.BlockSize	Required	Nonnegative scalar integer	Transport block size
EDCH.TTI	Required	Scalar integer (2 or 10)	Transmission Time Interval (TTI) in ms
EDCH.Modulation	Required	'BPSK' or '4PAM'	Specifyies the modulation scheme

Parameter Field	Required or Optional	Values	Description
EDCH.DataSource	Required	Scalar, vector, character vector, or cell array When defined as a cell array use standard PN sequences and a seed value: {PN, seed} PN options for character vector, or cell array include: `'PN9-ITU'`, `'PN9'`, `'PN11'`, `'PN15'`, `'PN23'`. If no seed is specified, the shift register is initialized with all ones.	E-DCH transport data source. The data source can be defined as one of the PN sequences or as a binary scalar or vector.

HSDPCCH Substructure

Include `HSDPCCH` substructure in `config` structure to add the high speed dedicated physical control channel to the output structure. The `HSDPCCH` substructure contains the following fields.

Parameter Field	Required or Optional	Values	Description
Enable	Required	`'On'`, or `'Off'`	Enable or disable the channel
Power	Required	Float (-inf to +inf)	HS-DPCCH channel power in dB
CQI	Required	Scalar integer or vector from 0 to 30	CQI values
HARQACK	Required	Scalar integer or vector (0, 1, 2, 3)	HARQACK messages
UEMIMO	Required	0 or 1	Flag to indicate MIMO mode

Output Arguments

`waveform` — Modulated baseband waveform containing the UMTS physical channels

complex vector array

Modulated baseband waveform containing the UMTS physical channels, returned as a complex vector array, sampled at (3.84 × `config.OversamplingRatio`) MHz.

Data Types: `double`
Complex Number Support: Yes

References

[1] 3GPP TS 25.101. "User Equipment (UE) Radio Transmission and Reception (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*. URL: http://www.3gpp.org.

[2] 3GPP TS 25.141. "Base Station (BS) conformance testing (FDD)." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network*.URL: http://www.3gpp.org.

See Also

See Also

`umtsDownlinkReferenceChannels` | `umtsDownlinkWaveformGenerator` | `umtsUplinkReferenceChannels`

Topics

"Uplink Reference Channel and Waveform Generation Parameter Structures"

Introduced in R2015a

rmlteobsolete

Remove obsolete LTE Toolbox interface from search path

Syntax

```
rmlteobsolete
```

Description

`rmlteobsolete` removes the `matlabroot\toolbox\lte\lteobsolete` directory from the MATLAB path, which disables the obsolete LTE Toolbox interface.

Note:

- This interface is provided for backwards compatibility. It will now result in runtime errors indicating which new functions to use.
- You can undo your changes by calling the `rmlteobsolete` function.

Examples

Remove Obsolete LTE Toolbox Interface from Search Path

Remove the directory associated with the obsolete LTE Toolbox interface from the MATLAB® path.

View the current MATLAB path by calling the `pathtool` command.

```
pathtool
```

The Set Path dialog box appears. Scroll down through the listings to find the LTE System Toolbox™ directories, as shown in the following figure.

If you do not see the listing `...\toolbox\lte\lteobsolete`, you do not need to run the `rmlteobsolete` function. Exit this example. Otherwise, click **Close** to close the Set Path dialog box.

Remove the obsolete LTE Toolbox interface from the path.

```
rmlteobsolete
```

```
Warning: Could not save updated path.
```

To confirm the changes, call the `pathtool` command again.

```
pathtool
```

The Set Path dialog box appears. Scroll down through the listings to find the LTE System Toolbox directories, as shown in the following figure.

The absence of the listing `...\toolbox\lte\lteobsolete` shows that you have successfully removed the obsolete LTE Toolbox interface from the search path. Click **Close** again to close the Set Path dialog box.

See Also

See Also

`addlteobsolete`

Introduced in R2014a

2

App Reference

LTE Test Model Generator

Generate LTE downlink test model (E-TM) waveforms

Description

The **LTE Test Model Generator** app generates preset E-UTRA test model (E-TM) waveforms. TS 36.141 [1], Section 6.1, specifies E-TMs for UE performance testing.

User Interface Settings

In the **LTE Downlink E-TM Generator** user interface, you can set these parameters:

Parameter (Equivalent Field)	Values	Description
Test model (`TMN`)	`'1.1'`, `'1.2'`, `'2'`, `'2a'`, `'3.1'`, `'3.1a'`, `'3.2'`, `'3.3'`	Test model number, as specified in TS 36.141, identifying the test model to use when generating the waveform
Bandwidth (`BW`)	`'1.4MHz'`, `'3MHz'`, `'5MHz'`, `'10MHz'`, `'15MHz'`, `'20MHz'`, `'9RB'`, `'11RB'`, `'27RB'`, `'45RB'`, `'64RB'`, `'91RB'`,	Channel bandwidth to use when generating test model waveforms
Cell identity (`NCellID`)	Integer from 0 to 503	Physical layer cell identity
Duplex mode (`DuplexMode`)	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
Number of subframes (`TotSubframes`)	Nonnegative scalar integer	Total number of subframes to generate
Windowing (samples) (`Windowing`)	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied

Parameter (Equivalent Field)	Values	Description
Waveform output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	Waveform output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.
Resource grid output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	Resource grid output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.
E-TM configuration output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	E-TM configuration output parameter structure name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace. The fields of this output configuration structure are initialized in accordance with the test models defined in TS 36.141 [1], Section 6.1.

Open the LTE Test Model Generator App

- MATLAB Toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the **LTE Test Model Generator** app icon.
- MATLAB command prompt: Enter `lteTestModelGenerator` or `lteTestModelTool`.

Examples

Generate E-TM 3.2 Waveform

Use the **LTE Test Model Generator** app to generate a time-domain signal and a 3-D array of the resource elements for the E-TM 3.2, as specified in TS 36.141.

Open the **LTE Test Model Generator** app.

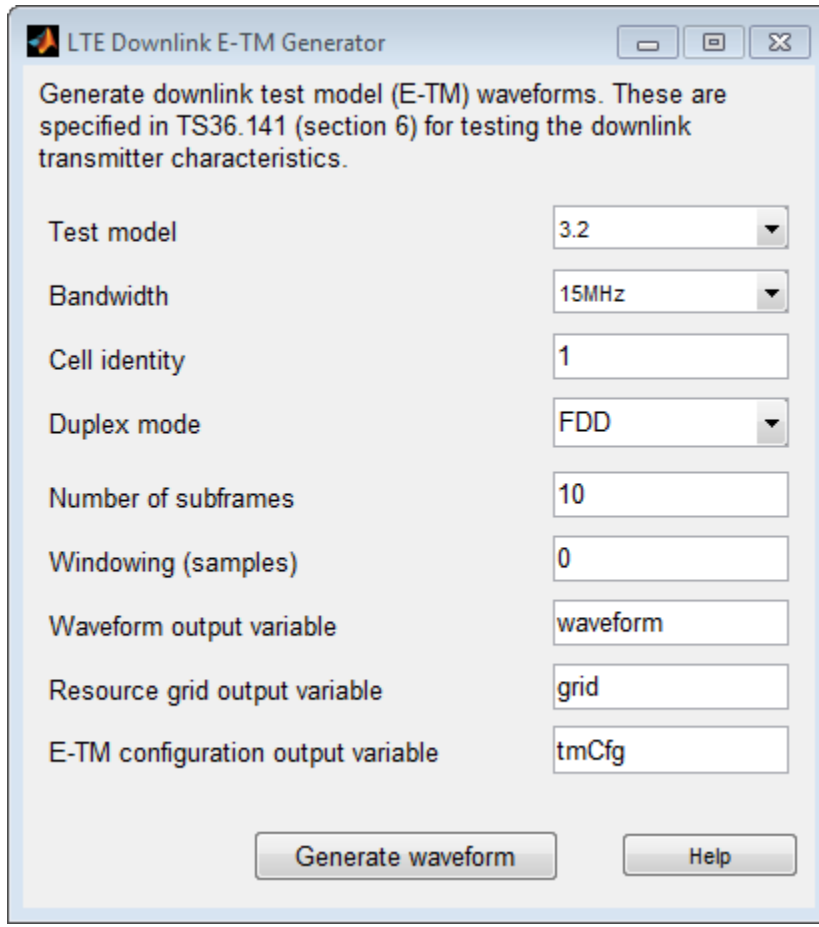
Adjust default runtime parameter settings:

- Set **Test model** to `3.2`.
- Set **Bandwidth** to `15MHz`.

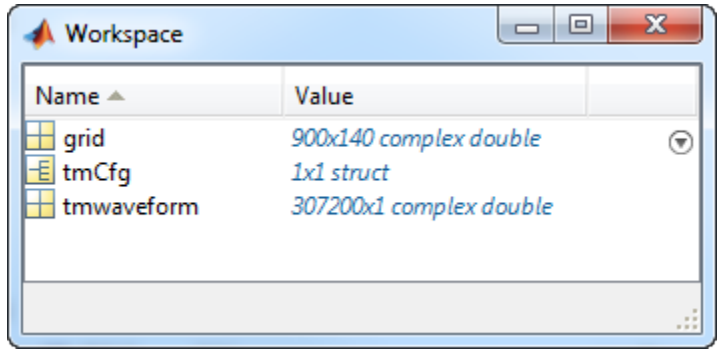
Specify output variable names:

- For **Waveform output variable**, enter `waveform`.
- For **Resource grid output variable**, enter `grid`.
- For **E-TM configuration output variable**, enter `tmCfg`.

The user interface entries should now match these:



Click **Generate waveform** and `waveform`, `grid`, and `tmCfg` variables now appear in the MATLAB Workspace browser.



Programmatic Use

See the `lteTestModelTool` function reference page for a description of the programmatic syntaxes supported.

References

[1] 3GPP TS 36.141. "Base Station (BS) conformance testing." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*. URL: http://www.3gpp.org.

See Also

See Also

Apps

LTE Downlink RMC Generator | LTE Uplink RMC Generator

Functions

`lteRMCDLTool` | `lteTestModel` | `lteTestModelTool`

Introduced in R2014a

LTE Downlink RMC Generator

Generate LTE downlink reference measurement channel (RMC) waveforms

Description

The **LTE Downlink RMC Generator** app generates preset PDSCH reference measurement channel (RMC) waveforms. TS 36.101 [1], Annex A.3 specifies RMCs for UE performance testing.

DL Reference Channel Options

The output configuration structure is initialized in accordance with the reference channels defined in TS 36.101, Annex A.3. Initialization choices available for the downlink reference channel and associated top-level configuration defaults include:

Reference channels	Reference channels (continued)
R.0 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)	R.31-3A FDD (CDD, 50 RB, 64QAM, CellRefP=2, R=0.85-0.90)
R.1 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)	R.31-3A TDD (CDD, 68 RB, 64QAM, CellRefP=2, R=0.87-0.90)
R.2 (Port0, 50 RB, QPSK, CellRefP=1, R=1/3)	R.31-4 (CDD, 100 RB, 64QAM, CellRefP=2, R=0.87-0.90)
R.3 (Port0, 50 RB, 16QAM, CellRefP=1, R=1/2)	R.43 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.4 (Port0, 6 RB, QPSK, CellRefP=1, R=1/3)	R.43 TDD (SpatialMux, 100 RB, 16QAM, CellRefP=4, R=1/2)
R.5 (Port0, 15 RB, 64QAM, CellRefP=1, R=3/4)	R.44 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.6 (Port0, 25 RB, 64QAM, CellRefP=1, R=3/4)	R.44 TDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)
R.7 (Port0, 50 RB, 64QAM, CellRefP=1, R=3/4)	R.45 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)

Reference channels	Reference channels (continued)
R.8 (Port0, 75 RB, 64QAM, CellRefP=1, R=3/4)	R.45-1 (Port7-14, 39 RB, 16QAM, CellRefP=2, R=1/2)
R.9 (Port0, 100 RB, 64QAM, CellRefP=1, R=3/4)	R.48 (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/2)
R.10 (TxDiversity|SpatialMux, 50 RB, QPSK, CellRefP=2, R=1/3)	R.50 FDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)
R.11 (TxDiversity|SpatialMux|CDD, 50 RB, 16QAM, CellRefP=2, R=1/2)	R.50 TDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.12 (TxDiversity, 6 RB, QPSK, CellRefP=4, R=1/3)	R.51 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)
R.13 (SpatialMux, 50 RB, QPSK, CellRefP=4, R=1/3)	R.6-27RB (Port0, 27 RB, 64QAM, CellRefP=1, R=3/4)
R.14 (SpatialMux|CDD, 50 RB, 16QAM, CellRefP=4, R=1/2)	R.12-9RB (TxDiversity, 9 RB, QPSK, CellRefP=4, R=1/3)
R.25 (Port5, 50 RB, QPSK, CellRefP=1, R=1/3)	R.11-45RB (CDD, 45 RB, 16QAM, CellRefP=2, R=1/2)
R.26 (Port5, 50 RB, 16QAM, CellRefP=1, R=1/2)	
R.27 (Port5, 50 RB, 64QAM, CellRefP=1, R=3/4)	
R.28 (Port5, 1 RB, 16QAM, CellRefP=1, R=1/2)	

Note: Reference channels `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` maintain the same code rate as the standard versions but are custom RMCs configured for nonstandard bandwidths.

User Interface Settings

In the **LTE Downlink RMC Generator** user interface, you can set these parameters:

Parameter (Equivalent Field)	Values	Description
Reference channel (RC)	`'R.0'` (default), `'R.1'`, `'R.2'`, `'R.3'`, `'R.4'`, `'R.5'`, `'R.6'`, `'R.7'`, `'R.8'`, `'R.9'`, `'R.10'`, `'R.11'`, `'R.12'`, `'R.13'`, `'R.14'`, `'R.25'`, `'R.26'`, `'R.27'`, `'R.28'`, `'R.31-3A'`, `'R.31-4'`, `'R.43'`, `'R.44'`, `'R.45'`, `'R.45-1'`, `'R.48'`, `'R.50'`, `'R.51'`, `'R.6-27RB'`, `'R.12-9RB'`, `'R.11-45RB'`	Reference measurement channel (RMC) number or type, as specified in TS 36.101, Annex A.3. • `'R.31-3A'` and `'R.31-4'` are sustained data rate RMCs with user data in subframe 5. • `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` are custom RMCs configured for non-standard bandwidths that maintain the same code rate as the standardized versions defined in TS 36.101, Annex A.3. The `'R6-27RB'`, `'R12-9RB'`, and `'R11-45RB'` RC values are custom RMC configured for nonstandard bandwidths, but with the same code rate as the standardized versions.
Duplex mode (`DuplexMode`)	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
Transmission scheme (`TxScheme`)	`'Port0'`, `'TxDiversity'`, `'CDD'`, `'SpatialMux'`, `'MultiUser'`, `'Port5'`, `'Port7-8'`, `'Port8'`, `'Port7-14'`.	PDSCH transmission scheme, specified as one of the following options.

<table>
<tr><th>Parameter (Equivalent Field)</th><th>Values</th><th>Description</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td><code>'Port0'</code></td><td>Single antenna port, port 0</td></tr>
<tr><td><code>'TxDiversity'</code></td><td>Transmit diversity</td></tr>
<tr><td><code>'CDD'</code></td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td><code>'SpatialMux'</code></td><td>Closed loop spatial multiplexing</td></tr>
<tr><td><code>'MultiUser'</code></td><td>Multi-user MIMO</td></tr>
<tr><td><code>'Port5'</code></td><td>Single-antenna port, port 5</td></tr>
<tr><td><code>'Port7-8'</code></td><td>Single-antenna port, port 7, when <code>NLayers</code> = 1. Dual layer transmission, ports 7 and 8, when <code>NLayers</code> = 2.</td></tr>
<tr><td><code>'Port8'</code></td><td>Single-antenna port, port 8</td></tr>
<tr><td><code>'Port7-14'</code></td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table>
</td></tr>
<tr><td>Cell identity (<code>NCellID</code>)</td><td>Integer from 0 to 503</td><td>Physical layer cell identity</td></tr>
<tr><td>RNTI (<code>RNTI</code>)</td><td>0 (default), scalar integer</td><td>Radio network temporary identifier (RNTI) value (16 bits)</td></tr>
</table>

Parameter (Equivalent Field)	Values	Description
RV sequence (`RVSeq`)	Integer vector (0,1,2,3), specified as a one or two row matrix (for one or two codewords)	Specifies the sequence of Redundancy Version (RV) indicators for each HARQ process. The number of elements in each row is equal to the number of transmissions in each HARQ process. If `RVSeq` is a row vector in a two codeword transmission, then the same RV sequence is applied to both codewords.
Rho (dB) (`Rho`)	0 (default), Numeric scalar	PDSCH resource element power allocation, in dB
OCNG (`OCNG`)	`'Off'`, `'On'`. `'Disable'` and `'Enable'` are also accepted.	OFDMA channel noise generator
Number of subframes (`TotSubframes`)	Nonnegative scalar integer	Total number of subframes to generate
Number of codewords (`NCodewords`)	1, 2	Number of PDSCH codewords to use in PDSCH transmission
PMI set (`PMISet`)	Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.
Number of HARQ processes (`NHARQProcesses`)	1, 2, 3, 4, 5, 6, 7, or 8	Number of HARQ processes per component carrier

Parameter (Equivalent Field)	Values	Description
Windowing (samples) (`Windowing`)	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied
Waveform output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	Waveform output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.
Resource grid output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	Resource grid output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.
RMC configuration output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	RMC configuration output parameter structure name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.

RMC Parameter Summary

The **LTE Downlink RMC Generator** use interface displays these RMC parameters:

Parameter (Equivalent Field)	Values	Description
Transmission scheme (`TxScheme`)	See valid values listed in "User Interface Settings" on page 2-8.	See description in "User Interface Settings" on page 2-8.
Number of downlink resource blocks (`NDLRB`)	Scalar integer from 6 to 110.	Number of downlink resource blocks. (N_{RB}^{DL})
Cell-specific reference signal ports (`CellRefP`)	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports

Parameter (Equivalent Field)	Values	Description
Modulation scheme (`Modulation`)	`'QPSK'`, `'16QAM'`, `'64QAM'`	Modulation type
Transmission layers (`NLayers`)	1 (default), 2, 3, 4, 5, 6, 7, 8	Number of transmission layers.
Total info bits per frame per codeword	Positive scalar integer	Total transport block capacity per frame per codeword

Codeword Input Data

In the **LTE Downlink RMC Generator** user interface, you can set the input data for codewords. These input data are equivalent to elements of the `trdata` cell array in the `lteRMCDLTool` function.

Input Data	Values	Description
Transport info bit stream (codeword 1)	**User defined**, **External file**	Information bits to transmit on PDSCH for codeword 1.
Transport info bit stream (codeword 2)	**User defined**, **External file**	Information bits to transmit on PDSCH for codeword 2.

For each input, you can select one of the following options from the drop-down lists.

- **User defined** — Select this option to specify the information bits as a vector of zeros and ones or a variable name. Either enter in the vector manually, or specify the name of an existing variable in the MATLAB workspace. Each vector contains the information bits stream to be coded across the duration of the generation, which represents multiple concatenated transport blocks. Internally, these vectors are looped if the number of bits required across all subframes of the generation exceeds the length of the vectors provided. This feature allows you to enter a short pattern, such as `[1;0;0;1]`, that is repeated as the input to the transport coding.
- **External file** — Select this option to specify a MAT-file in which the variable that you want to use as input data is stored. When you click **Load File**, the Select Files dialog box opens. Select the file that contains the input data, and click **Open**. The Import Wizard dialog box opens. Select the variable in this file that contains the information bits, and click **Finish**.

Open the LTE Downlink RMC Generator App

- MATLAB Toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the **LTE Downlink RMC Generator** app icon.
- MATLAB command prompt: Enter `lteDownlinkRMCGenerator` or `lteRMCDLTool`.

Examples

Generate RMC R.12 Waveform

Use the **LTE Downlink RMC Generator** app to generate a time-domain signal and a 3-D array of the resource elements for the RMC R.12, as specified in TS 36.101 [1].

Open the **LTE Downlink RMC Generator** app.

Adjust default runtime parameter settings:

- From the **RC** drop-down list, choose `R.12`.

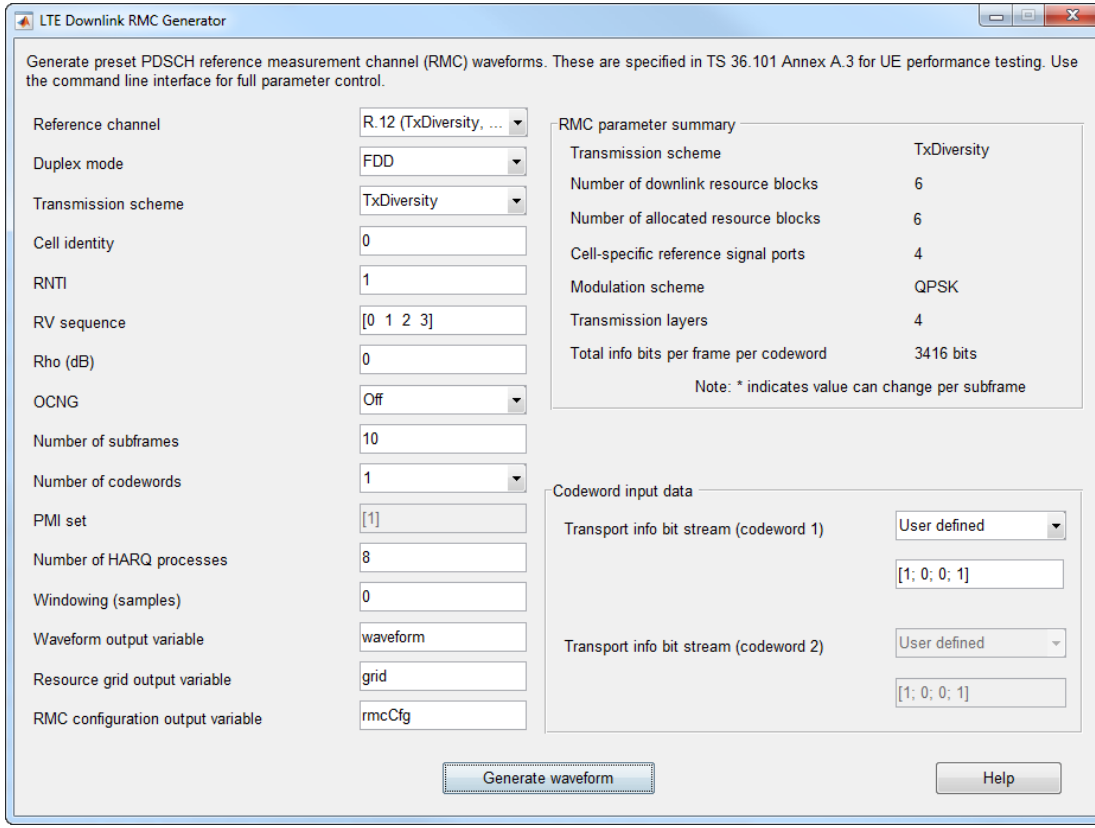
Specify output variable names:

For **Waveform output variable**, enter `waveform`.

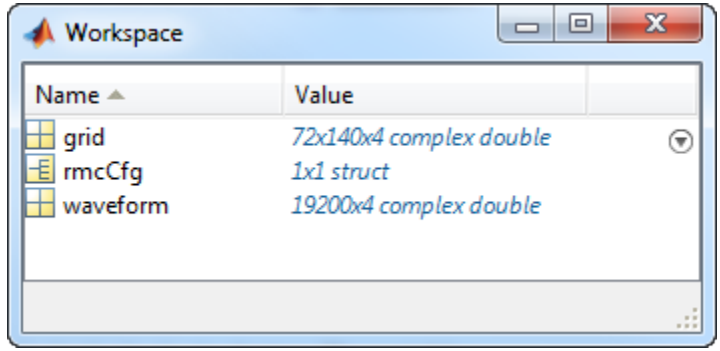
For **Resource grid output variable**, enter `grid`.

For **RMC configuration output variable**, enter `rmcCfg`.

The user interface entries should now match these:



Click **Generate waveform**. The `waveform`, `grid`, and `rmcCfg` variables now appear in the MATLAB Workspace browser.



Programmatic Use

See the `lteRMCDLTool` function reference page for a description of the programmatic syntaxes supported.

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

Apps

LTE Test Model Generator | LTE Uplink RMC Generator

Functions

`lteRMCDL` | `lteRMCDLTool` | `lteRMCULTool` | `lteTestModelTool`

Introduced in R2014a

LTE Throughput Analyzer

Generate throughput curves for physical downlink shared channel (PDSCH) conformance test analysis

Description

The **LTE Throughput Analyzer** app performs PDSCH demodulation performance testing. TS 36.101[1], Annex A.3 specifies RMCs for UE performance testing.

The app also performs analysis and testing for custom user-defined measurement channels settings. For an example, see "LTE Throughput Analyzer User Defined Testing" on page 2-22. This approach can also be used for simulating transmission modes 7–10, specifically, when the transmission scheme (`TxScheme`) is `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'` where DM-RS based channel estimation is required for PDSCH demodulation. In this case, the precoding matrix `W` is randomly defined per subframe according to TS 36.101 [1], Table 8.3.1-1 for FDD and Table 8.3.2-1 for TDD.

Dialog Box Inputs and Outputs

In the **LTE PDSCH Conformance Testing** user interface, you can set these parameters:

Parameter (Equivalent Field)	Values	Description
Reference channel (`RC`)	`'R0'` (default), `'R1'`, `'R2'`, `'R3'`, `'R4'`, `'R5'`, `'R6'`, `'R7'`, `'R8'`, `'R9'`, `'R10'`, `'R11'`, `'R12'`, `'R13'`, `'R14'`, `'R6-27RB'`, `'R12-9RB'`, `'R11-45RB'`, `User defined`	Reference measurement channel (RMC) number or type, as specified in TS 36.101, Annex A.3. • `'R.31-3A'` and `'R.31-4'` are sustained data rate RMCs with user data in subframe 5. • `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` are custom RMCs configured for non-standard bandwidths that maintain the same code rate as the standardized versions defined in TS 36.101, Annex A.3.

Parameter (Equivalent Field)	Values	Description
		To define your own reference channel, select `User defined`. The **User-defined configuration** dialog box opens. For **Configuration structure variable name**, type the name of an RC parameter structure variable in the MATLAB workspace. The tool expects this variable to be present in the MATLAB base workspace. Create the basic configuration structure with the function `lteRMCDL` by choosing a closely matched RMC and modifying to meet your requirements. Use this approach to simulate transmission modes 7–10. Specifically, when `TxScheme` = `'Port5'`, `'Port7-8'`, `'Port8'`, or `'Port7-14'`, where DM-RS based channel estimation is required for PDSCH demodulation. In this case, the precoding matrix, `W`, is randomly defined per subframe according to TS 36.101, Table 8.3.1-1, or Table 8.3.2-1.
Duplex mode (`DuplexMode`)	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex

<table>
<tr><th>Parameter (Equivalent Field)</th><th>Values</th><th>Description</th></tr>
<tr><td>Transmission scheme (TxScheme)</td><td>'Port0', 'TxDiversity', 'CDD', 'SpatialMux', 'MultiUser', 'P... 'Port7-8', 'Por... 'Port7-14'.</td><td>PDSCH transmission scheme, specified as one of the following options.
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td>PDSCH Rho (dB) (Rho)</td><td>0 (default), Numeric scalar</td><td>PDSCH resource element power allocation, in dB</td></tr>
<tr><td>Propagation Model (DelayProfile)</td><td>'Off', 'EPA' (default), 'EVA', 'ETU', 'HST'</td><td>Delay profile model. For more information, see “Propagation Channel Models”.</td></tr>
<tr><td>Doppler (Hz) (DopplerFreq)</td><td>'5', '70', '300', '750'</td><td>Maximum Doppler frequency, in Hz.</td></tr>
</table>

Parameter (Equivalent Field)	Values	Description
Antenna Correlation (`MIMOCorrelatio`)	`'Low'`, `'Medium'`, `'High'`	Correlation between UE and eNodeB antennas
No of receive antennas (`NRxAnts`)	Nonnegative scalar integer	Number of receive antennas
SNR (dB)	Numeric vector	SNR values, in dB
Simulation length (frames)	Positive scalar integer	Simulation length, in frames
Number of HARQ processes (`NHARQProcesses`)	1, 2, 3, 4, 5, 6, 7, or 8	Number of HARQ processes per component carrier
Perfect channel estimator	`'Yes'`, `'No'`	Channel estimator provides a perfect channel estimate when setting is `'Yes'`. For more information, see `lteDLPerfectChannelEstimate`.
PMI mode (`PMIMode`)	`'Wideband'` (default), `'Subband'`	PMI reporting mode. `PMIMode='Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and `PMIMode='Subband'` corresponds to PUSCH reporting Mode 3-1.
Simulation results	Variable name beginning with an alphabetical character and containing alphanumeric characters.	Simulation results output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.

Open the LTE Throughput Analyzer App

- MATLAB Toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the **LTE Throughput Analyzer** app icon.

- MATLAB command prompt: Enter `lteThroughputAnalyzer`.

Examples

Perform 4-by-2 Transmit Diversity Conformance Test

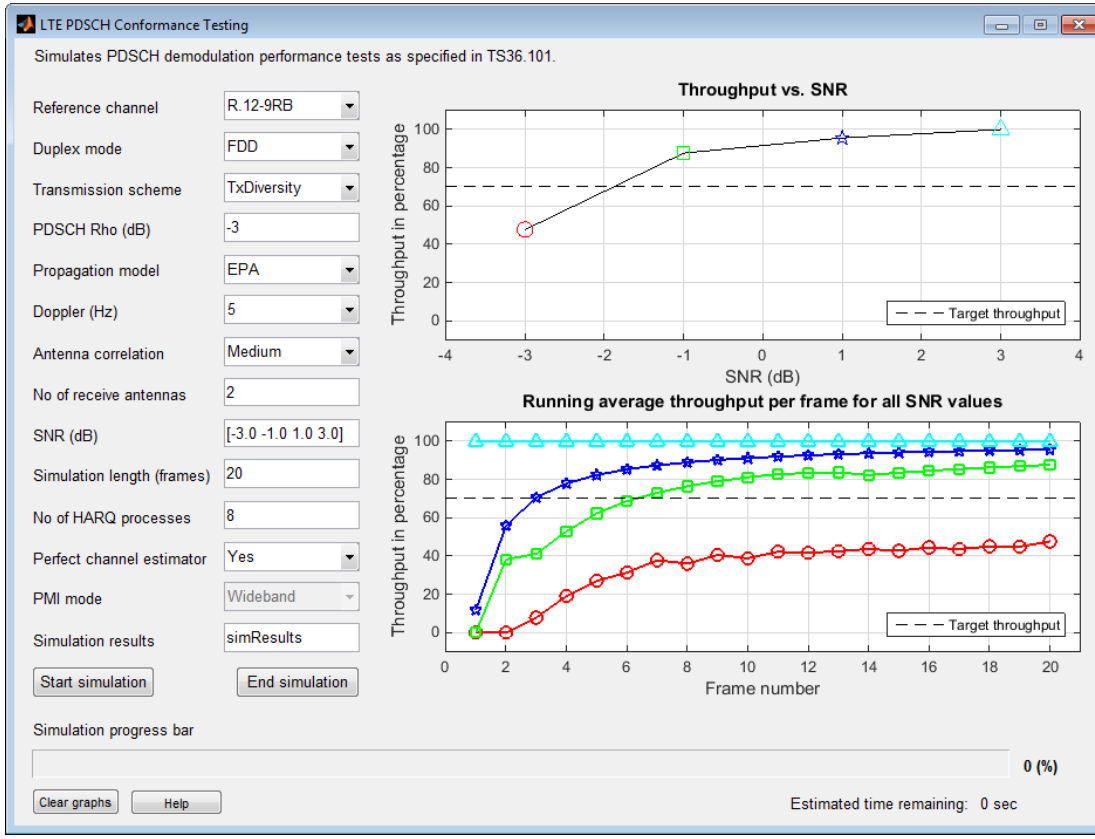
Use the **LTE Throughput Analyzer** app to run a conformance test for a single codeword RMC R.12-9RB for the transmit diversity transmission scheme with EPA-5 fading.

Open the **LTE Throughput Analyzer** app.

Adjust default runtime parameter settings:

- Set **Reference channel** to `R.12-9RB`.
- For **SNR (dB)**, enter `[-3.0 -1.0 1.0 3.0]`.
- For **Simulation length (frames)**, enter `20`.

Click **Start simulation**. The app provides the **Estimated time remaining**. When the simulation finishes, the dialog box updates to show performance curves.



The simulation result for a 20-frame run is displayed in the MATLAB Command Window.

```
Result for -3 dB SNR
Throughput: 47.65%

Result for -1 dB SNR
Throughput: 87.65%

Result for 1 dB SNR
Throughput: 95.59%

Result for 3 dB SNR
Throughput: 100.00%
```

In addition, the `simResults` variable now appears in the MATLAB workspace. View its contents.

```
simResults
```

```
simResults =

1x4 struct array with fields:

    throughput
    tpPerFrame
    rawBER
```

LTE Throughput Analyzer User Defined Testing

Open the LTE throughput analyzer app to run a user defined measurement channel. Define a cutom measurement channel. Any RMC can be used and any settings can be changed. When settings are changed care must be taken not to define an invalid configuartion.

For this example, start with an R.3 RMC, and adjust the number of resource blocks from 50 to 30.

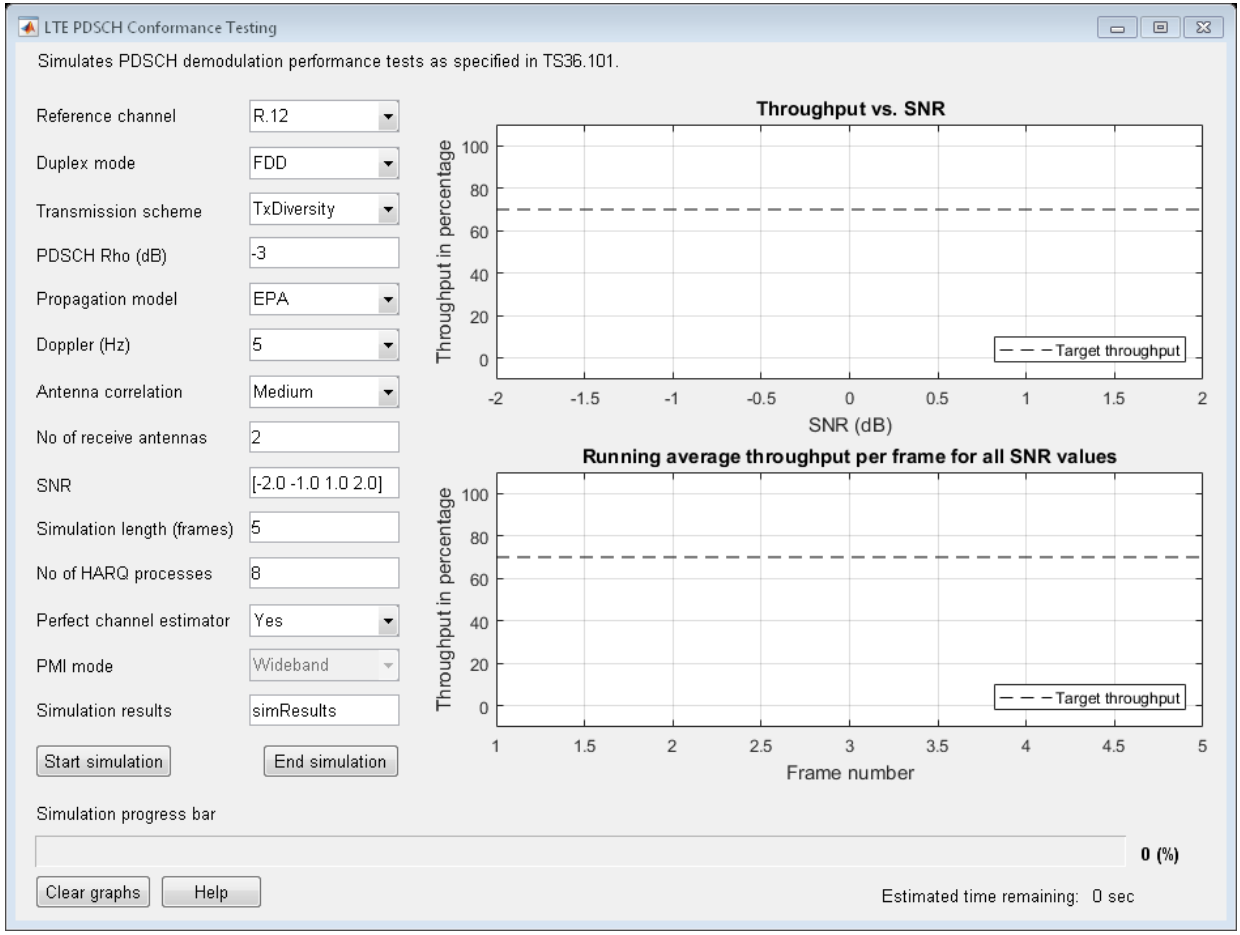
```
cmc = lteRMCDL('R.3')
cmc.NDLRB = 30
```

```
cmc =

  struct with fields:

                RC: 'R.3'
             NDLRB: 50
           CellRefP: 1
            NCellID: 0
       CyclicPrefix: 'Normal'
                CFI: 2
        PCFICHPower: 0
                 Ng: 'Sixth'
      PHICHDuration: 'Normal'
              HISet: [112×3 double]
         PHICHPower: 0
             NFrame: 0
          NSubframe: 0
```

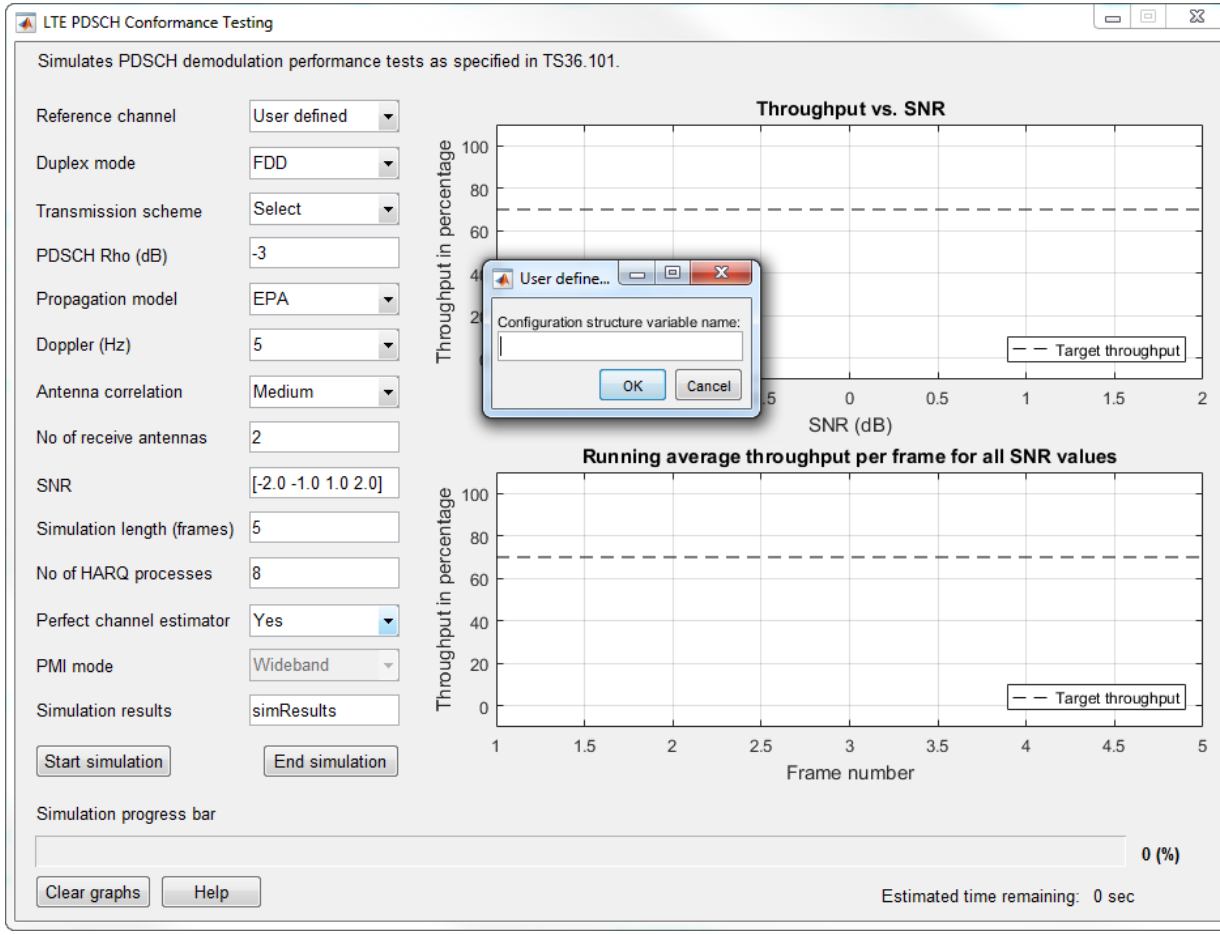
```
       TotSubframes: 10
          Windowing: 0
         DuplexMode: 'FDD'
              PDSCH: [1×1 struct]
    OCNGPDCCHEnable: 'Off'
     OCNGPDCCHPower: 0
    OCNGPDSCHEnable: 'Off'
     OCNGPDSCHPower: 0
          OCNGPDSCH: [1×1 struct]


cmc =

  struct with fields:

                RC: 'R.3'
             NDLRB: 30
           CellRefP: 1
            NCellID: 0
       CyclicPrefix: 'Normal'
                CFI: 2
        PCFICHPower: 0
                 Ng: 'Sixth'
      PHICHDuration: 'Normal'
              HISet: [112×3 double]
         PHICHPower: 0
             NFrame: 0
          NSubframe: 0
       TotSubframes: 10
          Windowing: 0
         DuplexMode: 'FDD'
              PDSCH: [1×1 struct]
    OCNGPDCCHEnable: 'Off'
     OCNGPDCCHPower: 0
    OCNGPDSCHEnable: 'Off'
     OCNGPDSCHPower: 0
          OCNGPDSCH: [1×1 struct]
```

Open the LTE throughput analyzer app.

```
lteThroughputAnalyzer
```



Choose the `Reference channel` drop down menu and select `User defined`.



Enter the custom measurement channel configuration structure name, `cmc`, in the prompt. When the simulation is run this user defined configuration will be run.

- "Analyze Throughput for PDSCH Demodulation Performance Test"

References

[1] 3GPP TS 36.101. "User Equipment (UE) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access*

Network; Evolved Universal Terrestrial Radio Access (E-UTRA). URL: http://www.3gpp.org.

See Also

See Also

Apps
LTE Downlink RMC Generator

Functions
`lteRMCDL`

Topics
"Analyze Throughput for PDSCH Demodulation Performance Test"

Introduced in R2014a

LTE Uplink RMC Generator

Generate LTE uplink reference measurement channel (RMC) waveforms

Description

The **LTE Uplink RMC Generator** app generates preset PUSCH reference measurement channel (RMC) waveforms. TS 36.104 [1], Annex A specifies fixed reference channels (FRC) for base station performance testing.

UL Reference Channel Options

Initialization choices available for the uplink reference channel and associated top-level configuration defaults include:

Reference channels	Reference channels (continued)	Reference channels (continued)
A1-1 (6 RB, QPSK, R=1/3)	A4-1 (1 RB, 16QAM, R=3/4)	A7-1 (3 RB, 16QAM, R=3/4)
A1-2 (15 RB, QPSK, R=1/3)	A4-2 (1 RB, 16QAM, R=3/4)	A7-2 (6 RB, 16QAM, R=3/4)
A1-3 (25 RB, QPSK, R=1/3)	A4-3 (6 RB, 16QAM, R=3/4)	A7-3 (12 RB, 16QAM, R=3/4)
A1-4 (3 RB, QPSK, R=1/3)	A4-4 (15 RB, 16QAM, R=3/4)	A7-4 (25 RB, 16QAM, R=3/4)
A1-5 (9 RB, QPSK, R=1/3)	A4-5 (25 RB, 16QAM, R=3/4)	A7-5 (25 RB, 16QAM, R=3/4)
A2-1 (6 RB, 16QAM, R=2/3)	A4-6 (50 RB, 16QAM, R=3/4)	A7-6 (25 RB, 16QAM, R=3/4)
A2-2 (15 RB, 16QAM, R=2/3)	A4-7 (75 RB, 16QAM, R=3/4)	A8-1 (3 RB, QPSK, R=1/3)
A2-3 (25 RB, 16QAM, R=2/3)	A4-8 (100 RB, 16QAM, R=3/4)	A8-2 (6 RB, QPSK, R=1/3)

Reference channels	Reference channels (continued)	Reference channels (continued)
A3-1 (1 RB, QPSK, R=1/3)	A5-1 (1 RB, 64QAM, R=5/6)	A8-3 (12 RB, QPSK, R=1/3)
A3-2 (6 RB, QPSK, R=1/3)	A5-2 (6 RB, 64QAM, R=5/6)	A8-4 (25 RB, QPSK, R=1/3)
A3-3 (15 RB, QPSK, R=1/3)	A5-3 (15RB, 64QAM, R=5/6)	A8-5 (25 RB, QPSK, R=1/3)
A3-4 (25 RB, QPSK, R=1/3)	A5-4 (25 RB, 64QAM, R=5/6)	A8-6 (25 RB, QPSK, R=1/3)
A3-5 (50 RB, QPSK, R=1/3)	A5-5 (50 RB, 64QAM, R=5/6)	A11-1 (3RB, QPSK, R=11/27)
A3-6 (75 RB, QPSK, R=1/3)	A5-6 (75 RB, 64QAM, R=5/6)	A3-2-9RB (6 RB, QPSK, R=1/3)
A3-7 (100 RB, QPSK, R=1/3)	A5-7 (100 RB, 64QAM, R=5/6)	

The fields in the output configuration structure are initialized in accordance with the reference channels defined in TS 36.104 [1], Annex A.

- `'A3-2-9RB'` is a custom RMC configured for non-standard bandwidth that uses the same code rate as the standardized version.
- `'A11-1'` enables TTI bundling and the corresponding HARQ pattern (enhanced HARQ pattern for FDD).

User Interface Settings

In the **LTE Uplink RMC Generator** user interface, you can set these parameters:

Parameter (Equivalent Field)	Values	Description
Reference channel (RC)	`'A1-1'` (default), `'A1-2'`, `'A1-3'`, `'A1-4'`, `'A1-5'`, `'A2-1'`, `'A2-2'`, `'A2-3'`, `'A3-1'`, `'A3-2'`, `'A3-3'`,	Reference measurement channel (RMC) number

Parameter (Equivalent Field)	Values	Description
	`'A3-4'`, `'A3-5'`, `'A3-6'`, `'A3-7'`, `'A4-1'`, `'A4-2'`, `'A4-3'`, `'A4-4'`, `'A4-5'`, `'A4-6'`, `'A4-7'`, `'A4-8'`, `'A5-1'`, `'A5-2'`, `'A5-3'`, `'A5-4'`, `'A5-5'`, `'A5-6'`, `'A5-7'`, `'A7-1'`, `'A7-2'`, `'A7-3'`, `'A7-4'`, `'A7-5'`, `'A7-6'`, `'A8-1'`, `'A8-2'`, `'A8-3'`, `'A8-4'`, `'A8-5'`, `'A8-6'`, `'A11-1'`, `'A3-2-9RB'`, `'A4-3-9RB'`	or type, as specified in TS 36.104 Annex A.
Total number of uplink resource blocks (`NULRB`)	Integer from 6 to 110	Number of uplink resource blocks. (N_{RB}^{UL})
Duplex mode (`DuplexMode`)	`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
Cell identity (`NCellID`)	Integer from 0 to 503	Physical layer cell identity
RNTI (`RNTI`)	0 (default), scalar integer	Radio network temporary identifier (RNTI) value (16 bits)

Parameter (Equivalent Field)	Values	Description
RV sequence (`RVSeq`)	Integer vector (0,1,2,3), specified as a one or two row matrix (for one or two codewords)	Specifies the sequence of Redundancy Version (RV) indicators for each HARQ process. The number of elements in each row is equal to the number of transmissions in each HARQ process. If `RVSeq` is a row vector in a two codeword transmission, then the same RV sequence is applied to both codewords.
Number of subframes (`TotSubframes`)	Nonnegative scalar integer	Total number of subframes to generate
Windowing (samples) (`Windowing`)	Nonnegative scalar integer	Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied
Waveform output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	Waveform output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.

Parameter (Equivalent Field)	Values	Description
Resource grid output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	Resource grid output variable name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.
RMC configuration output variable	Variable name, beginning with an alphabetical character and containing alphanumeric characters	RMC configuration output parameter structure name. When you click **Generate waveform**, a new variable with this name is created in the MATLAB workspace.

PUSCH Parameter Summary

The **LTE Uplink RMC Generator** user interface displays these RMC parameters:

Parameter (Equivalent Field)	Values	Description
Allocated resource blocks	Integer from 6 to 110	Number of resource blocks allocated to PUSCH $\leq N_{\mathrm{RB}}^{\mathrm{UL}}$
Modulation (`Modulation`)	`'QPSK'`, `'16QAM'`, `'64QAM'`	Modulation type
Total info bits per frame	Positive scalar integer	Total transport block capacity per frame

Codeword Input Data

In the **LTE Uplink RMC Generator** user interface, you can set the input data for codewords. The input data is equivalent to elements of the `trdata` cell array in the `lteRMCDLTool` function.

Input Data	Values	Description
Transport info bit stream	Logical column vector, variable name	Information bits to transmit on PUSCH

Either enter in the vector manually, or specify the name of an existing variable in the MATLAB workspace. Each vector contains the information bits stream to be coded across the duration of the generation, which represents multiple concatenated transport blocks. If the number of bits required across all subframes of the generation exceeds the length of the vectors provided, these vectors are looped internally. This feature allows you to enter a short pattern, such as `[1;0;0;1]`, that is repeated as the input to the transport coding.

Open the LTE Uplink RMC Generator App

- MATLAB Toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the **LTE Uplink RMC Generator** app icon.
- MATLAB command prompt: Enter `lteUplinkRMCGenerator`.

Examples

Generate RMC A1-1 Waveform

Use the **LTE Uplink RMC Generator** app to generate a time-domain signal and a 3-D array of the resource elements for the A1-1 reference measurement channel, as specified in TS 36.104.

Open the **LTE Uplink RMC Generator** app.

Adjust default runtime parameter settings:

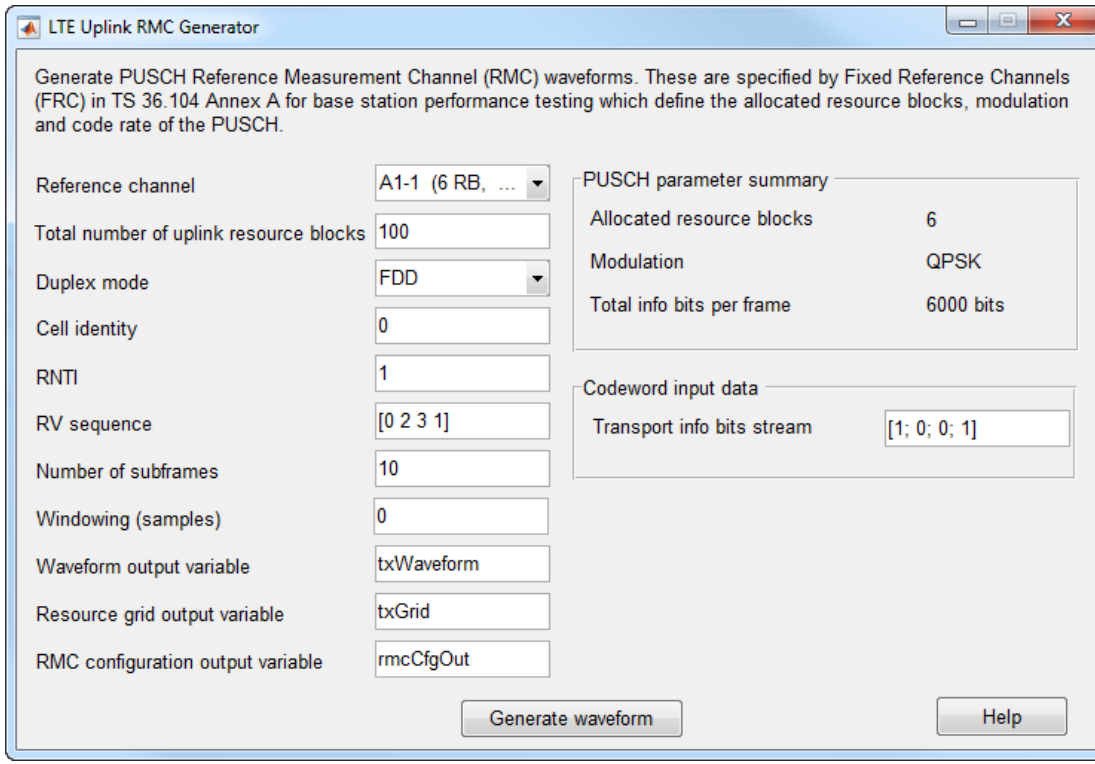
- Set **RC** to `A1-1`.

Specify output variable names:

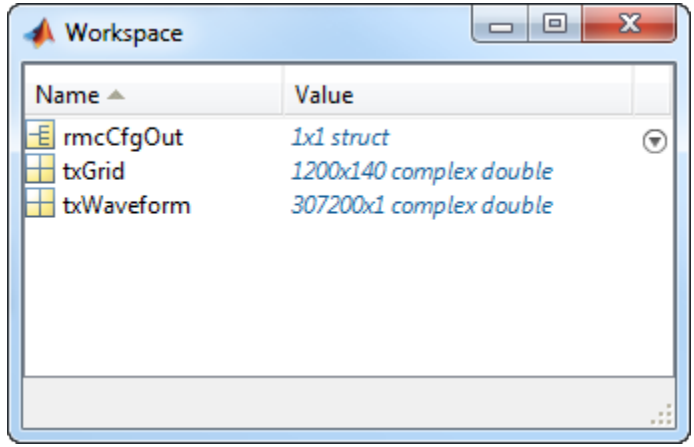
- For **Waveform output variable**, enter `txWaveform`.
- For **Resource grid output variable**, enter `txgrid`.

- For **RMC configuration output variable**, enter `rmcCfgOut`.

The user interface entries should now match these:



Click **Generate waveform** and the `txWaveform`, `txGrid`, and `rmcCfgOut` variables appear in the MATLAB Workspace browser.



Programmatic Use

See the `lteRMCULTool` function reference page for a description of the programmatic syntaxes supported.

References

[1] 3GPP TS 36.104. "Base Station (BS) Radio Transmission and Reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

See Also

Apps

LTE Downlink RMC Generator

Functions

`lteRMCDLTool` | `lteRMCUL` | `lteRMCULTool`

Introduced in R2014a

Other Reference Pages

Parameter Field Names

Find names of fields to populate parameter structures

List of Structure Field Names

An alphabetical list of all field names used within the LTE System Toolbox functions, their descriptions, their valid values, default values, and in which functions they are used is shown in the following table.

Field name	Used by Functions	Values	Description
`Alpha`	`lteSRS`		Reference signal cyclic shift (*alpha*)
	`lteSRS`, `ltePUCCH1`, `ltePUCCH1DRS`, `ltePUCCH2`, `ltePUCCH2DRS`		A row vector, containing the reference signal cyclic shift (*alpha*) for each OFDM symbol
	`ltePUSCHDRS`		A two-column row vector, containing the reference signal cyclic shift (*alpha*) for each slot
`BaseFreq`			Base (cell-specific) frequency domain starting position (*k_0 bar*), from which this UE-specific SRS is offset as a function of the UE-specific SRS Bandwidth value, *B_SRS*. UE-specific SRS configuration cannot result in a frequency domain starting position (*k_0*) lower than this, given the cell-specific SRS bandwidth configuration value, *C_SRS*.
`BaseOffset`			Base timing offset, in microseconds, for detection test in TS 36.104 (duration of *N_CS*/2)

Field name	Used by Functions	Values	Description
`BetaACK`		numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for HARQ-ACK bits. This field was previously named `BetaHI`; if this field is absent but `BetaHI` is present, it is used as before.
`BetaCQI`		numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for CQI and PMI bits
`BetaHI`			Modulation and Coding Scheme (MCS) offset for HARQ-ACK bits. **Note:** The field name `BetaHI` is deprecated and should be replaced with `BetaACK`.
`BetaRI`		numeric scalar, 2.0 (default)	Modulation and coding scheme (MCS) offset for RI bits
`BLKCRC`			Type-24A transport block CRC decoding error
`Bout`			Total number of bits in all segments
`BW`	`lteSRS`, `lteSRSIndices`, `lteRMCUL`, `lteRMCULTool`	0…3	UE-specific SRS Bandwidth value (B_{SRS})
	`lteTestModelTool`, `lteTestModel`		Channel bandwidth to use when generating test model waveforms
`BWConfig`		0…7	Cell-specific SRS Bandwidth Configuration value (C_{SRS})
`C`			Total number of code blocks
`CarrierFreq`			Carrier frequency, in hertz

Field name	Used by Functions	Values	Description
`CBSBuffers`			Cell array of vectors representing the LLR soft buffer states for the set of code blocks associated with a single transport block. The buffers are positioned at the input to the turbo decoder, after explicit rate recovery.
`CBSCRC`			Array of type-24B code block set CRC decoding results
`CellOffset`		0…9	Cell-specific sounding reference signal (SRS) offsets
`CellPeriod`		1, 2, 5, 10	Cell-specific sounding reference signal (SRS) periodicity, in milliseconds
`CellRefP`	`lteBCH`	1, 2, 4	Number of cell-specific reference signal (CRS) antenna ports
`CellRS`		`'Off'`, `'OmitEdgeRBs'`, `'On'`	Cell-specific reference signal (CRS) correlation mode
`CellRSPower`			Cell-specific reference symbol power adjustment, in dB
`CFI`		1, 2, or 3 Scalar or if the CFI varies per subframe, a vector of length 10 (corresponding to a frame).	Control format indicator (`CFI`) value. In TDD mode, `CFI` varies per subframe for the RMCs (`'R.0'`, `'R.5'`, `'R.6'`, `'R.6-27RB'`, `'R.12-9RB'`)
`ChannelFilterDelay`			The implementation delay of the internal channel filtering, in samples.

Field name	Used by Functions	Values	Description
`Cm`			Number of code blocks of size `Km` (*C–*)
`CodebookIdx`		0…15	Codebook index used during precoding
`CodedTrBlkSizes`			Coded transport block sizes for one or two codewords. This parameter field is only for informational purposes.
`ConfigIdx`	`lteSRS`, `lteSRSIndices`, `lteRMCUL`, `lteRMCULTool`	0…636	Configuration index for UE-specific periodicity and subframe offset
	`ltePRACH`, `ltePRACHInfo`	0…63	PRACH Configuration Index (*prach-ConfigurationIndex*)
`Cp`			Number of code blocks of size `Kp` (*C+*)
`CSI`		`'Off'`, `'On'`	Flag provides control over weighting the soft values that are used to determine the output values with the channel state information (CSI) calculated during the equalization process. If `'On'`, soft values are weighted by CSI.
`CSIRefP`		1, 2, 4, 8	Array of number of CSI-RS antenna ports
`CSIRSConfig`			Array CSI-RS configuration indices. See TS 36.211, Table 6.10.5.2-1.

Field name	Used by Functions	Values	Description
`CSIRSPeriod`		`'On'`, `'Off'`, `Icsi-rs`, `[Tcsi-rs Dcsi-rs]`	CSI-RS subframe configurations for one or more CSI-RS resources. Multiple CSI-RS resources can be configured from a single common subframe configuration or from a cell array of configurations for each resource.
`CyclicOffset`			For High Speed mode, cyclic shift or shifts corresponding to a Doppler Shift of 1/*T_SEQ* (*d_u*)
`CyclicPrefix`	Downlink functions (`lteBCH`, `lteBCHDecode`))	`'Normal'` (default), `'Extended'`	Cyclic prefix length
	Uplink functions	`'Normal'` (default), `'Extended'`	Cyclic prefix length in the downlink
`CyclicPrefixUL`	Uplink functions	`'Normal'` (default), `'Extended'`	Current cyclic prefix length
`CyclicShift`	`ltePUSCHDRS`, `lteRMCUL`, `lteRMCULTool`, `lteULFrameOffset`	0...7	Number of cyclic shifts used for PUSCH DM-RS (yields $n_{\mathrm{DMRS}}^{(1)}$).
	`ltePRACH`, `ltePRACHInfo`		Cyclic shift or shifts of Zadoff-Chu sequence (*C_v*)
	`lteSRS`, `lteSRSIndices`, `lteRMCUL`, `lteRMCULTool`	0...7	UE-specific cyclic shift ($n_{\mathrm{SRS}}^{\mathrm{cs}}$)

Field name	Used by Functions	Values	Description
`CyclicShiftIdx`		0...15	Cyclic shift configuration index (*zeroCorrelationZoneConfig*, yields N_{CS})
`CyclicShifts`		0...7	Number of cyclic shifts used for format 1 in resource blocks (RBs) with a mixture of format 1 and format 2 PUCCH, specified as an integer from 0 to 7. ($N_{cs}^{(1)}$)
`DCIFormat`			Downlink control information (DCI) format
`DelayProfile`		`'EPA'`, `'EVA'`, `'ETU'`	Delay profile model. For more information, see "Propagation Channel Models".
`DeltaOffset`		0, 1, 2	(Δ_{offset}). Warning: The use of this parameter field is not advised. It applies only to 3GPP releases preceding v8.5.0. This parameter will be removed in a future release.
`DeltaShift`		1, 2, 3	Delta shift, specified as 1, 2, or 3. (Δ_{shift})
`Dmin`			eNodeB to railway track distance, in meters
`DopplerFreq`			Maximum *Doppler* frequency, in Hz.
`Ds`			`Ds`/2 is initial distance between train and eNodeB, in meters

Field name	Used by Functions	Values	Description
`DuplexMode`		`'FDD'` (default), `'TDD'`	Duplexing mode, specified as: • `'FDD'` for Frequency Division Duplex or • `'TDD'` for Time Division Duplex
`DynCyclicShift`		0…7	Cyclic shift for DM-RS (yields $n_{\mathrm{DMRS}}^{(2)}$).
`EV`			Normalized error vector
`F`			Number of filler bits in first block
`Fields`			A 1-by-4 vector of PRACH field lengths, [*OFFSET T_CP T_SEQ GUARD*], where *T_CP* and *T_SEQ* are the length of cyclic prefix and PRACH sequence in fundamental time periods (*T_s*), *OFFSET* is the number of fundamental time periods from the start of configured subframe to the start of the cyclic prefix (non-zero only for TDD special subframes), and *GUARD* is the number of fundamental time periods from the end of the PRACH sequence to the end of the number of subframes spanned by the PRACH
`Format`		0…4	Preamble format
`FreqIdx`	`ltePRACH`, `ltePRACHDetect`, `ltePRACHInfo`	0…5	Frequency resource index (f_{RA}). Only required for `'TDD'` duplexing mode.

Field name	Used by Functions	Values	Description
	`lteSRSIndices`	0...*B_SRS*	A vector specifying the frequency position index (*n_b*) for each *b*
`FreqOffset`		0...94	PRACH frequency offset ($n_{\text{PRBoffset}}$). Only required for Preamble format 0–3.
`FreqPosition`		0...23	Frequency domain position (n_{RRC})
`FreqStart`			Frequency domain starting position (*k_0*), the 0-based subcarrier index of the lowest SRS subcarrier
`FreqWindow`			Size of window in resource elements used to average over frequency during channel estimation
`G`	`ltePDSCHIndices`		A one- or two-element vector, specifying the number of coded and rate matched DL-SCH data bits for each codeword
	`ltePUSCHIndices`, `lteULSCH`, `lteULSCHInfo`		A one- or two-element vector, specifying the number of coded and rate matched UL-SCH data bits for each codeword
`Gd`	`ltePDSCHIndices`		Number of coded and rate matched DL-SCH data symbols, equal to the number of rows in the PDSCH indices
	`ltePUSCHIndices`		Number of coded and rate matched UL-SCH data symbols, equal to the number of rows in the PUSCH indices

Field name	Used by Functions	Values	Description
	`lteULSCH`, `lteULSCHInfo`		Number of coded and rate matched UL-SCH data symbols
`HighSpeed`		0...1	High Speed flag (*highSpeedFlag*). A value of 1 signifies a restricted set. A value of 0 signifies an unrestricted set.
`Hopping`	`ltePUCCH1`, `ltePUCCH2`, `ltePUCCH3`	`'Off'`, `'Group'`	Frequency hopping method.
	`ltePUSCH`	`'Off'`, `'Group'`, `'Sequence'`	Frequency hopping method
`HoppingBW`		0...3	SRS Frequency hopping configuration index (b_{hop})
`HoppingOffset`			A vector specifying the offset term due to frequency hopping (*F_b*), used in calculation of *n_b*
`InitCyclicPrefixUL`		`'Normal'`, `'Extended'`, `CyclicPrefixUL` (default)	Cyclic prefix length of initial transmit subframe. This is the length used during the first transmission of this transport block. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `CyclicPrefixUL`.

Field name	Used by Functions	Values	Description
`InitPRBSet`		1- or 2-column integer matrix, `PRBSet` (default)	PRB indices used in the initial transmission PUSCH allocation. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `PRBSet`.
`InitShortened`		0, 1, `Shortened` (default)	Initial transmit subframe shortened flag. If 1, the initial transmit subframe was shortened for possible SRS. If this field is absent, its value is assumed to be the same as the value for the associated current subframe field, `Shortened`.
`InitTime`	`lteFadingChannel`		Fading process time offset, in seconds
	`lteHSTChannel`		*Doppler* shift timing offset, in seconds
	`lteMovingChannel`		Fading process and timing adjustment offset, in seconds

<table>
<tr><th>Field name</th><th>Used by Functions</th><th>Values</th><th>Description</th></tr>
<tr><td>InterpType</td><td>lteDLChannelEstima
lteULChannelEstima
lteULChannelEstima
lteULChannelEstima
lteULChannelEstima</td><td>'nearest',
'linear',
'natural',
'cubic', 'v4'</td><td>Type of 2-D interpolation used during interpolation. For details, see griddata. Supported choices are shown in the following table.
<table><tr><th>Value</th><th>Description</th></tr><tr><td>'neares</td><td>Nearest neighbor interpolation</td></tr><tr><td>'linear</td><td>Linear interpolation</td></tr><tr><td>'natura</td><td>Natural neighbor interpolation</td></tr><tr><td>'cubic'</td><td>Cubic interpolation</td></tr><tr><td>'v4'</td><td>MATLAB 4 griddata method</td></tr><tr><td>'none'</td><td>Disables interpolation</td></tr></table></td></tr>
<tr><td>InterpWindow</td><td></td><td>'Causal',
'Non-causal',
'Centred'</td><td>Interpolation window type used during channel estimation. Options 'Centred' and 'Centered' are equivalent.</td></tr>
<tr><td>InterpWinSize</td><td></td><td></td><td>Window size across which to interpolate. The interpolation window size is specified in number of subframes.</td></tr>
<tr><td>IsSRSSubframe</td><td></td><td></td><td>This field is present only if the UE contains NSubframe. Value is 1 if NSubframe satisfies the equation: mod(NSubframe, CellPeriod)=CellOffset Value is 0 otherwise.</td></tr>
</table>

Field name	Used by Functions	Values	Description
`k`			Subband size, in resource blocks (equal to `NRB` for wideband PMI reporting or transmission schemes without PMI reporting).
`K`			Ratio of uplink data to PRACH subcarrier spacing (*K*)
`Km`			Lower code block size (*K*–)
`Kp`			Upper code block size (*K*+)
`KTxComb`			Offset to the frequency domain starting position (*k_TC*), a function of the transmission comb parameter
`L`			Number of segment cyclic redundancy check (CRC) bits
`MacTxNumber`		0…27	Number of the current MAC (re-)transmission, *CURRENT_TX_NB*
`MaxPMI`	`ltePMIInfo`		Maximum permitted PMI value for the given configuration. Valid PMI values range from 0 to `MaxPMI`. For CSI reporting, when `CSIRefP = 8`, or for CSI reporting with the alternative codebook for four antennas,`MaxPMI` is a 2–element vector, indicating the maximum permissible values of *i1* and *i2*, the first and second codebook indices. For transmission schemes without PMI reporting, `MaxPMI = 0`.

Field name	Used by Functions	Values	Description
	`lteULPMIInfo`		Indicates the maximum permitted PMI value for the given configuration. Valid PMI values range from 0 to `MaxPMI`.
`MIMOCorrelation`		`'Low'`, `'Medium'`, `'High'`	Correlation between UE and eNodeB antennas
`ModelType`	`lteFadingChannel`	`'Dent'`, `'GMEDS'`	*Rayleigh* fading model type
`Modulation`	`lteACKDecode`, `lteACKEncode`	`'QPSK'`, `'16QAM'`, `'64QAM'`, or `'256QAM'`	Modulation type, specified as a character vector or cell array of character vectors. If blocks, each cell is associated with a transport block.
		`'QPSK'`, `'16QAM'`, `'64QAM'`	Modulation scheme associated with one codeword
`MovingScenario`		`'Scenario1'`, `'Scenario2'`	Moving channel scenario
`MTot`			Total number of bits associated with PDCCHs (8×`NRE`)
`NAllocatedPDCCHREG`			Number of allocated PDCCH REGs as per Test Model number and BW
`N1DMRS`			Component of the reference signal cyclic shift, signaled from higher layers (*n1_DMRS*)
`N2DMRS`			Component of the reference signal cyclic shift, signaled from the most recent DCI format 0 message (*n2_DMRS*)

Field name	Used by Functions	Values	Description
`NBundled`	`lteACKDecode`, `lteACKEncode`	0 (default), 1, ..., 9	TDD HARQ-ACK bundling scrambling sequence index. When set to 0, the function disables the TDD HARQ-ACK bundling scrambling. Therefore, it is off by default.
`NCCE`			Number of control channel elements available for actual PDCCH usage
`NCellCyclicShift`			A row vector, containing the cell-specific cyclic shift (*ncell_cs*) for each OFDM symbol
`NCellID`			Physical layer cell identity
`NCodewords`		1, 2	Number of codewords
`NCS`			Length of zero correlation zone, plus 1 (*N_CS*)
`NDLRB`		Scalar integer from 6 to 110	Number of downlink resource blocks. ($N_{\mathrm{RB}}^{\mathrm{DL}}$)
`NF4RachPreambles`		0...27	Number of RACH preamble frequency resources of Format 4 in *UpPTS*
`Nfft`			Number of fast *Fourier* transform (FFT) points
`NFrame`			Frame number
`Ng`		`'Sixth'`, `'Half'`, `'One'`, `'Two'`	HICH group multiplier
`Ngroups`			Number of PHICH groups
`NHARQProcesses`		1...8	Number of HARQ processes per component carrier

Field name	Used by Functions	Values	Description
NIR			Number of soft bits associated with transport block. Soft buffer size for entire input transport block
NL			Number of layers used in rate matching calculation
NLayers	lteDLSCH, lteDLSCHDecode, lteULSCH, lteULSCHDecode	1 (default), 2, 3, 4, 5, 6, 7, 8	Total number of transmission layers associated with the transport block or blocks.
	Downlink modulation	1,…,8, depending on TxScheme	Number of transmission layers (downlink modulation)
	Uplink modulation (lteACKDecode, lteACKEncode)	1 (default), 2, 3, 4	Number of transmission layers, total or per codeword
NMappingUnits			Number of PHICH mapping units
NPHICH			Number of individual PHICH available
NPRS			A two-column row vector, containing the cell-specific component of the reference signal cyclic shift (*n_PRS*) for each slot
NPRSRB		0…NDLRB	Number of PRS physical resource blocks
NRE	ltePCFICHInfo		Number of resource elements (REs) assigned to PCFICH (4×NREG)
	ltePDCCHInfo		Total number of resource elements (REs) associated with PDCCHs (4×NREG)

Field name	Used by Functions	Values	Description
	`ltePHICHInfo`		Number of resource elements (REs) assigned to all PHICH
	`lteULSCH`, `lteULSCHInfo`		Number of resource elements (REs) used for PUSCH transmission
`NREG`	`ltePCFICHInfo`		Number of resource element groups (REGs) assigned to PCFICH
	`ltePDCCHInfo`, `ltePDCCHSpace`		Total number of resource element groups (REGs) associated with PDCCHs (4×`NRE`)
	`ltePHICHInfo`		Number of resource element groups assigned to all PHICH
`NREGUsed`			Number of resource element groups (REGs) available for actual PDCCH usage
`NResourceIdx`			A two-column row vector, containing the resource indices (n') for each slot
`NREUsed`			Number of resource elements (REs) available for actual PDCCH usage
`NRxAnts`		1 or more	Number of receive antennas
`NSCID`		0, 1	Scrambling identity (*ID*)
`NSequences`			Number of orthogonal sequences in each PHICH group
`NSoftbits`		Nonnegative scalar integer (default 0)	Total number of soft buffer bits. The default setting of 0 signifies that there is no buffer limit.

Field name	Used by Functions	Values	Description
`NSRSTx`			Number of UE-specific SRS transmissions (*n_SRS*)
`NSubbands`	`ltePMIInfo`, `lteULPMIInfo`		Number of subbands for PMI reporting (equal to 1 for wideband PMI reporting) or transmission schemes without PMI reporting.
`NSubframe`			Subframe number
`NSymbols`	`lteDuplexingInfo`		Total number of symbols in the subframe
	`ltePDCCHInfo`		Total number of OFDM symbols spanned by the PDCCH
`NSymbolsDL`			Number of symbols used for transmission in the downlink (DL)
`NSymbolsGuard`			Number of symbols in the guard period
`NSymbolsUL`			Number of symbols used for transmission in the uplink (UL)
`NSymbSlot`			A vector indicating the number of OFDM symbols in each slot ([*N_SF,0_PUCCH N_SF,1_PUCCH*])
`NTerms`		power of 2	Number of oscillators used in fading path modeling
`NTurboDecIts`			Number of turbo decoder iteration cycles
`NTxAnts`	`lteDMRSIndices`, `ltePDSCHIndices`	0 or more	Number of transmission antenna ports. This argument is only present for UE-specific demodulation reference symbols.

Field name	Used by Functions	Values	Description
	Uplink modulation	1. 2, 4	Number of transmission antennas.
`NULRB`			Number of uplink resource blocks. (N_{RB}^{UL})
`NZC`	`ltePRACHDetect`, `ltePRACHInfo`		Zadoff-Chu sequence length (*N_ZC*)
	`ltePUSCHDRS`, `lteSRS`		Zadoff-Chu sequence length (*NRS_ZC*)
`OACK`	`lteACKDecode`	nonnegative scalar integer, 0 (default)	Number of uncoded HARQ-ACK bits.
			Number of uncoded symbols for ACK/NACK
`OCQI`	`lteCQIDecode`	nonnegative scalar integer, 0 (default)	Number of uncoded channel quality information (CQI) bits
			Number of coded channel quality information (CQI) symbols in UL-SCH
`OCNG`		`'Disable'`, `'Enable'`	OFDMA channel noise generator
`OdACK`			Number of coded symbols for ACK/NACK (*Q'_ACK*)
`OdCQI`			Number of coded symbols for CQI (*Q'_CQI*)
`OdRI`			Number of coded symbols for RI (*Q'_RI*)

Field name	Used by Functions	Values	Description
`OffsetIdx`		0...1	Choice of SRS Subframe Offset in the case of 2 ms SRS periodicity. This parameter indexes the two SRS Subframe Offset entries in the row specified by the `ConfigIdx` parameter in table 8.2-2 of TS 36.213 for the SRS Configuration Index.
`ORI`			Number of uncoded symbols for RI
			Number of uncoded RI bits
`OrthCover`		`'On'`, `'Off'`	Applies (`'On'`), or does not apply (`'Off'`), orthogonal cover sequence *w* (*Activate-DMRS-with OCC*).
`OrthSeq`	`ltePUCCH1`, `ltePUCCH3`		A 4-by-2 matrix where each column contains the orthogonal sequence (*w_n_oc*) for each slot
	`ltePUCCH1DRS`, `ltePUCCH2DRS`, `ltePUCCH3DRS`		A two-column matrix where each column contains the orthogonal sequence (*w bar*) for each slot
	`ltePUSCHDRS`		A vector containing the orthogonal cover value (*w*) for each slot
`OrthSeqIdx`	`ltePUCCH1`, `ltePUCCH3`, `ltePUCCH3DRS`		A two-column row vector, containing the orthogonal sequence index (*n_oc*) for each slot
	`ltePUCCH1DRS`		A two-column row vector, containing the orthogonal sequence index (*n_oc bar*) for each slot

Field name	Used by Functions	Values	Description
`PBCHPower`			PBCH symbol power adjustment, in dB
`PCFICHPower`			PCFICH symbol power adjustment, in dB
`PDCCHFormat`		0, 1, 2, 3	PDCCH format
`PDCCHPower`			PDCCH symbol power adjustment, in dB
`PDSCH`			PDSCH transmission configuration substructure
`PDSCHPowerBoosted`			PDSCH symbol power adjustment, in dB, for the boosted physical resource blocks (PRBs)
`PDSCHPowerDeboosted`			PDSCH symbol power adjustment, in dB, for the de-boosted physical resource blocks (PRBs)
`Peak`			Peak error vector magnitude (EVM), the largest single EVM value calculated across all input values
`Phi`			Frequency domain location offset (phi)
`PHICHDuration`		`'Normal'`, `'Extended'`	PHICH duration
`PilotAverage`		`'TestEVM'`, `'UserDefined'`	Type of pilot averaging
`PMI`		0...23	Scalar precoder matrix indication (PMI) to be used during precoding

Field name	Used by Functions	Values	Description
`PMIMode`		`'Wideband'`, `'Subband'`	PMI reporting mode. `PMIMode='Wideband'` corresponds to PUSCH reporting Mode 1-2 or PUCCH reporting Mode 1-1 (PUCCH Report Type 2) and `PMIMode='Subband'` corresponds to PUSCH reporting Mode 3-1.
`PMISet`		Integer vector with element values from 0 to 15.	Precoder matrix indication (PMI) set. It can contain either a single value, corresponding to single PMI mode, or multiple values, corresponding to multiple or subband PMI mode. The number of values depends on CellRefP, transmission layers and TxScheme. For more information about setting PMI parameters, see `ltePMIInfo`.
`Port`			Antenna port number used for transmission (p)

Field name	Used by Functions	Values	Description
`PRBSet`	Downlink modulation	Integer column vector or two-column matrix	Zero-based physical resource block (PRB) indices corresponding to the slot wise resource allocations for this PDSCH. `PRBSet` can be assigned as: • a column vector, the resource allocation is the same in both slots of the subframe, • a two-column matrix, this parameter specifies different PRBs for each slot in a subframe, • a cell array of length 10 (corresponding to a frame, if the allocated physical resource blocks vary across subframes). PRBSet varies per subframe for the RMCs `'R.25'`(TDD), `'R.26'`(TDD), `'R.27'`(TDD), `'R.43'`(FDD), `'R.44'`, `'R.45'`, `'R.48'`, `'R.50'`, and `'R.51'`.
	Uplink modulation	Integer column vector or two-column matrix	0-based physical resource block indices (PRBs) for the slots of the current PUSCH resource allocation. As a column vector, the resource allocation is the same in both slots of the subframe. As a two-column matrix, it specifies different PRBs for each slot in a subframe.

Field name	Used by Functions	Values	Description
	`ltePRACHInfo`		PRBs occupied by PRACH preamble (starts at *n_PRB*, 0-based)
	`lteSRSIndices`		A vector specifying the PRBs occupied by the indices in each slot of the subframe (0-based)
`PreambleIdx`		0...63	Preamble index within cell (*ra-PreambleIndex*)
`PRSPeriod`		`'On'`, `'Off'`, `Iprs`, `[Tprs Dprs]`	Positioning reference signal (PRS) subframe configuration
`PSS`		`'Off'`, `'On'`	Primary synchronization signal (PSS) correlation mode
`PSSPower`			Primary synchronization signal (PSS) symbol power adjustment, in dB
`PUSCH`			PUSCH transmission configuration structure
`PUSCHHopping`		`'Inter'`, `'InterAndIntra`	Uplink subframe hopping mode
`PUSCHHoppingOffset`		0...98	PUSCH hopping offset
`QdACK`	`lteACKEncode`	nonnegative scalar integer	Number of coded HARQ-ACK symbols for ACK or NACK (*Q'_ACK*)
`QdCQI`	`lteCQIEncode`	nonnegative scalar integer	Number of coded channel quality information (CQI) symbols (*Q'_CQI*)
`QdRI`			Number of coded symbols for RI (*Q'_RI*)
`Qm`			Bits per symbol variable used in rate matching calculation
			Number of bits per symbol

Field name	Used by Functions	Values	Description
`RBIdx`			PUCCH logical resource block index (m)
`RC`			Reference measurement channel (RMC) number or type, as specified in TS 36.101, Annex A.3. • `'R.31-3A'` and `'R.31-4'` are sustained data rate RMCs with user data in subframe 5. • `'R.6-27RB'`, `'R.12-9RB'`, and `'R.11-45RB'` are custom RMCs configured for non-standard bandwidths that maintain the same code rate as the standardized versions defined in TS 36.101, Annex A.3.
`Reference`	`lteDLChannelEstima`	`'DMRS'`, `'CSIRS'`	Specifies point of reference (signals to internally generate) for channel estimation
	`lteULChannelEstima` `lteULPMISelect`	`'Antennas'`, `'Layers'`, `'None'`	Specifies point of reference (signals to internally generate)

Field name	Used by Functions	Values	Description
`ResourceIdx`	`ltePUCCH1`, `ltePUCCH1Decode`, `ltePUCCH1DRS`, `ltePUCCH1DRSIndice` `ltePUCCH1Indices`, `lteULChannelEstima` `lteULFrameOffsetPU`	0...2047	PUCCH resource indices, specified as an integer or a vector of integers. Values range from 0 to 2047. These indices determine the physical resource blocks, cyclic shift and orthogonal cover used for transmission. ($n^{(1)}_{PUCCH}$). Define one index for each transmission antenna.
	`ltePUCCH2`, `ltePUCCH2Decode`, `ltePUCCH2DRS`, `ltePUCCH2DRSDecode` `ltePUCCH2DRSIndice` `ltePUCCH2Indices`, `lteULChannelEstima` `lteULFrameOffsetPU`	0...1185	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission. ($n^{(2)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.
	`ltePUCCH3`, `ltePUCCH3Decode`, `ltePUCCH3DRS`, `ltePUCCH3DRSIndice` `ltePUCCH3Indices`, `lteULChannelEstima` `lteULFrameOffsetPU`	0...549	PUCCH resource indices which determine the physical resource blocks, cyclic shift, and orthogonal cover used for transmission ($n^{(3)}_{\mathrm{PUCCH}}$). Define one index for each transmission antenna.
`ResourceSize`		0...63	Size of resource allocated to PUCCH format 2 ($N^{(2)}_{\mathrm{RB}}$)
`Rho`			PDSCH resource element power allocation, in dB

Field name	Used by Functions	Values	Description
`RMS`			Root mean square (RMS) error vector magnitude (EVM), the square root of the mean square of the EVM across all input values
`RNTI`			Radio network temporary identifier (RNTI) value (16 bits)
`RootSeq`	`ltePRACH`, `ltePRACHDetect`, `ltePRACHInfo`		Physical root Zadoff-Chu sequence index or indices (u)
	`lteSRS`		Root Zadoff-Chu sequence index (q)
	`ltePUSCHDRS`		A two-column row vector, containing the Root Zadoff Chu sequence index (q) for each slot
`RV`		Integer vector (0,1,2,3). A one or two column matrix (for one or two codewords).	Specifies the redundancy version for one or two codewords used in the initial subframe number, `NSubframe`. This parameter field is only for informational purposes and is Read-Only.
		0, 1, 2, 3	RV value associated with one codeword

Field name	Used by Functions	Values	Description
`RVSeq`			Specifies the sequence of Redundancy Version (RV) indicators for each HARQ process. The number of elements in each row is equal to the number of transmissions in each HARQ process. If `RVSeq` is a row vector in a two codeword transmission, then the same RV sequence is applied to both codewords.
`SamplingRate`	`lteOFDMModulate`, `lteOFDMInfo`, `lteSCFDMAModulate`, `lteSCFDMAInfo`		Sampling rate of the time-domain waveform
	`ltePRACH`, `ltePRACHDetect`, `ltePRACHInfo`		Sampling rate of the PRACH modulator
	`lteSRS`		Input signal sampling rate, the rate of each sample in the rows of the input matrix, `in`.
`ScrambSeq`			A two-column row vector, containing the scrambling value (S) for each slot
`Seed`			Random number generator seed for channel models. Set to zero for a random seed.
`SeqGroup`	`lteSRS`	0…29	SRS sequence group number (u)
	`ltePUSCHDRS`, `lteRMCUL`, `lteRMCULTool`, `lteULFrameOffset`	0…29	PUSCH sequence group assignment (Δ_{SS}).

Field name	Used by Functions	Values	Description
	`ltePUCCH1`, `ltePUCCH1DRS`, `ltePUCCH2`, `ltePUCCH2DRS`, `ltePUCCH3DRS`, `ltePUSCHDRS`		A two-column row vector, containing the base sequence group number (u) for each slot
	`lteSRS`		Base sequence group number (u)
`SeqIdx`	`lteSRS`	0, 1	Base sequence number (v)
	`ltePUCCH1`, `ltePUCCH1DRS`, `ltePUCCH2`, `ltePUCCH2DRS`, `ltePUCCH3DRS`, `ltePUSCHDRS`		A two-column row vector, containing the base sequence number (v) for each slot
	`ltePRACH`, `ltePRACHDetect`, `ltePRACHInfo`	0...837	Logical root sequence index (*RACH_ROOT_SEQUENCE*)
`Shortened`		0 (default), 1	Option to shorten the subframe by omitting the last symbol, specified as 0 or 1. If `1`, the last symbol of the subframe is not used. For subframes with possible SRS transmission, set `Shortened` to 1 to maintain a standard compliant configuration.
`SRS`		`'on'`	Enable SRS related configuration parameters (set SRS to `'on'`) for RMCs which optionally support SRS, or a complete or part SRS structure. If absent, no SRS configuration is created.

Field name	Used by Functions	Values	Description
`SSC`		0 (default), 1, 2, 3, 4, 5, 6, 7, 8, 9	Special subframe configuration (SSC)
`SSS`		`'Off'`, `'On'`	Secondary synchronization signal (SSS) correlation mode
`SSSPower`			Secondary synchronization signal (SSS) symbol power adjustment, in dB
`SubcarrierSpacing`			Subcarrier spacing of PRACH preamble, in Hz (*deltaf_RA*)
`SubframeConfig`		0...15	Sounding reference signal (SRS) subframe configuration
`SubframeType`		`'Downlink'`, `'Uplink'`, `'Special'`	Type of subframe
`Symbols`	`ltePUCCH1`		A row vector containing the modulated data symbols (*d(0)*) for each OFDM symbol
	`ltePUCCH1DRS`, `ltePUCCH2DRS`, `ltePUCCH3DRS`		A row vector containing the modulated data symbols (*z*) for each OFDM symbol
	`ltePUCCH2`, `ltePUCCH3`		A row vector containing the modulated data symbols (*d*) for each OFDM symbol
`TDDConfig`		0 (default), 1, 2, 3, 4, 5, 6	Uplink–downlink configuration
`TimeWindow`			Size of window in resource elements used to average over time during channel estimation
`TimingOffset`			PRACH timing offset, in microseconds

Field name	Used by Functions	Values	Description
`TMN`			Test model number, as specified in TS 36.141, identifying the test model to use when generating the waveform
`TotSubframes`	`lteDLPerfectChanne` `lteRMCDL`, `lteRMCDLTool`, `lteRMCUL`, `lteRMCULTool`, `lteULPerfectChanne`		Total number of subframes to generate
	`ltePRACHInfo`		The number of subframes duration of the PRACH. Each subframe lasts 30,720 fundamental periods; therefore, `TotSubframes` is ceil(sum(*Fields*)/30720), the number of subframes required to hold the entire PRACH waveform. The duration of the PRACH is a function of the Preamble Format as described in table 5.7.1-1 of TS 36.211.
`TrBlkSizes`			Transport block sizes for each subframe in a frame
`TxComb`		0, 1	Transmission comb. Controls SRS positions; SRS is transmitted in 6 carriers per resource block on odd (1) and even (0) resource indices.

<table>
<tr><th>Field name</th><th>Used by Functions</th><th>Values</th><th>Description</th></tr>
<tr><td>TxScheme</td><td></td><td>'Port0', 'TxDiversity', 'CDD', 'SpatialMux', 'Multi 'Port5 'Port7 'Port8 'Port7</td><td>PDSCH transmission scheme, specified as one of the following options.
<table>
<tr><th>Transmission scheme</th><th>Description</th></tr>
<tr><td>'Port0'</td><td>Single antenna port, port 0</td></tr>
<tr><td>'TxDiversity'</td><td>Transmit diversity</td></tr>
<tr><td>'CDD'</td><td>Large delay cyclic delay diversity scheme</td></tr>
<tr><td>'SpatialMux'</td><td>Closed loop spatial multiplexing</td></tr>
<tr><td>'MultiUser'</td><td>Multi-user MIMO</td></tr>
<tr><td>'Port5'</td><td>Single-antenna port, port 5</td></tr>
<tr><td>'Port7-8'</td><td>Single-antenna port, port 7, when NLayers = 1. Dual layer transmission, ports 7 and 8, when NLayers = 2.</td></tr>
<tr><td>'Port8'</td><td>Single-antenna port, port 8</td></tr>
<tr><td>'Port7-14'</td><td>Up to eight layer transmission, ports 7–14</td></tr>
</table></td></tr>
<tr><td>UeOffset</td><td></td><td>0...319</td><td>UE-specific SRS offset</td></tr>
<tr><td>UePeriod</td><td></td><td>2, 5, 10, 20, 40, 80, 160, 320</td><td>UE-specific SRS periodicity, in milliseconds</td></tr>
<tr><td>Velocity</td><td>lteHSTChannel</td><td></td><td>Train velocity, in kilometers per hour</td></tr>
</table>

Field name	Used by Functions	Values	Description
`W`	`lteDMRS`		`NLayers`-by-*P* precoding matrix for the wideband UE-specific beamforming of the DM-RS. *P* is the number of transmit antennas. An empty matrix, `[]`, signifies no precoding.
	`ltePDSCH`	Numeric matrix, `[]` (default)	`NLayers`-by-*P* precoding matrix for the wideband UE-specific beamforming of the PDSCH symbols. *P* is the number of transmit antennas. An empty matrix, `[]`, signifies no precoding.
`Window`		`'Left'`, `'Right'`, `'Centred'`, `'Centered'`	If more than one subframe is input this parameter is required to indicate the position of the subframe from *rxgrid* and *refgrid* containing the desired channel estimate. Only channel estimates for this subframe will be returned. For the `'Centred'` and `'Centered'` settings, the window size must be odd.
`Windowing`	`lteOFDMModulate`, `lteOFDMInfo`, `lteRMCDL`, `lteTestModel`		Number of time-domain samples over which windowing and overlapping of OFDM symbols is applied
	`lteRMCUL`, `lteSCFDMAModulate`, `lteSCFDMAInfo`		The number of time-domain samples over which windowing and overlapping of SC-FDMA symbols is applied

References

[1] 3GPP TS 36.104. "Base Station (BS) radio transmission and reception." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[2] 3GPP TS 36.141. "Base Station (BS) conformance testing." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[3] 3GPP TS 36.211. "Physical Channels and Modulation." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

[4] 3GPP TS 36.213. "Physical layer procedures." *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA).* URL: http://www.3gpp.org.

See Also

Topics

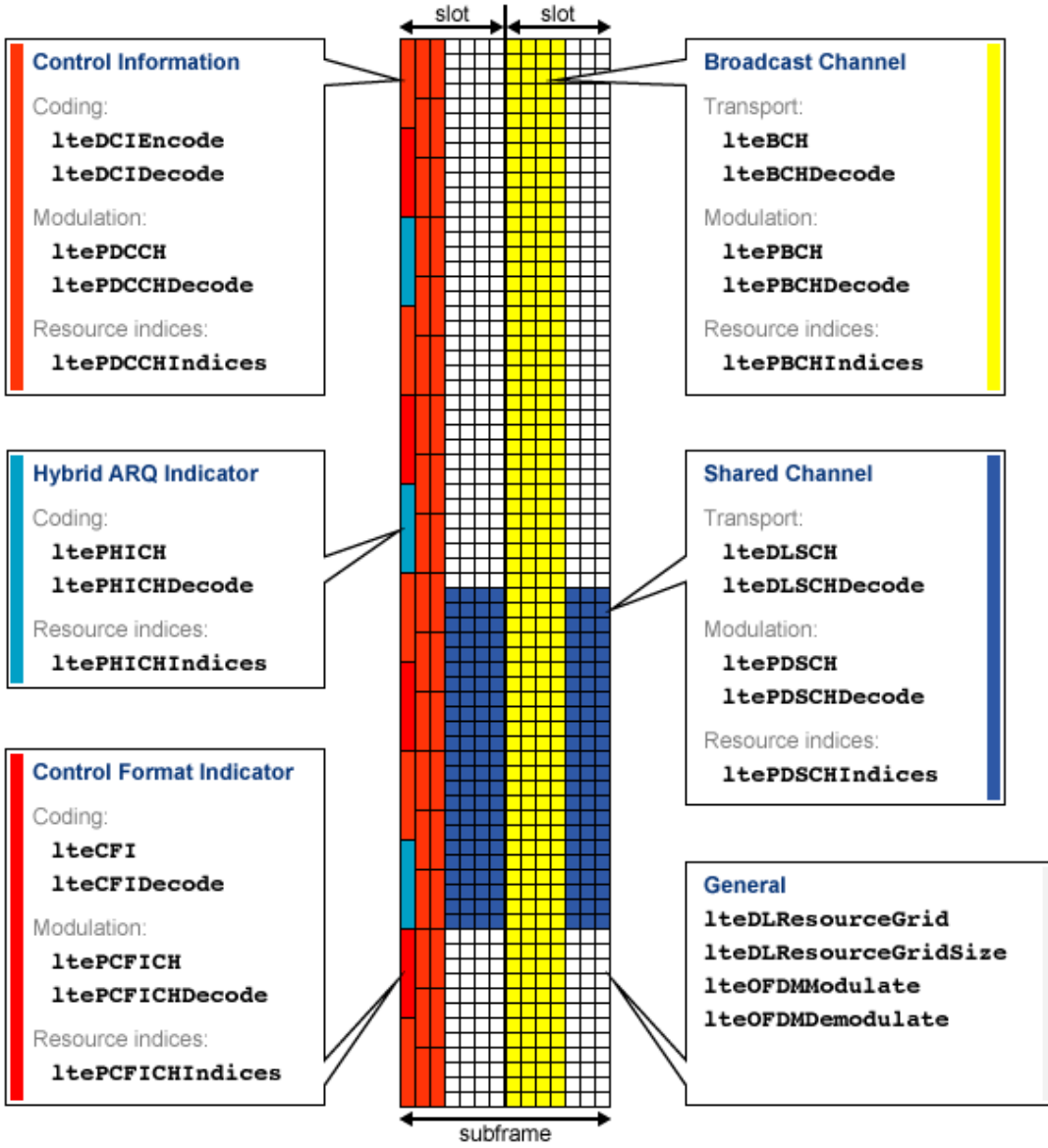
"Parameterization"
"UL-SCH Parameterization"

4

Resource Grid and Block Diagrams

Downlink Physical Channels Grid

The downlink physical channels, their associated functions, and their locations on the resource grid are shown in the following figure.



- Control Information

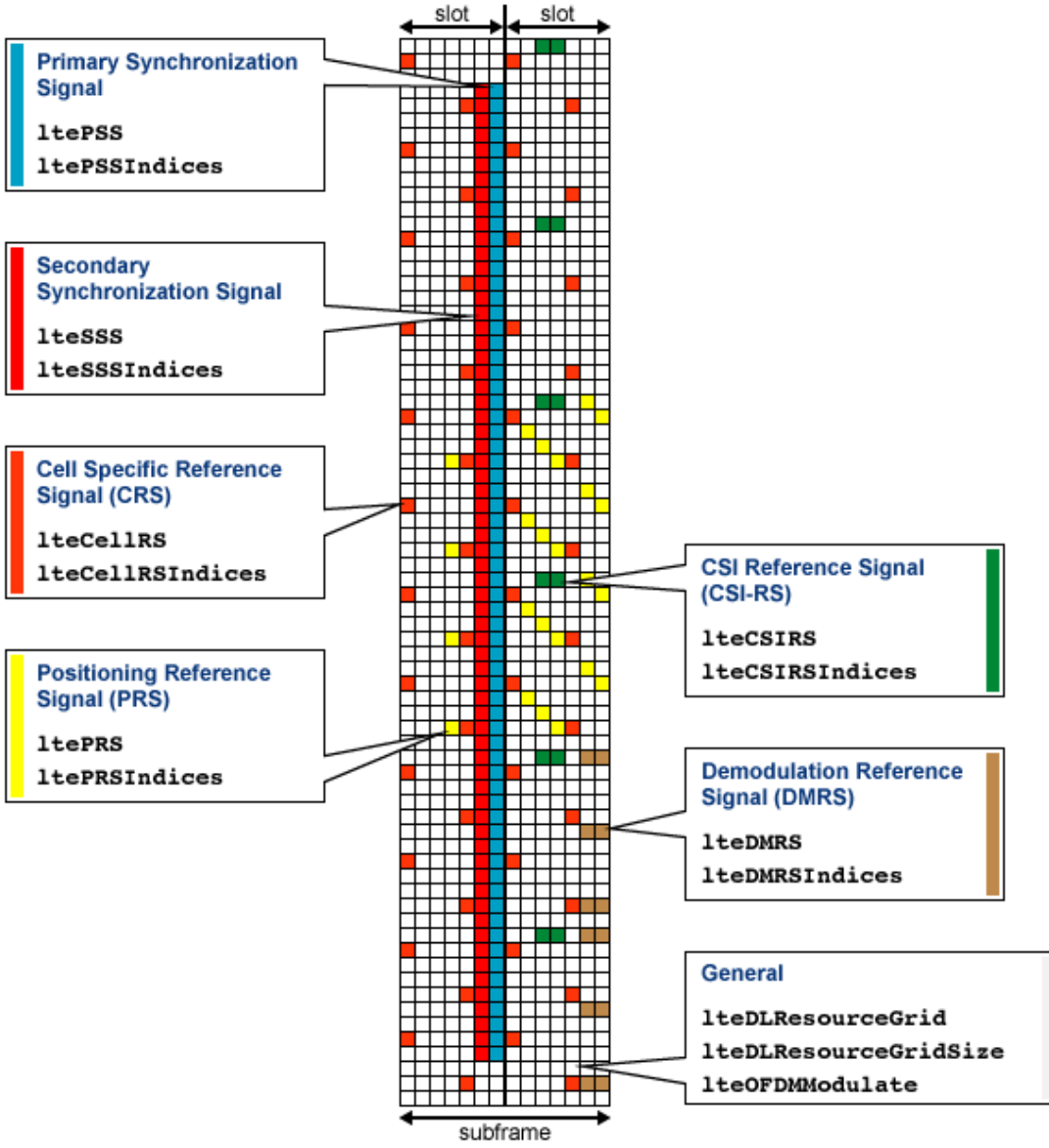
- Coding
  - `lteDCIEncode`
  - `lteDCIDecode`
- Modulation
  - `ltePDCCH`
  - `ltePDCCHDecode`
- Resource Indices — `ltePDCCHIndices`

- Hybrid ARQ Indicator
  - Coding
    - `ltePHICH`
    - `ltePHICHDecode`
  - Resource Indices — `ltePHICHIndices`
- Control Format Indicator
  - Coding
    - `lteCFI`
    - `lteCFIDecode`
  - Modulation
    - `ltePCFICH`
    - `ltePCFICHDecode`
  - Resource Indices — `ltePCFICHIndices`
- Broadcast Channel
  - Transport
    - `lteBCH`
    - `lteBCHDecode`
  - Modulation
    - `ltePBCH`

        - `ltePBCHDecode`
    - Resource Indices — `ltePBCHIndices`
- Shared Channel
    - Transport
        - `lteDLSCH`
        - `lteDLSCHDecode`
    - Modulation
        - `ltePDSCH`
        - `ltePDSCHDecode`
    - Resource Indices — `ltePDSCHIndices`
- General
    - `lteDLResourceGrid`
    - `lteDLResourceGridSize`
    - `lteOFDMModulate`
    - `lteOFDMDemodulate`

Downlink Physical Signals Grid

The downlink physical signals, their associated functions, and their locations on the resource grid are shown in the following figure.

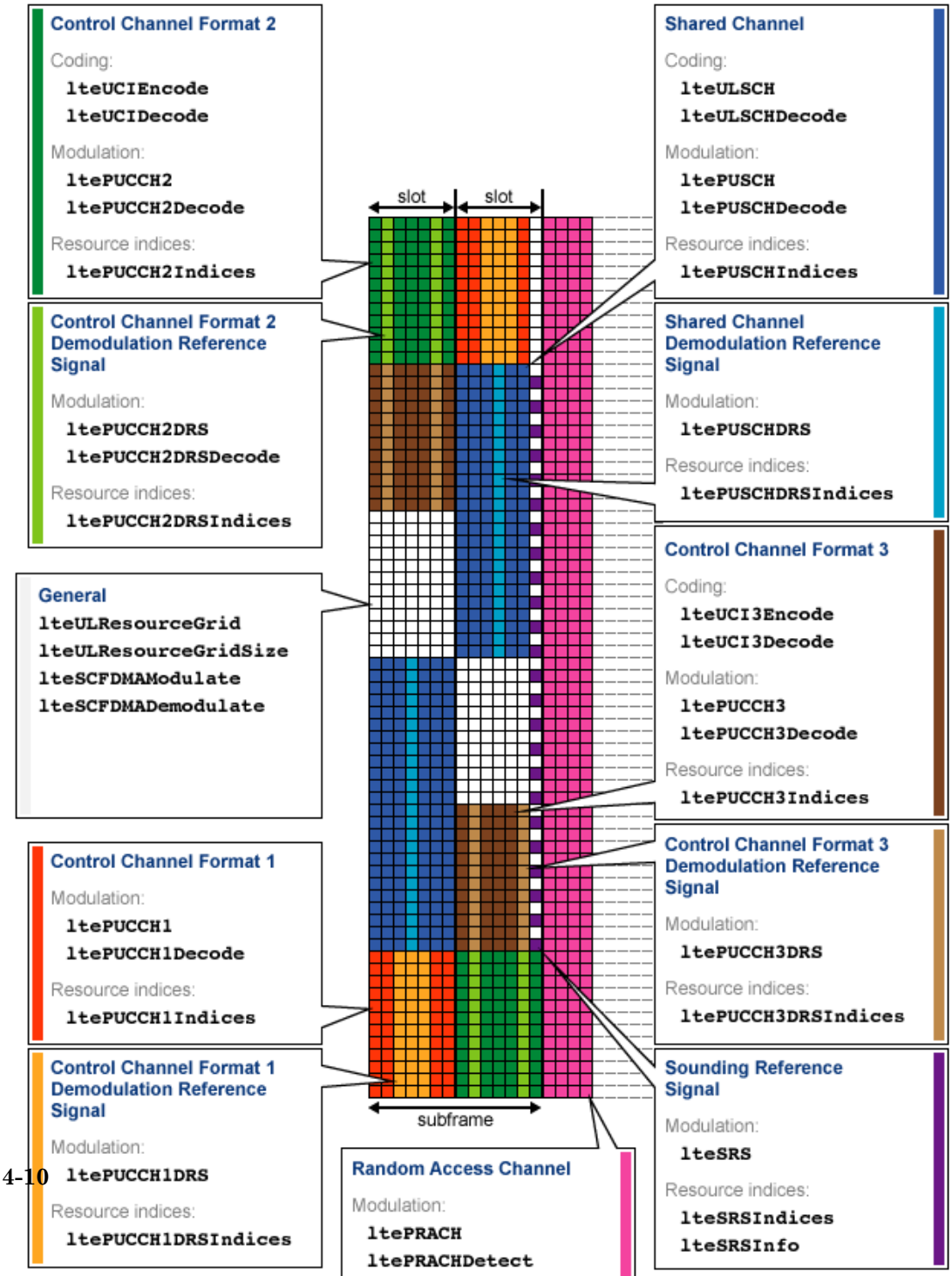


- Primary Synchronization Signal (PSS)

    - `ltePSS`
    - `ltePSSIndices`
- Secondary Synchronization Signal (SSS)
    - `lteSSS`
    - `lteSSSIndices`
- Cell-specific Reference Signal (CRS)
    - `lteCellRS`
    - `lteCellRSIndices`
- Positioning Reference Signal (PRS)
    - `ltePRS`
    - `ltePRSIndices`
- Channel State Information Reference Signal (CSI-RS)
    - `lteCSIRS`
    - `lteCSIRSIndices`
- Demodulation Reference Signal (DMRS)
    - `lteDMRS`
    - `lteDMRSIndices`
- General
    - `lteDLResourceGrid`
    - `lteDLResourceGridSize`
    - `lteOFDMModulate`

Uplink Physical Channels and Signals Grid

The uplink physical channels and signals, their associated functions, and their locations on the resource grid are shown in the following figure.


Control Channel Format 2
Coding:
lteUCIEncode
lteUCIDecode
Modulation:
ltePUCCH2
ltePUCCH2Decode
Resource indices:
ltePUCCH2Indices
Control Channel Format 2 Demodulation Reference Signal
Modulation:
ltePUCCH2DRS
ltePUCCH2DRSDecode
Resource indices:
ltePUCCH2DRSIndices
General
lteULResourceGrid
lteULResourceGridSize
lteSCFDMAModulate
lteSCFDMADemodulate
Control Channel Format 1
Modulation:
ltePUCCH1
ltePUCCH1Decode
Resource indices:
ltePUCCH1Indices
Control Channel Format 1 Demodulation Reference Signal
Modulation:
ltePUCCH1DRS
Resource indices:
ltePUCCH1DRSIndices
slot
slot
subframe
Random Access Channel
Modulation:
ltePRACH
ltePRACHDetect
Shared Channel
Coding:
lteULSCH
lteULSCHDecode
Modulation:
ltePUSCH
ltePUSCHDecode
Resource indices:
ltePUSCHIndices
Shared Channel Demodulation Reference Signal
Modulation:
ltePUSCHDRS
Resource indices:
ltePUSCHDRSIndices
Control Channel Format 3
Coding:
lteUCI3Encode
lteUCI3Decode
Modulation:
ltePUCCH3
ltePUCCH3Decode
Resource indices:
ltePUCCH3Indices
Control Channel Format 3 Demodulation Reference Signal
Modulation:
ltePUCCH3DRS
Resource indices:
ltePUCCH3DRSIndices
Sounding Reference Signal
Modulation:
lteSRS
Resource indices:
lteSRSIndices
lteSRSInfo

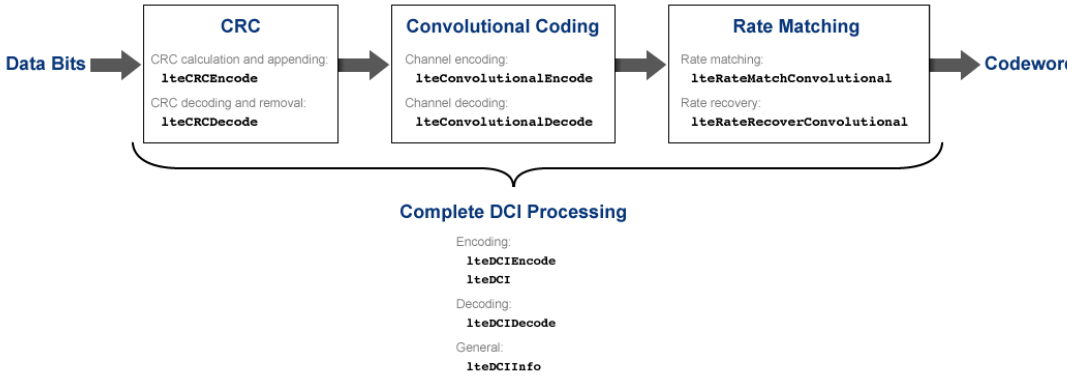
- Control Channel Format 1
  - Modulation
    - `ltePUCCH1`
    - `ltePUCCH1Decode`
  - Resource Indices — `ltePUCCH1Indices`
- Control Channel Format 2
  - Coding
    - `lteUCIEncode`
    - `lteUCIDecode`
  - Modulation
    - `ltePUCCH2`
    - `ltePUCCH2Decode`
  - Resource Indices — `ltePUCCH2Indices`
- Control Channel Format 3
  - Coding
    - `lteUCI3Encode`
    - `lteUCI3Decode`
  - Modulation
    - `ltePUCCH3`
    - `ltePUCCH3Decode`
  - Resource Indices — `ltePUCCH3Indices`
- Random Access Channel
  - Modulation
    - `ltePRACH`
    - `ltePRACHDetect`
  - General — `ltePRACHInfo`
- Shared Channel

    - Transport
        - `lteULSCH`
        - `lteULSCHDecode`
    - Modulation
        - `ltePUSCH`
        - `ltePUSCHDecode`
    - Resource Indices
        - `ltePUSCHIndices`
- Control Channel Format 1 Demodulation Reference Signal
    - Modulation — `ltePUCCH1DRS`
    - Resource Indices — `ltePUCCH1DRSIndices`
- Control Channel Format 2 Demodulation Reference Signal
    - Modulation
        - `ltePUCCH2DRS`
        - `ltePUCCH2DRSDecode`
    - Resource Indices — `ltePUCCH2DRSIndices`
- Control Channel Format 3 Demodulation Reference Signal
    - Modulation — `ltePUCCH3DRS`
    - Resource Indices — `ltePUCCH3DRSIndices`
- Sounding Reference Signal
    - Modulation — `lteSRS`
    - Resource Indices — `lteSRSIndices`
    - General — `lteSRSInfo`
- Shared Channel Demodulation Reference Signal
    - Modulation — `ltePUSCHDRS`
    - Resource Indices — `ltePUSCHDRSIndices`
- General

- `lteULResourceGrid`
- `lteULResourceGridSize`
- `lteSCFDMAModulate`
- `lteSCFDMADemodulate`

DCI Processing Functions

The complete downlink control information process and associated low-level and mid-level DCI functions are shown in the following block diagram.



- Cyclic redundancy check (CRC)
  - CRC calculation and appending — `lteCRCEncode`
  - CRC decoding and removal — `lteCRCDecode`
- Convolutional channel coding
  - Channel encoding — `lteConvolutionalEncode`
  - Channel decoding — `lteConvolutionalDecode`
- Rate matching and recovery
  - Rate matching — `lteRateMatchConvolutional`
  - Rate recovery — `lteRateRecoverConvolutional`
- Complete DCI processing
  - Encoding
    - `lteDCIEncode`
    - `lteDCI`
  - Decoding — `lteDCIDecode`

- General — `lteDCIInfo`

Related Examples

- "Model DCI and PDCCH"

More About

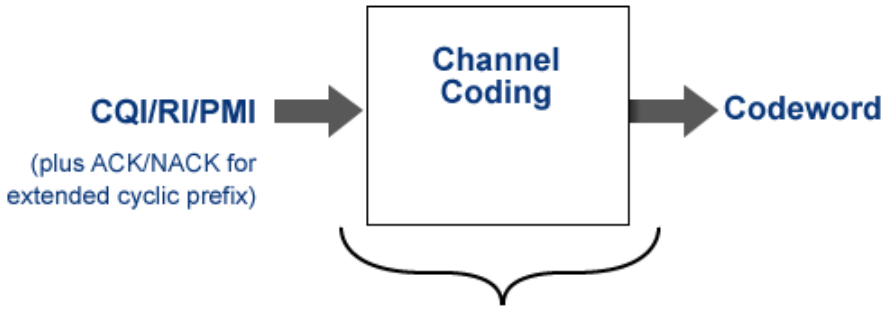
- "Downlink Control Channel"

UCI Processing Functions

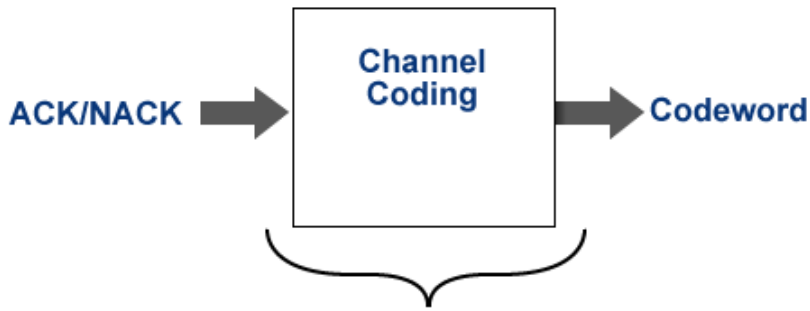
The uplink control information process for PUCCH format 1, 2, and 3 and associated mid-level UCI functions are shown in the following block diagram.

PUCCH Format 1:

PUCCH Format 2:



PUCCH Format 3:



- PUCCH format 2 complete UCI processing
  - `lteUCIEncode`
  - `lteUCIDecode`
- PUCCH format 3 complete UCI processing
  - `lteUCI3Encode`
  - `lteUCI3Decode`

Related Examples

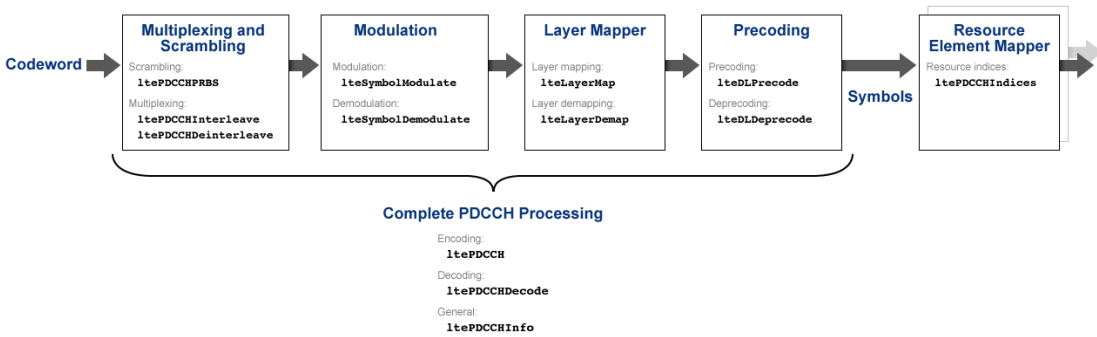
- "Model PUCCH Format 2"

More About

- "Uplink Control Channel Format 1"
- "Uplink Control Channel Format 2"

PDCCH Processing Functions

The complete physical downlink control channel process and associated low-level and mid-level PDCCH functions are shown in the following block diagram.



- Multiplexing and scrambling
  - Scrambling — `ltePDCCHPRBS`
  - Multiplexing
    - `ltePDCCHInterleave`
    - `ltePDCCHDeinterleave`
- Symbol modulation and demodulation
  - Modulation — `lteSymbolModulate`
  - Demodulation — `lteSymbolDemodulate`
- Layer mapper and de-mapper
  - Layer mapping — `lteLayerMap`
  - Layer demapping — `lteLayerDemap`
- Precoding and deprecoding
  - Precoding — `lteDLPrecode`
  - Deprecoding — `lteDLDeprecode`
- Resource element mapper

  - Resource indices — `ltePDCCHIndices`
- Complete PDCCH processing
  - Encoding — `ltePDCCH`
  - Decoding — `ltePDCCHDecode`
  - General — `ltePDCCHInfo`

Related Examples

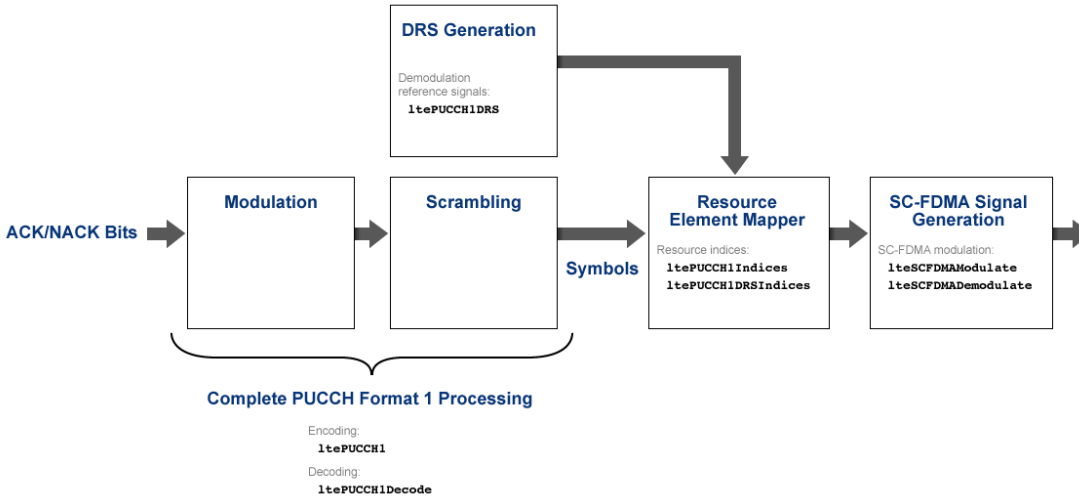
- "Model DCI and PDCCH"

More About

- "Downlink Control Channel"

PUCCH Format 1 Processing Functions

The complete physical uplink control channel format 1 process and associated low-level and mid-level PUCCH format 1 functions are shown in the following block diagram.



- Demodulation reference signal (DRS) generation
  - Demodulation reference signals — `ltePUCCH1DRS`
- Resource element mapper
  - Resource indices — `ltePUCCH1Indices`
  - DRS resource indices — `ltePUCCH1DRSIndices`
- SC-FDMA signal generation
  - SC-FDMA modulation — `lteSCFDMAModulate`
  - SC-FDMA demodulation — `lteSCFDMADemodulate`
- Complete PUCCH format 1 processing
  - Encoding — `ltePUCCH1`
  - Decoding — `ltePUCCH1Decode`

Related Examples

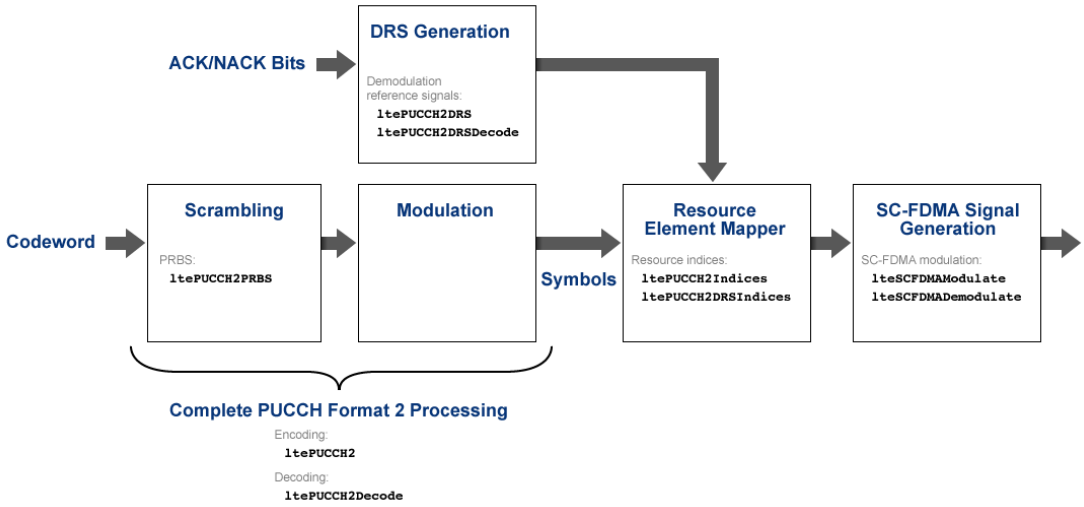
- “Model PUCCH Format 1”
- “PUCCH1a ACK Missed Detection Probability Conformance Test”
- “PUCCH1a Multi User ACK Missed Detection Probability Conformance Test”

More About

- “Uplink Control Channel Format 1”

PUCCH Format 2 Processing Functions

The complete physical uplink control channel format 2 process and associated low-level and mid-level PUCCH format 2 functions are shown in the following block diagram.



- Scrambling
  - Pseudo-random binary sequence (PRBS) — `ltePUCCH2PRBS`
- Demodulation reference signal (DRS) generation
  - Demodulation reference signals — `ltePUCCH2DRS`
  - Demodulation reference signal decoding — `ltePUCCH2DRSDecode`
- Resource element mapper
  - Resource indices — `ltePUCCH2Indices`
  - DRS resource indices — `ltePUCCH2DRSIndices`
- SC-FDMA signal generation
  - SC-FDMA modulation — `lteSCFDMAModulate`
  - SC-FDMA demodulation — `lteSCFDMADemodulate`
- Complete PUCCH format 2 processing

- Encoding — `ltePUCCH2`
- Decoding — `ltePUCCH2Decode`

Related Examples

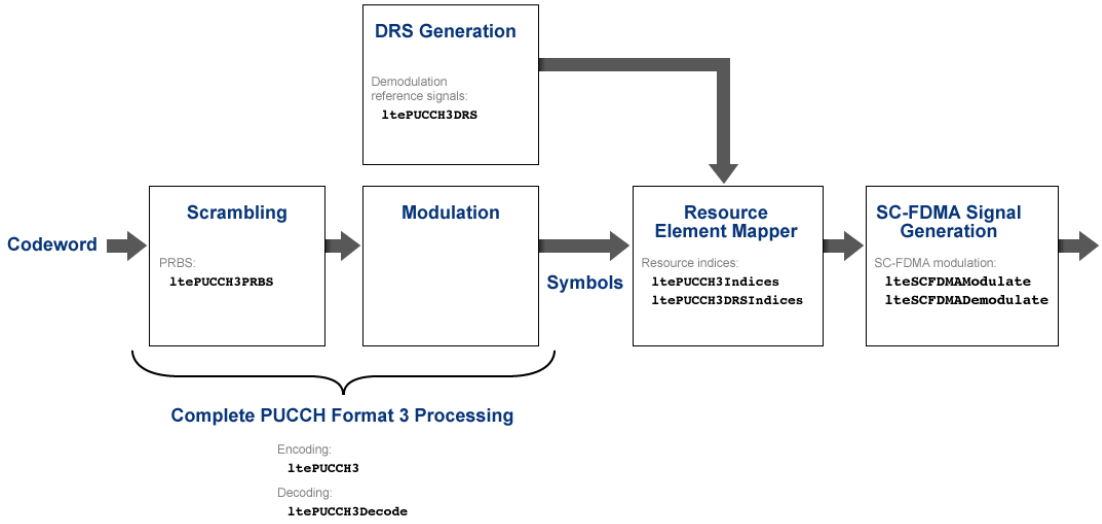
- "Model PUCCH Format 2"

More About

- "Uplink Control Channel Format 2"

PUCCH Format 3 Processing Functions

The complete physical uplink control channel format 3 process and associated low-level and mid-level PUCCH format 3 functions are shown in the following block diagram.

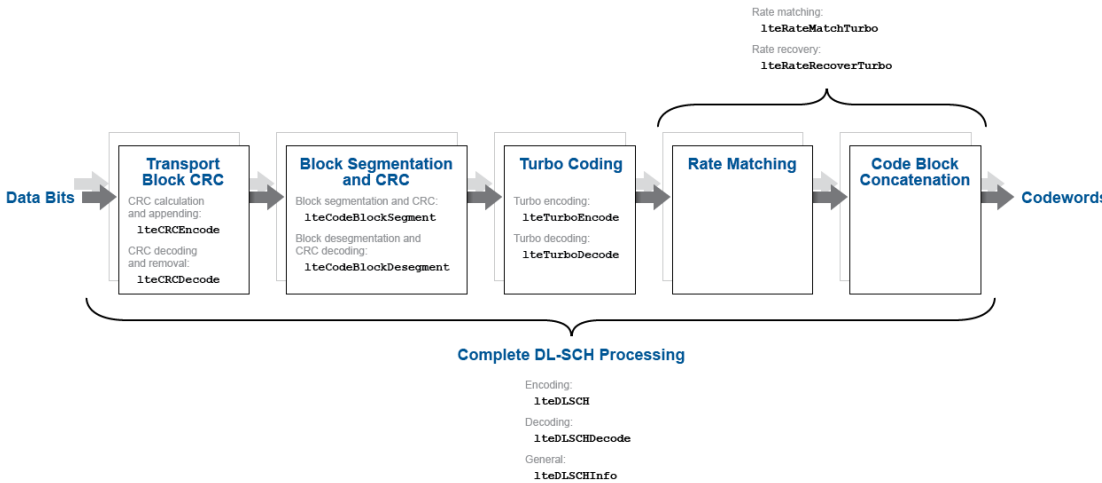


- Scrambling
  - Pseudo-random binary sequence (PRBS) — `ltePUCCH3PRBS`
- Demodulation reference signal (DRS) generation
  - Demodulation reference signals — `ltePUCCH3DRS`
- Resource element mapper
  - Resource indices — `ltePUCCH3Indices`
  - DRS resource indices — `ltePUCCH3DRSIndices`
- SC-FDMA signal generation
  - SC-FDMA modulation — `lteSCFDMAModulate`
  - SC-FDMA demodulation — `lteSCFDMADemodulate`
- Complete PUCCH format 3 processing

- Encoding — `ltePUCCH3`
- Decoding — `ltePUCCH3Decode`

DL-SCH Processing Functions

The complete downlink shared channel process and associated low-level and mid-level DL-SCH functions are shown in the following block diagram.



- Transport block cyclic redundancy check (CRC)
  - CRC calculation and appending — `lteCRCEncode`
  - CRC decoding and removal — `lteCRCDecode`
- Block segmentation and CRC
  - Block segmentation and CRC attachment — `lteCodeBlockSegment`
  - Block desegmentation and CRC decoding — `lteCodeBlockDesegment`
- Turbo encoding and decoding
  - `lteTurboEncode`
  - `lteTurboDecode`
- Rate matching and recovery
  - Rate matching — `lteRateMatchTurbo`
  - Rate recovery — `lteRateRecoverTurbo`
- Complete DL-SCH processing

- Encoding — `lteDLSCH`
- Decoding — `lteDLSCHDecode`
- General — `lteDLSCHInfo`

Related Examples

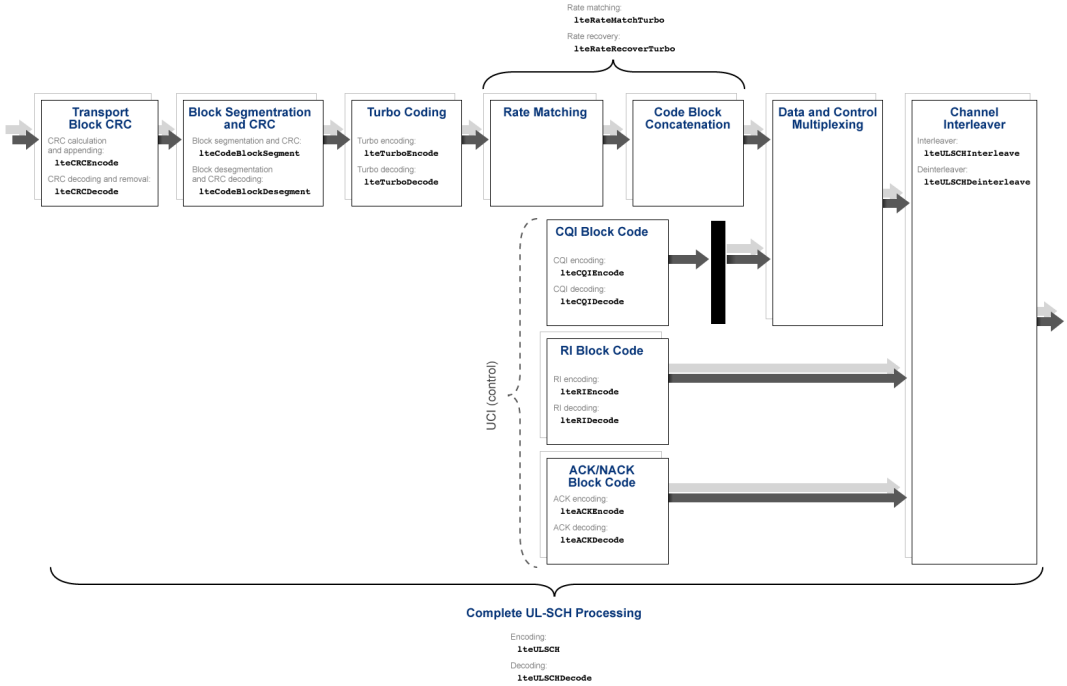
- "Model DL-SCH and PDSCH"
- "DL-SCH HARQ Modeling"

More About

- "Downlink Shared Channel"

UL-SCH Processing Functions

The complete uplink shared channel process and associated low-level and mid-level UL-SCH functions are shown in the following block diagram.



- Transport block cyclic redundancy check (CRC)
  - CRC calculation and appending — `lteCRCEncode`
  - CRC decoding and removal — `lteCRCDecode`
- Block segmentation and CRC
  - Block segmentation and CRC attachment — `lteCodeBlockSegment`
  - Block desegmentation and CRC decoding — `lteCodeBlockDesegment`
- Turbo encoding and decoding
  - `lteTurboEncode`

    - `lteTurboDecode`
- Rate matching and recovery
    - Rate matching — `lteRateMatchTurbo`
    - Rate recovery — `lteRateRecoverTurbo`
- Uplink control information (UCI)
    - Channel quality information (CQI) block code
        - CQI encoding — `lteCQIEncode`
        - CQI decoding — `lteCQIDecode`
    - Rank indicator (RI) block code
        - RI encoding — `lteRIEncode`
        - RI decoding — `lteRIDecode`
    - Acknowledgement (ACK) or Negative acknowledgement (NACK) block code
        - ACK encoding — `lteACKEncode`
        - ACK decoding — `lteACKDecode`
- Channel interleaver
    - Interleaver — `lteULSCHInterleave`
    - Deinterleaver — `lteULSCHDeinterleave`
- Complete UL-SCH processing
    - Encoding — `lteULSCH`
    - Decoding — `lteULSCHDecode`

Related Examples

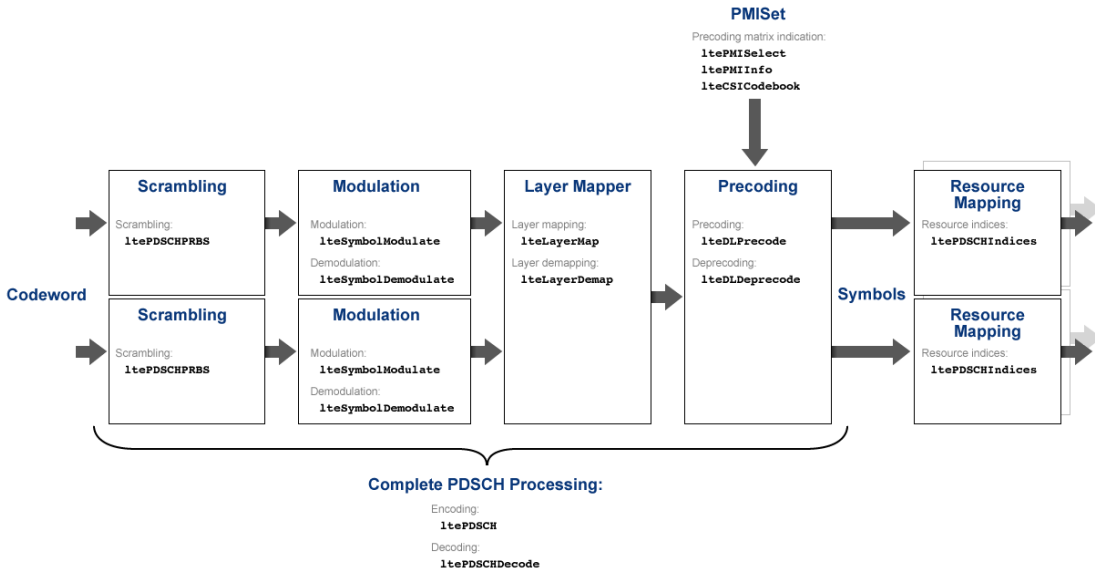
- "Model UL-SCH and PUSCH"

More About

- "Uplink Shared Channel"

PDSCH Processing Functions

The complete physical downlink shared channel process and associated low-level and mid-level PDSCH functions are shown in the following block diagram.



- Scrambling — `ltePDSCHPRBS`
- Symbol modulation and demodulation
  - Modulation — `lteSymbolModulate`
  - Demodulation — `lteSymbolDemodulate`
- Layer mapping
  - Layer mapping — `lteLayerMap`
  - Layer demapping — `lteLayerDemap`
- Precoding and deprecoding
  - Precoding — `lteDLPrecode`
  - Deprecoding — `lteDLDeprecode`
- Downlink precoding matrix indication (PMI)

    - `ltePMISelect`
    - `ltePMIInfo`
    - `lteCSICodebook`
- Resource mapping
    - Resource indices — `ltePDSCHIndices`
- Complete PDSCH processing
    - Encoding — `ltePDSCH`
    - Decoding — `ltePDSCHDecode`

Related Examples

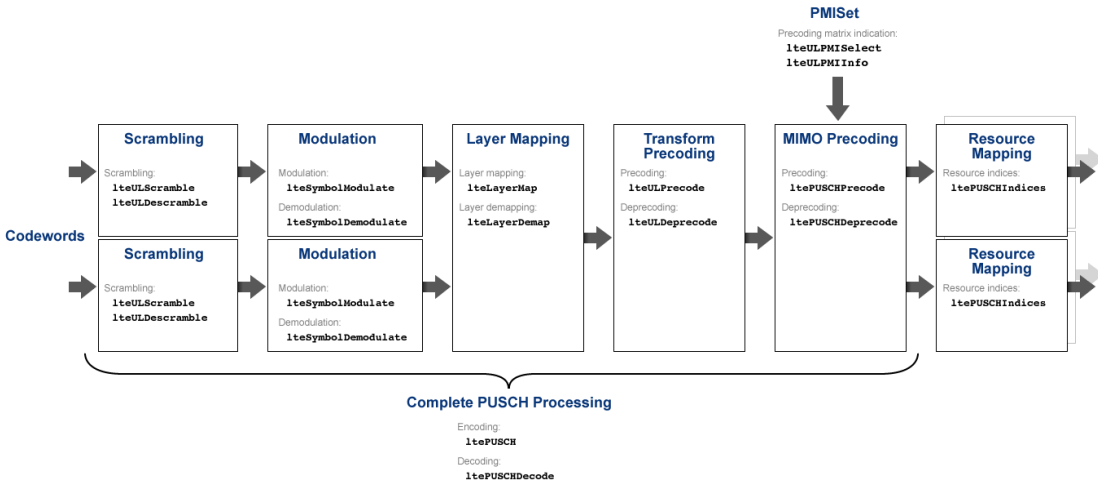
- "Model DL-SCH and PDSCH"
- "PDSCH Bit Error Rate Curve Generation"

More About

- "Downlink Shared Channel"

PUSCH Processing Functions

The complete physical uplink shared channel process and associated low-level and mid-level PUSCH functions are shown in the following block diagram.



- Scrambling
  - Scrambling — `lteULScramble`
  - Descrambling — `lteULDescramble`
- Symbol modulation and demodulation
  - Modulation — `lteSymbolModulate`
  - Demodulation — `lteSymbolDemodulate`
- Layer mapping
  - Layer mapping — `lteLayerMap`
  - Layer demapping — `lteLayerDemap`
- Transform precoding and deprecoding
  - Transform precoding — `lteULPrecode`
  - Transform deprecoding — `lteULDeprecode`

- Multiple-input multiple-output (MIMO) precoding and deprecoding
  - MIMO precoding — `ltePUSCHPrecode`
  - MIMO deprecoding — `ltePUSCHDeprecode`
- Uplink (UL) precoding matrix indication (PMI)
  - `lteULPMISelect`
  - `lteULPMIInfo`
- Resource mapping
  - Resource indices — `ltePUSCHIndices`
- Complete PUSCH processing
  - Encoding — `ltePUSCH`
  - Decoding — `ltePUSCHDecode`

Related Examples

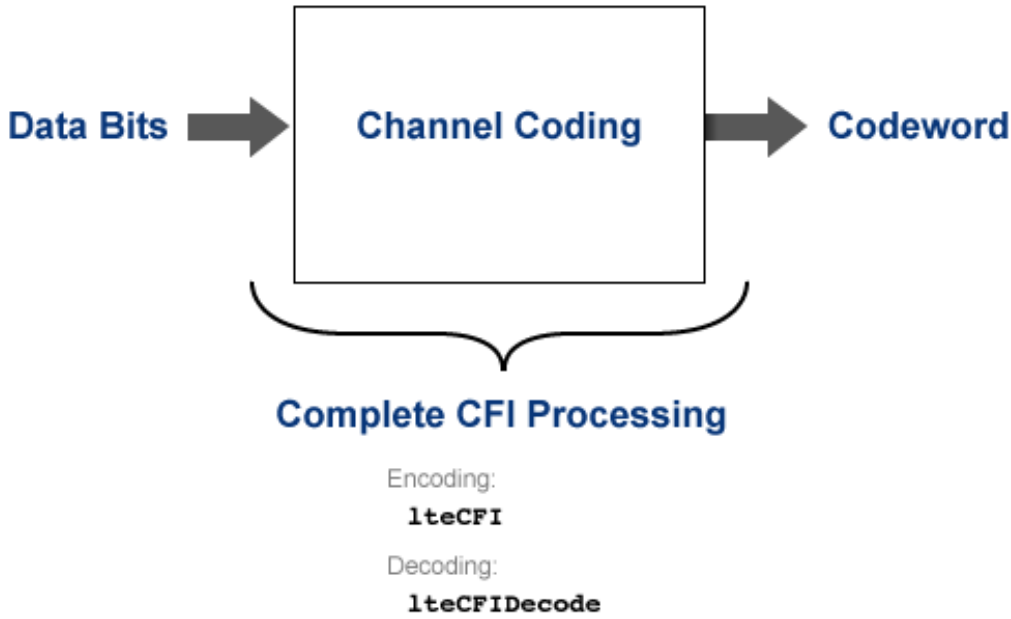
- "Model UL-SCH and PUSCH"

More About

- "Uplink Shared Channel"

CFI Processing Functions

The complete control format information process and associated low-level and mid-level CFI functions are shown in the following block diagram.



- Complete CFI processing
  - Encoding — `lteCFI`
  - Decoding — `lteCFIDecode`

Related Examples

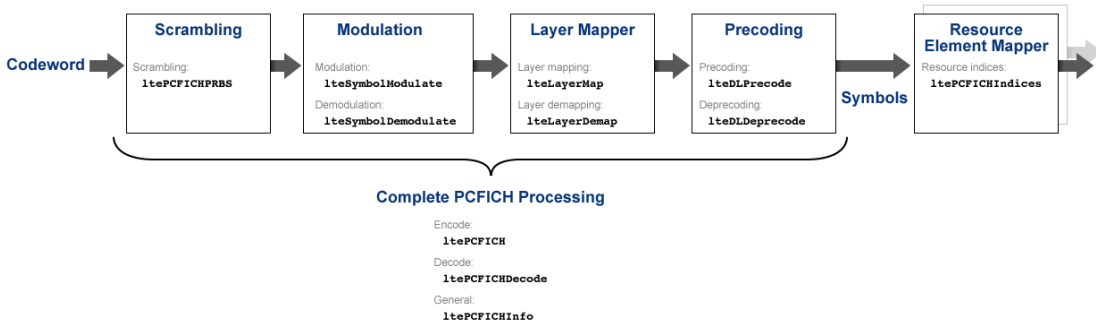
- "Model CFI and PCFICH"

More About

- "Control Format Indicator (CFI) Channel"

PCFICH Processing Functions

The complete physical downlink control format indicator channel process and associated low-level and mid-level PCFICH functions are shown in the following block diagram.



- Scrambling — `ltePCFICHPRBS`
- Symbol modulation and demodulation
  - Modulation — `lteSymbolModulate`
  - Demodulation — `lteSymbolDemodulate`
- Layer mapper and demapper
  - Layer mapping — `lteLayerMap`
  - Layer demapping — `lteLayerDemap`
- Precoding and deprecoding
  - Precoding — `lteDLPrecode`
  - Deprecoding — `lteDLDeprecode`
- Resource element mapper
  - Resource indices — `ltePCFICHIndices`
- Complete PCFICH processing
  - Encoding — `ltePCFICH`
  - Decoding — `ltePCFICHDecode`
  - General — `ltePCFICHInfo`

Related Examples

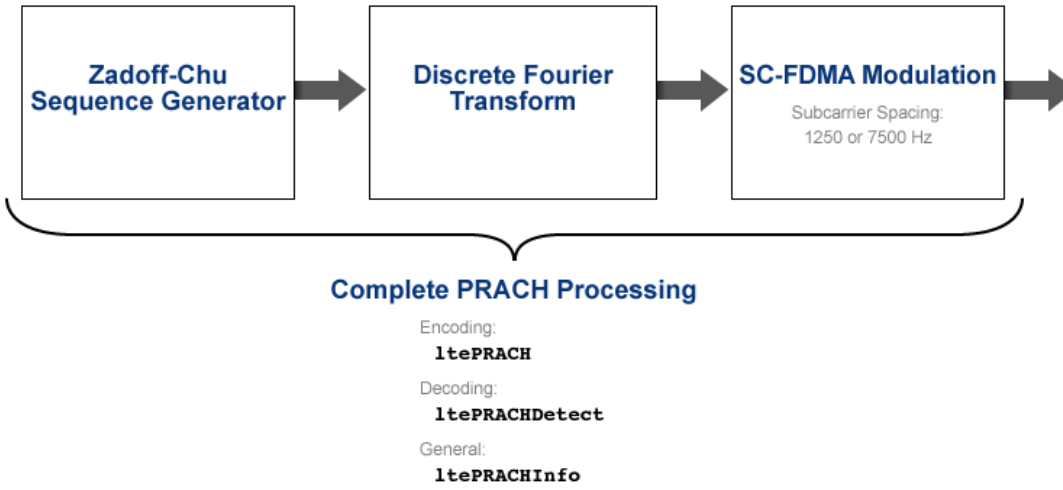
- “Model CFI and PCFICH”

More About

- “Control Format Indicator (CFI) Channel”

PRACH Processing Functions

The random access channel process and associated PRACH functions are shown in the following block diagram.



- Complete PRACH processing
  - Encoding — `ltePRACH`
  - Decoding — `ltePRACHDetect`
  - General — `ltePRACHInfo`

Related Examples

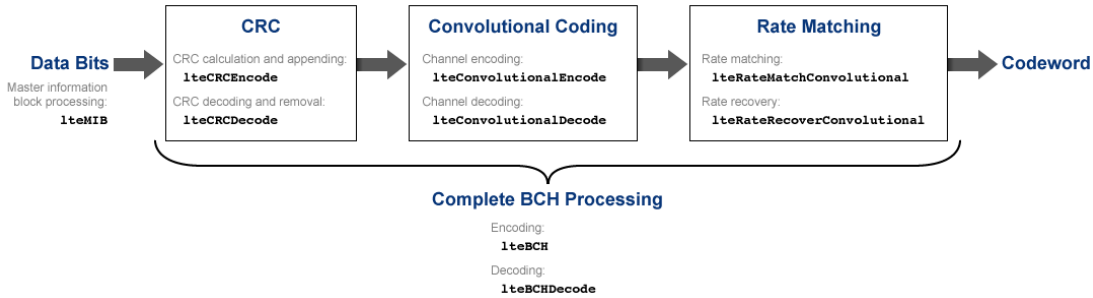
- "PRACH False Alarm Probability Conformance Test"
- "PRACH Detection Conformance Test"

More About

- "Random Access Channel"

BCH Processing Functions

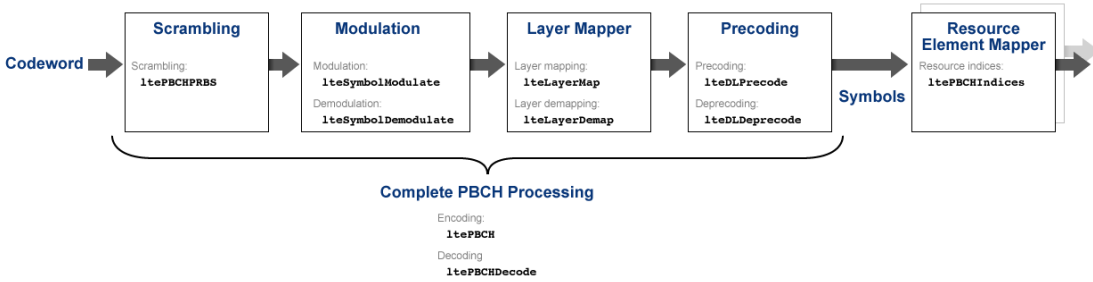
The complete broadcast channel process and associated low-level and mid-level BCH functions are shown in the following block diagram.



- Cyclic redundancy check (CRC)
  - CRC calculation and appending — `lteCRCEncode`
  - CRC decoding and removal — `lteCRCDecode`
- Convolutional channel encoding and decoding
  - `lteConvolutionalEncode`
  - `lteConvolutionalDecode`
- Rate matching and recovery
  - Rate matching — `lteRateMatchConvolutional`
  - Rate recovery — `lteRateRecoverConvolutional`
- Master information block (MIB) processing — `lteMIB`
- Complete BCH processing
  - Encoding — `lteBCH`
  - Decoding — `lteBCHDecode`

PBCH Processing Functions

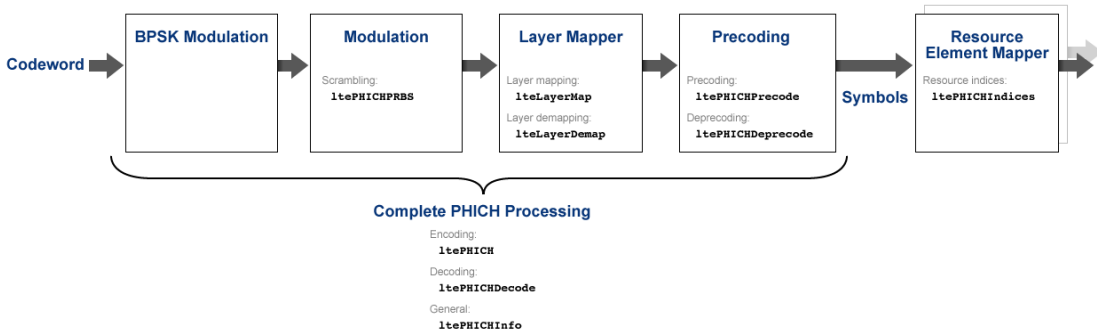
The complete physical broadcast channel process and associated low-level and mid-level PBCH functions are shown in the following block diagram.



- Scrambling — `ltePBCHPRBS`
- Symbol modulation and demodulation
  - Modulation — `lteSymbolModulate`
  - Demodulation — `lteSymbolDemodulate`
- Layer mapper and demapper
  - Layer mapping — `lteLayerMap`
  - Layer demapping — `lteLayerDemap`
- Precoding and deprecoding
  - Precoding — `lteDLPrecode`
  - Deprecoding — `lteDLDeprecode`
- Resource element mapper
  - Resource indices — `ltePBCHIndices`
- Complete PBCH processing
  - Encoding — `ltePBCH`
  - Decoding — `ltePBCHDecode`

PHICH Processing Functions

The complete physical hybrid automatic repeat request (HARQ) indicator channel process and associated low-level and mid-level PHICH functions are shown in the following block diagram.



- Scrambling — `ltePHICHPRBS`
- Layer mapper and demapper
  - Layer mapping — `lteLayerMap`
  - Layer demapping — `lteLayerDemap`
- Precoding and deprecoding
  - Precoding — `ltePHICHPrecode`
  - Deprecoding — `ltePHICHDeprecode`
- Resource element mapper
  - Resource indices — `ltePHICHIndices`
- Complete PBCH processing
  - Encoding — `ltePHICH`
  - Decoding — `ltePHICHDecode`
  - General — `ltePHICHInfo`

Related Examples

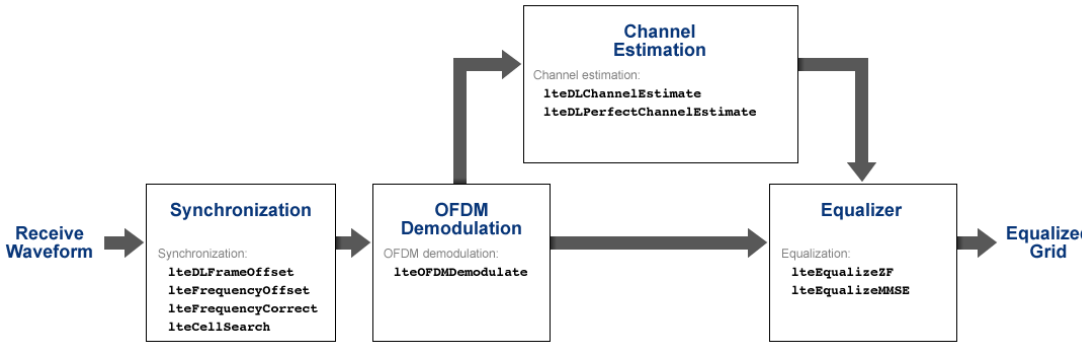
- "Model HARQ Indicator and PHICH"

More About

- “HARQ Indicator (HI) Channel”

Downlink Receiver Functions

The complete downlink (DL) receiver process and associated functions are shown in the following block diagram.



- Synchronization
  - `lteDLFrameOffset`
  - `lteFrequencyOffset`
  - `lteFrequencyCorrect`
  - `lteCellSearch`
- OFDM demodulation — `lteOFDMDemodulate`
- Channel estimation
  - `lteDLChannelEstimate`
  - `lteDLPerfectChannelEstimate`
- Equalization
  - `lteEqualizeZF`
  - `lteEqualizeMMSE`

Related Examples

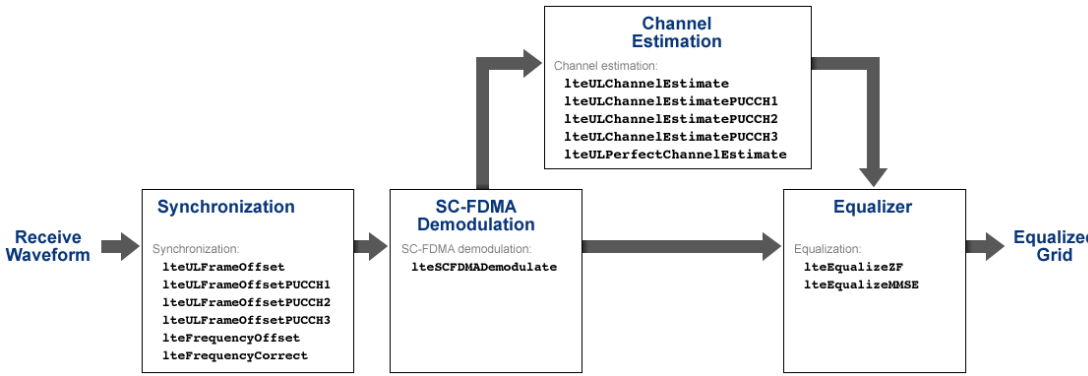
- "LTE Downlink Channel Estimation and Equalization"

More About

- “Channel Estimation”

Uplink Receiver Functions

The complete uplink (UL) receiver process and associated functions are shown in the following block diagram.



- Synchronization
  - `lteULFrameOffset`
  - `lteULFrameOffsetPUCCH1`
  - `lteULFrameOffsetPUCCH2`
  - `lteULFrameOffsetPUCCH3`
  - `lteFrequencyOffset`
  - `lteFrequencyCorrect`
- SC-FDMA demodulation — `lteSCFDMADemodulate`
- Channel estimation
  - `lteULChannelEstimate`
  - `lteULChannelEstimatePUCCH1`
  - `lteULChannelEstimatePUCCH2`
  - `lteULChannelEstimatePUCCH3`
  - `lteULPerfectChannelEstimate`
- Equalization

- `lteEqualizeZF`
- `lteEqualizeMMSE`

Related Examples

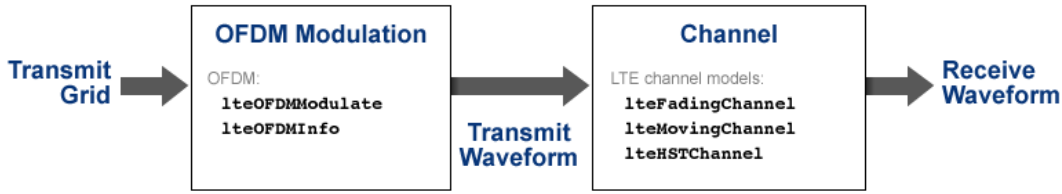
- "PUCCH2 CQI BLER Conformance Test"

More About

- "Channel Estimation"

OFDM Modulation and Propagation Channel Models

The orthogonal frequency-division multiplexing (OFDM) modulation process, propagation channel models, and their associated functions are shown in the following block diagram.



- OFDM modulation
  - `lteOFDMModulate`
  - `lteOFDMInfo`
- LTE propagation channel models
  - `lteFadingChannel`
  - `lteMovingChannel`
  - `lteHSTChannel`

Related Examples

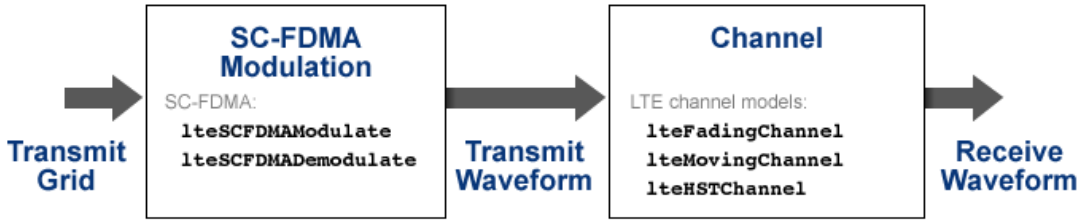
- "Simulate Propagation Channels"
- "Find Channel Impulse Response"

More About

- "Propagation Channel Models"

SC-FDMA Modulation and Propagation Channel Models

The single-carrier frequency-division multiple access (SC-FDMA) modulation process, propagation channel models, and their associated functions are shown in the following block diagram.



- SC-FDMA modulation
  - `lteSCFDMAModulate`
  - `lteSCFDMADemodulate`
- LTE propagation channel models
  - `lteFadingChannel`
  - `lteMovingChannel`
  - `lteHSTChannel`

Related Examples

- "Simulate Propagation Channels"
- "Find Channel Impulse Response"

More About

- "Propagation Channel Models"

Glossary

This list defines commonly used LTE abbreviations and acronyms. These terms may appear in some or all of the documents that describe MathWorks products that model communications and LTE.

3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
ACK	Acknowledgement — in ARQ protocols
ACLR	Adjacent Channel Leakage Power Ratio
	Adjacent Channel Leakage Ratio
ARQ	Automatic Repeat Request
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BER	Bit Error Rate
	Bit Error Ratio
BLER	Block Error Rate
	Block Error Ratio
BPSK	Binary Phase-Shift Keying
BS	Base Station
BW	Bandwidth
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CellRS	Cell-specific Reference Signal

CFI	Control Format Indicator
CP	Cyclic Prefix
CQI	Channel Quality Indicator
	Channel Quality Information
CRC	Cyclic Redundancy Check
CRS	Cell-specific Reference Signal
CSI	Channel State Information
CSI-RS	CSI Reference Signals
DCI	Downlink Control Information
DL	Downlink
DL-SCH	Downlink Shared Channel
DM-RS	Demodulation Reference Signal
DRS	Demodulation Reference Signal
DwPTS	Downlink Pilot Time Slot — the downlink part of the special subframe, for TDD operation
eICIC	Enhanced Inter-Cell Interference Coordination
eMBMS	Evolved Multimedia Broadcast and Multicast Service
eNB	eNodeB
eNodeB	E-UTRAN NodeB
EPA	Extended Pedestrian A
EPC	Evolved Packet Core
EPDCCH	Enhanced Physical Downlink Control Channel
EPS	Evolved Packet System

E-TM	E-UTRA Test Model
ETU	Extended Typical Urban model
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
EVA	Extended Vehicular A
EVM	Error Vector Magnitude
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
FRC	Fixed Reference Channel
GP	Guard Period
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HARQ	Hybrid ARQ
HetNets	Heterogeneous Networks
HI	HARQ Indicator
HST	High Speed Train
ICIC	Inter-Cell Interference Coordination
IFFT	Inverse Fast Fourier Transform
IP	Internet Protocol
LCS	Location Services

LLR	Log-Likelihood Ratio
LTE	Long Term Evolution
MAC	Medium Access Control
MIB	Master Information Block
MIMO	Multiple-Input Multiple-Output
ML	Maximum Likelihood
MMSE	Minimum Mean Square Error
NACK	Negative Acknowledgement — in ARQ protocols
NAK	Negative Acknowledgement — in ARQ protocols
NodeB	A logical node handling transmission and reception in multiple cells. A NodeB commonly, but not necessarily, corresponds to a base station.
NRE	Number of Resource Elements
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSFBC	Orthogonal Space Frequency Block Code
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PHICH	Physical Hybrid-ARQ Indicator Channel
PHY	Physical layer

PLMN	Public Land Mobile Network
PMI	Precoding Matrix Indicator
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PRBS	Pseudorandom Binary Sequence
PRS	Positioning Reference Signal
PSD	Power Spectral Density
PSS	Primary Synchronization Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
	Quaternary Phase Shift Keying
RACH	Random Access Channel
RB	Resource Block
RE	Resource Element
REG	Resource Element Group
RI	Rank Indication
	Rank Indicator
RLC	Radio Link Control
RMC	Reference Measurement Channel
RMS	Root Mean Square

RNTI	Radio Network Temporary Identifier
RS	Reference Symbol
RV	Redundancy Version
RX	Receive
	Receiver
SC-FDMA	Single Carrier Frequency Division Multiple Access
SFN	System Frame Number
SI	System Information
SIB	System Information Block
SIB1	System Information Block type 1
SRS	Sounding Reference Signal
SSS	Secondary Synchronization Signal
TBS	Transport Block Size
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TDOA	Time Difference of Arrival
TPC	Transmit Power Control
TS	Technical Specification
TX	Transmit
	Transmitter
UCI	Uplink Control Information
UE	User Equipment — the 3GPP name for the mobile terminal

UE-RS	UE-specific Reference Signal
UL	Uplink
UL-SCH	Uplink Shared Channel
UMTS	Universal Mobile Telecommunication System
UpPTS	Uplink Pilot Time Slot — the uplink part of the special subframe, for TDD operation
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
WiMAX	Worldwide interoperability for Microwave Access
ZF	Zero Forcing

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