

5G Toolbox™ Release Notes



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*5G Toolbox™ Release Notes*

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# R2021b

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**Version: 2.3**

**New Features**

**Bug Fixes**

## 5G Waveform Generator app updates

The **5G Waveform Generator** app now provides these capabilities.

- Export waveforms to a Simulink® block. Use the generated block as a waveform source in a Simulink model. For more information, see the Waveform From Wireless Waveform Generator App block.
- Export NR test models (NR-TM) and NR uplink and downlink FRC waveform generation parameters to a MATLAB® script. Use the exported scripts to programmatically generate waveforms from the command line.
- Physical uplink control channel (PUCCH) support.
- Sounding reference signal (SRS) for positioning support, as defined in Release 16 of TS 38.211 Section 6.4.1.4. This support includes the extended ranges for the starting position of the SRS within a slot, number of SRS symbols, symbol repetition, and comb number and offset.
- Complementary cumulative distribution function (CCDF) visualization to measure the peak-to-average power ratio (PAPR) of the generated waveform. The CCDF visualization also supports time-duplexed waveforms and signal bursts when you select burst mode in the CCDF plot.
- Control resource set (CORESET) visualization in the resource grid when configuring NR downlink, NR-TM, or NR downlink FRC waveforms.

### Enhanced PUCCH support in programmatic waveform generation

The `nrULCarrierConfig` object now enables you to configure 5G NR uplink waveforms containing PUCCH by using the `PUCCH` property of the object. You can use the objects listed in this table for the PUCCH configuration. This enhanced capability replaces the example-specific implementation in previous releases.

Object	Description
<code>nrWavegenPUCCH0Config</code>	PUCCH format 0 configuration parameters for 5G waveform generation
<code>nrWavegenPUCCH1Config</code>	PUCCH format 1 configuration parameters for 5G waveform generation
<code>nrWavegenPUCCH2Config</code>	PUCCH format 2 configuration parameters for 5G waveform generation
<code>nrWavegenPUCCH3Config</code>	PUCCH format 3 configuration parameters for 5G waveform generation
<code>nrWavegenPUCCH4Config</code>	PUCCH format 4 configuration parameters for 5G waveform generation

### Enhanced support for PUCCH decoding

Use the `nrPUCCHDecode` function to decode PUCCH formats 0, 1, 2, 3, and 4 and to calculate the detection metric. This function replaces the example-specific implementation in previous releases.

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## Release 16 updates to PRACH generation

- The `nrPRACH`, `nrPRACHIndices`, and `nrPRACHConfig` features now support physical random access channel (PRACH) preamble lengths 1151 and 571, as defined in Release 16 of TS 38.211 Section 6.3.3.
- You can now set the `LRA` property of the `nrPRACHConfig` configuration object when you set the `SubcarrierSpacing` property to 15 or 30.
- The upper bound of the `ConfigurationIndex` property of the `nrPRACHConfig` configuration object is now 262 instead of 255 for frequency range 1 (FR1) and time division duplex (TDD) mode.

## Support for TR 38.901 propagation path loss

Use the `nrPathLossConfig` object and the `nrPathLoss` function to configure and calculate the propagation path loss between a base station (BS) and user equipment (UE), as defined in TR 38.901 Section 7.4.1.

- The `nrPathLossConfig` object configures rural macrocell (RMa), urban macrocell (UMa), urban microcell (UMi), indoor hotspot (InH), or indoor factory (InF) scenarios.
- The `nrPathLoss` function calculates the path loss between a BS and UE in line-of-sight (LOS) or non-LOS at a carrier frequency.

The “Include Path Loss in NR Link-Level Simulations” example shows how to analyze the performance impact of path loss, transmit power, and receive noise in 5G NR link-level simulations.

## TDL and CDL channel model updates

- The `nrTDLChannel System` object™ now supports simplified channel profiles. Configure the tapped delay line (TDL) delay profiles from TS 38.101-4 Annexes B.2.1.1, B.2.1.2 and TS 38.104 Annexes G.2.1.1, G.2.1.2 by specifying 'TDLA30', 'TDLB100', 'TDLC300', or 'TDLC60' for the `DelayProfile` property of the object.
- You can now disable channel filtering in the `nrTDLChannel System` object. Generate channel path gains without filtering a waveform by setting the `ChannelFiltering` property of the object to `false`. The `NumTimeSamples` and `OutputDataType` properties specify the duration and output data type of the path gains when you disable channel filtering.
- The `nrCDLChannel System` object now enables you to specify the output data type of the generated path gains by using the `OutputDataType` object property when you disable channel filtering.

## TDD reciprocity-based PDSCH MU-MIMO using SRS

The “TDD Reciprocity-Based PDSCH MU-MIMO Using SRS” example shows how to exploit channel reciprocity in a TDD scenario to calculate physical downlink shared channel (PDSCH) beamforming weights for multiuser multiple-input multiple-output (MU-MIMO).

## Modeling downlink control information formats

The “NR Downlink Control Information Formats” example shows how to use MATLAB classes to represent downlink control information (DCI) formats and how to encode and decode DCI bit payloads.

## RI computation

The “5G NR Downlink CSI Reporting” example now shows how to compute the rank indicator (RI) over a TDL channel. The example also shows how to compute channel state information (CSI) parameters using type 1 multipanel codebooks.

## 5G NR waveform acquisition and analysis

The “5G NR Waveform Acquisition and Analysis” example shows how to generate a 5G NR test model (NR-TM) waveform using the **5G Waveform Generator** app and download the generated waveform to a Keysight™ vector signal generator for over-the-air transmission (requires Instrument Control Toolbox™). The example then captures the transmitted over-the-air signal using a Keysight signal analyzer and analyzes the signal in MATLAB.

## NR RF transmitter and receiver updates

The NR RF models in the “Modeling and Testing an NR RF Transmitter” and “Modeling and Testing an NR RF Receiver with LTE Interference” examples now use test models that are configured and exported from the **5G Waveform Generator** app.

## UE positioning within network of gNBs

The “NR Positioning Using PRS” example shows how to calculate the position of the user equipment (UE) within a network of gNodeBs (gNBs) using NR positioning reference signals (PRSs).

## System-level simulation updates

- Use the `nrPCAPWriter` object to write 5G NR MAC packets to PCAP or PCAPNG files by encapsulating the packets into a pseudo protocol with a link type.
- Use the `pcapReader` object to read a PCAP file and filter packets and to decode protocol packets. The object enables you to decode Ethernet and eCPRI protocol packets and to plug in custom protocol decoders.
- Use the `nrMACBSR` function to generate a regular, periodic, or padding buffer status report (BSR) control element (CE).
- The “NR Cell Performance Evaluation with MIMO” example now shows how to model a 5G NR cell with MIMO antenna configurations in the uplink direction by using the SRS. This example also shows how to import and use ray-trace results in the system-level simulation.
- The “NR Intercell Interference Modeling” example now shows how to model the effects of intracell mobility of UEs on the downlink performance of a 5G NR network with multiple cells.
- The “Plug In Custom Scheduler in System-Level Simulation” example shows how to create and integrate a custom scheduling strategy into system-level simulation framework and observe the network performance.

# R2021a

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**Version: 2.2**

**New Features**

**Bug Fixes**

**Compatibility Considerations**

## App support for NR uplink and downlink vector waveform generation

The **5G Waveform Generator** app now enables you to parameterize, visualize, and generate NR uplink and downlink vector waveforms. You can export the generated waveforms to your workspace or to a `.mat` or `.bb` file. Alternatively, you can export waveform generation parameters to a runnable MATLAB script that you can use to programmatically generate your waveform from the command line, without the app. You can also transmit the generated waveforms over the air by using signal-generator instruments. The use of the transmit feature requires the Instrument Control Toolbox product.

## Enhanced support for programmatic 5G NR UL waveform generation

The `nrWaveformGenerator` function now enables you to generate 5G NR uplink waveforms. You can now use the objects listed in this table to configure uplink waveform generation. This enhanced capability replaces the example-specific implementation in previous releases.

Object	Description
<code>nrULCarrierConfig</code>	5G uplink waveform configuration parameters
<code>nrSCSCarrierConfig</code>	Subcarrier spacing (SCS) carrier configuration parameters
<code>nrWavegenBWPConfig</code>	Bandwidth part configuration parameters for 5G waveform generation
<code>nrWavegenPUSCHConfig</code>	Physical uplink shared channel (PUSCH) configuration parameters for 5G waveform generation (including uplink control information (UCI) and Release 16 CG-UCI parameters)
<code>nrWavegenSRSConfig</code>	Sounding reference signal (SRS) configuration parameters for 5G waveform generation (including Release16 SRS for positioning parameters)

For an example of how to use these features to configure and create mixed numerology uplink waveforms containing PUSCH and SRS, see [5G NR Uplink Vector Waveform Generation](#).

## Support for PRS

Use the features listed in these tables to configure and generate positioning reference signal (PRS) symbols and resource element indices.

Function	Description
<code>nrPRS</code>	Generate PRS symbols
<code>nrPRSIndices</code>	Generate PRS resource element indices

  

Object	Description
<code>nrPRSConfig</code>	PRS configuration parameters

For an example of how to learn the effects of different PRS resource set configurations on the time-frequency structure of PRS resources, see [NR Positioning Reference Signal](#).

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## Enhanced support for PUCCH

Use the features listed in these tables to model the physical uplink control channel (PUCCH) formats 0, 1, 2, 3, and 4 and the corresponding demodulation reference signals (DM-RS). These enhancements replace the example-specific implementation in previous releases.

Function	Description
nrPUCCH	Generate PUCCH modulation symbols
nrPUCCHIndices	Generate PUCCH resource element indices
nrPUCCHDMRS	Generate PUCCH DM-RS symbols
nrPUCCHDMRSIndices	Generate PUCCH DM-RS resource element indices

Object	Description
nrPUCCH0Config	PUCCH format 0 configuration parameters
nrPUCCH1Config	PUCCH format 1 configuration parameters
nrPUCCH2Config	PUCCH format 2 configuration parameters
nrPUCCH3Config	PUCCH format 3 configuration parameters
nrPUCCH4Config	PUCCH format 4 configuration parameters

For an example of how to measure the block error rate (BLER) of uplink control information (UCI) transmitted on the PUCCH in a 5G NR link, see NR PUCCH Block Error Rate.

## Support for channel reciprocity in CDL and TDL channel models

Model a time division duplexing (TDD) operation while retaining channel reciprocity in the `nrCDLChannel` and `nrTDLChannel` channel models by using the `swapTransmitAndReceive` object function. Use the `TransmitAndReceiveSwapped` property of either objects to establish whether the channel model has its receive and transmit antennas swapped.

## Support for custom antenna elements and arrays in CDL channel model (requires Phased Array System Toolbox)

You can now specify the `TransmitAntennaArray` and `ReceiveAntennaArray` properties of the `nrCDLChannel` channel model by using Phased Array System Toolbox™ antenna array objects. These antenna array objects enable you to specify different antenna array configurations, including predefined and custom antenna elements. You can design custom antenna elements by using Phased Array System Toolbox or Antenna Toolbox™ features.

To specify custom antenna elements in 5G rectangular multipanel arrays, as defined in TR 38.901 Section 7.3, use the `phased.NRRectangularPanelArray` (Phased Array System Toolbox) object.

## PUSCH enhancements

- The `nrPUSCH`, `nrPUSCHDecode`, and `nrPUSCHIndices` functions now enable you to handle the phase tracking reference signal (PT-RS) within the processing of the physical uplink shared channel (PUSCH).

- The `nrPUSCHDecode` function now enables you to handle the UCI placeholder bit locations.

## Release 16 updates to low-PAPR sequence generation

The `nrLowPAPRS` function now supports type 2 low peak-to-average power ratio (low-PAPR) sequence generation, as defined in Release 16 of TS 38.211 Section 5.2.3.

## Release 16 updates to SRS generation

- The `nrSRS`, `nrSRSIndices`, and `nrSRSConfig` features now support SRS for positioning, as defined in Release 16 of TS 38.211 Section 6.4.1.4.
- Use the `SubcarrierOffsetTable` read-only property of the `nrSRSConfig` object to determine the SRS subcarrier offset for each OFDM symbol and to obtain valid combinations of the number of OFDM symbols and the transmission comb number.
- The range of the `SymbolStart` property of the `nrSRSConfig` object now starts from 0 instead of 6. You can transmit the SRS in any symbol of a slot.

## TDD reciprocity-based PDSCH beamforming using SRS

The TDD Reciprocity-Based PDSCH Beamforming Using SRS example shows how to exploit channel reciprocity to calculate the physical downlink shared channel (PDSCH) beamforming weights in a TDD scenario. The beamforming weights calculation uses a channel estimate based on uplink SRS. Using these beamforming weights, the example uses the same channel for a downlink PDSCH transmission.

## 5G NR downlink carrier aggregation, demodulation, and analysis

The 5G NR Downlink Carrier Aggregation, Demodulation, and Analysis example shows how to generate, aggregate, and demodulate multiple 5G NR downlink carriers. To perform carrier aggregation (CA), calculate the frequency offsets for the intraband contiguous CA case, as described in TS 38.104 Section 5.3A. The example also supports customized intraband noncontiguous and interband CA scenarios.

## EVM measurement of PUSCH FRC

Measure the standard-defined error vector magnitude (EVM) of physical uplink shared channel (PUSCH) fixed reference channel (FRC) waveforms. For more information, see the EVM Measurement of 5G NR PUSCH Waveforms example.

## CDL channel model customization with ray tracing

The CDL Channel Model Customization with Ray Tracing example shows how to customize the CDL channel model parameters by using the output of a ray tracing analysis.

The example shows how to:

- Specify the location of a transmitter and a receiver in a 3-D environment
- Use ray tracing to calculate these geometric aspects of the channel: number of rays, angles, delays, and attenuations



- 
- Configure the CDL channel model with the result of ray tracing analysis
  - Specify the channel antenna arrays using Phased Array System Toolbox features
  - Visualize the transmit and receive array radiation patterns based on singular value decomposition of a perfect channel estimate

## Compute 5G NR CQI and PMI

Compute downlink channel state information (CSI) parameters, such as the channel quality indicator (CQI) and precoding matrix indicator (PMI) for MIMO scenarios with type-1 single panel codebooks over a tapped delay line (TDL) channel. For more information, see the 5G NR Downlink CSI Reporting example.

## System-level simulation updates

### Video conference application traffic pattern generation

Use the `networkTrafficVideoConference` object to generate a video conference application traffic pattern and model real-world data traffic in system-level simulations.

### 5G NR cell performance evaluation with configurable DM-RS parameters

You can now simulate and evaluate 5G NR cell performance by configuring DM-RS parameters. For more information, see the NR TDD Symbol Based Scheduling Performance Evaluation example.

### 5G NR cell performance evaluation with MIMO

Model a 5G NR cell with multiple-input multiple-output (MIMO) antenna configurations in downlink direction. You can customize the scheduling strategy to leverage the MIMO capabilities and evaluate the network performance. For more information, see NR Cell Performance Evaluation with MIMO.

### 5G NR cluster performance evaluation with toroidal wrap-around

The NR Interference Modeling with Toroidal Wrap-Around example shows how to evaluate the performance of a 19-cell cluster with toroidal wrap-around to remove edge effects.

## Functionality being removed or changed

### Subcarrier offset range in SS burst configuration has changed

*Behavior change*

The range of the `KSSB` property of the `nrWavegenSSBurstConfig` object for frequency range 1 (FR1) now depends on the value of the `SubcarrierSpacingCommon` property of that object.

- If `SubcarrierSpacingCommon` is 15, specify `KSSB` as an integer from 0 to 11.
- If `SubcarrierSpacingCommon` is 30, specify `KSSB` as an integer from 0 to 23.

### Orientation field of antenna array properties in `nrCDLChannel` will be removed

*Warns*

- The `Orientation` field of the `TransmitAntennaArray` property of the `nrCDLChannel` System object will be removed in a future release. Use the `TransmitArrayOrientation` property of that object instead.

- The `Orientation` field of the `ReceiveAntennaArray` property of the `nrCDLChannel` System object will be removed in a future release. Use the `ReceiveArrayOrientation` property of that object instead.

# R2020b

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**Version: 2.1**

**New Features**

**Bug Fixes**

**Compatibility Considerations**

## Enhanced support for 5G NR DL waveform generation

You can now use the features listed in these tables to generate 5G NR downlink (DL) waveforms. These features replace the example-specific implementation in previous releases.

Function	Description
nrWaveformGenerator	Generate 5G NR downlink waveform

Object	Description
nrDLCarrierConfig	5G downlink waveform configuration parameters
nrSCSCarrierConfig	Subcarrier spacing (SCS) carrier configuration parameters
nrWavegenBWPConfig	Bandwidth part configuration parameters for 5G waveform generation
nrWavegenCSIRSConfig	Channel state information reference signal (CSI-RS) configuration parameters for 5G waveform generation
nrWavegenPDCCHConfig	Physical downlink control channel (PDCCH) configuration parameters for 5G waveform generation
nrWavegenPDSCHConfig	Physical downlink shared channel (PDSCH) configuration parameters for 5G waveform generation
nrWavegenSSBurstConfig	Synchronization signal (SS) burst configuration parameters for 5G waveform generation

### Additional enhancements used in 5G waveform generation

- The nrCORESETConfig object now provides a property to set a mnemonic description for the specified control resource set (CORESET) configuration.
- The nrSearchSpaceConfig object now provides properties to set a mnemonic description and ID for the specified search space set configuration.

## Enhanced support for OFDM modulation and demodulation

You can now use the functions listed in this table to perform OFDM modulation and demodulation. These functions replace the example-specific implementations in previous releases.

Function	Description
nrOFDMModulate	Generate OFDM modulated waveform
nrOFDMDemodulate	Demodulate OFDM waveform
nrOFDMInfo	Get OFDM information
nrResourceGrid	Generate empty carrier slot resource grid
nrPRACHOFDMModulate	Generate physical random access channel (PRACH) OFDM modulated waveform
nrPRACHOFDMInfo	Get PRACH OFDM information

You can now use the nrCarrierConfig object as an input argument in the nrChannelEstimate, nrPerfectChannelEstimate, and nrTimingEstimate functions to specify OFDM-related

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parameters. In addition, `nrPerfectChannelEstimate` and `nrTimingEstimate` accept OFDM-related name-value pair arguments.

## Enhanced support for UL-SCH data and control multiplexing

You can now use the functions listed in this table to perform uplink shared channel (UL-SCH) data and control multiplexing and demultiplexing. These functions replace the example-specific implementation in previous releases. For an example of how to configure and perform data and control multiplexing to form a codeword on the physical uplink shared channel (PUSCH), see NR UCI Multiplexing on PUSCH.

Function	Description
<code>nrULSCHMultiplex</code>	Perform UL-SCH data and control multiplexing
<code>nrULSCHDemultiplex</code>	Perform UL-SCH data and control demultiplexing

### Additional enhancements

- The `nrULSCHInfo` function now provides the bit capacity and symbol capacity information of data and uplink control information (UCI).
- The `nrPUSCHConfig` object now contains properties to specify the parameters required to calculate the bit and symbol capacities of each UCI type when performing UCI multiplexing and demultiplexing.
- The `nrPUSCHDescramble` function now enables you to handle the UCI placeholder bit locations.

## Support for CDL channel characteristics visualization

Visualize channel characteristics of the clustered delay line (CDL) channel model by using the `displayChannel` object function of the `nrCDLChannel` System object. The function displays geometric and electromagnetic characteristics of the CDL channel model at the transmitter and receiver ends. The visualization includes the position, polarization, and directivity radiation pattern of the antenna elements, cluster paths directions, and average path gains.

## Enhanced support for TBS calculation

You can now use the `nrTBS` function to determine the transport block size (TBS) that is associated with each codeword in the shared channel transmission. This function replaces the example-specific implementation in previous releases.

## PDCCH enhancements

If the higher-layer parameter `pdcc-DMRS-ScramblingID` is not configured, you can now also set the `DMRSScramblingID` property of the `nrPDCCHConfig` object to `[]`. The object then automatically sets the PDCCH DM-RS scrambling identity to the physical layer cell identity specified by the `NCellID` property of the carrier.

## PRACH enhancements

- The `nrPRACHGrid` function now enables you to specify the output data type of the generated PRACH grid.

- The `nrPRACHConfig` object now provides read-only properties `SubframesPerPRACHSlot` and `PRACHSlotsPeriod` to determine the total number of subframes spanned by a nominal PRACH slot and the number of PRACH slots in a period.

## Perform NR cell search and MIB and SIB1 recovery

Synchronize, demodulate, and decode a live gNodeB signal and decode the master information block (MIB) and the first system information block (SIB1). For more information, see NR Cell Search and MIB and SIB1 Recovery.

## Perform subband PDSCH precoding

The NR PDSCH Throughput example now includes optional subband precoding of the PDSCH. When you enable subband precoding, the example selects a different beamforming matrix for each subband, which can increase performance for large bandwidths in frequency-selective channels.

## Measure standard-defined EVM

Measure standard-defined error vector magnitude (EVM) of NR test model (NR-TM) or fixed reference channel (FRC) waveforms. For more information, see EVM Measurement of 5G NR PDSCH Waveforms.

## Model phase noise and CPE compensation

Model the impact of phase noise in a 5G OFDM system and use the phase tracking reference signal (PT-RS) in compensating the common phase error (CPE). Measure the error vector magnitude (EVM) and bit error rate (BER) with and without CPE compensation. For more information, see NR Phase Noise Modeling and Compensation.

## Employ beam sweeping and beam refinement procedures

Employ beam sweeping at both the transmitter (gNB) and receiver (UE) ends of a 5G NR system by using synchronization signal blocks (SSB) for beam management procedures during initial access. For more information, see NR SSB Beam Sweeping.

Perform beam refinement procedure at the downlink transmitter end of a 5G NR system by using CSI-RS. You can transmit multiple CSI-RS resources in different directions in a scattering environment and select the optimal transmit beam based on reference signal received power (RSRP) measurements. For more information, see NR Downlink Transmit-End Beam Refinement Using CSI-RS.

## System-level simulation updates

### Write MAC packets to PCAP file

Use the objects listed in this table to write generated and recovered 5G NR MAC packets to a file.

Object	Description
<code>pcapWriter</code>	PCAP file writer of protocol packets

Object	Description
pcapngWriter	PCAPNG file writer of protocol packets

### Generate application traffic patterns

Use the objects listed in this table to generate application traffic patterns in 5G system-level simulations to accurately model real-world data traffic.

Object	Description
networkTrafficFTP	File transfer protocol (FTP) application traffic pattern generator
networkTrafficOnOff	On-Off application traffic pattern generator
networkTrafficVoIP	Voice over Internet protocol (VoIP) application traffic pattern generator

For an example of how to generate an FTP application traffic pattern based on the IEEE 802.11ax-Evaluation-Methodology and 3GPP TR 36.814 specification, see Generate and Visualize FTP Application Traffic Pattern.

### Evaluate performance of 5G NR cell with MAC, physical layer, and channel modeling

Evaluate the performance of a 5G New Radio (NR) cell by modeling a gNB and multiple UE devices. You can simulate gNB and UE devices with application, radio link control (RLC), medium access control (MAC), and physical layers of the protocol stack along with channel model. For more information, see NR Cell Performance Evaluation with Physical Layer Integration.

### Model 5G NR intercell interference

Evaluate the performance of 5G NR network with multiple cells by modeling the effect of intercell interference in downlink. For more information, see NR Intercell Interference Modeling.

## Functionality being removed or changed

### DM-RS reference point updates for CORESET ID 0

*Behavior change*

The reference point for the DM-RS sequence-to-subcarrier resource mapping for CORESET ID 0 is now the lowest physical resource block of the CORESET instead of the common resource block 0 (CRB0). This update affects the PDCCH and PDCCH DM-RS resources for CORESET ID 0 that you generate with the `nrPDCCHSpace` and `nrPDCCHResources` functions. For all other CORESET ID values, the reference point remains CRB0.

### Updates to upper limit of UE identifier in PDCCH encoding

*Behavior change*

For the `nrPDCCH`, `nrPDCCHDecode`, and `nrPDCCHPRBS` functions, the upper limit of UE identifier `nrnti` is now 65,519 instead of 65,535.





# R2020a

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**Version: 2.0**

**New Features**

**Bug Fixes**

**Compatibility Considerations**

## App support for NR-TM, NR uplink FRC, and NR downlink FRC waveform generation

Use the **5G Waveform Generator** app to generate NR test models (NR-TM) and NR uplink and downlink fixed reference channel (FRC) waveforms.

### Support for PRACH

Use these functions and this object to model the physical random access channel (PRACH).

Function	Description
nrPRACH	Generate PRACH symbols
nrPRACHIndices	Generate PRACH resource element indices
nrPRACHGrid	Generate PRACH resource grid

  

Object	Description
nrPRACHConfig	PRACH configuration parameters

For more information on PRACH time resources, preambles, configurations, and how to map PRACH symbols to the resource grid, see 5G NR PRACH Configuration.

You can configure and generate time-domain waveform for a single PRACH configuration in a single carrier. For an example, see 5G NR PRACH Waveform Generation.

You can measure the probability of correct detection of the PRACH preamble in the presence of a preamble signal. For an example, see 5G NR PRACH Detection Test.

## Enhanced support for DM-RS and PT-RS

### DM-RS and PT-RS for PUSCH

You can now use these functions and objects to model demodulation reference signals (DM-RS) and phase-tracking reference signals (PT-RS) for the physical uplink shared channel (PUSCH). These enhancements replace the example-specific implementations in previous releases.

Function	Description
nrPUSCHDMRS	Generate PUSCH DM-RS symbols
nrPUSCHDMRSIndices	Generate PUSCH DM-RS indices
nrPUSCHPTRS	Generate PUSCH PT-RS symbols
nrPUSCHPTRSIndices	Generate PUSCH PT-RS indices

  

Object	Description
nrPUSCHDMRSConfig	PUSCH DM-RS configuration parameters
nrPUSCHPTRSConfig	PUSCH PT-RS configuration parameters

For more information on how to configure and generate the PUSCH reference signals, see NR PUSCH Resource Allocation and DM-RS and PT-RS Reference Signals.

## DM-RS and PT-RS for PDSCH

You can now use these functions and objects to model DM-RS and PT-RS for the physical downlink shared channel (PDSCH). These enhancements replace the example-specific implementations in previous releases.

Function	Description
nrPDSCHDMRS	Generate PDSCH DM-RS symbols
nrPDSCHDMRSIndices	Generate PDSCH DM-RS indices
nrPDSCHPTRS	Generate PDSCH PT-RS symbols
nrPDSCHPTRSIndices	Generate PDSCH PT-RS indices

  

Object	Description
nrPDSCHDMRSConfig	PDSCH DM-RS configuration parameters
nrPDSCHPTRSConfig	PDSCH PT-RS configuration parameters

For more information on how to configure and generate the PDSCH reference signals, see NR PDSCH Resource Allocation and DM-RS and PT-RS Reference Signals.

## Enhanced support for PDSCH indices and PDSCH configuration

You can now use this function and these objects to configure and generate PDSCH resource element indices. These enhancements replace the example-specific implementation in previous releases.

Function	Description
nrPDSCHIndices	Generate PDSCH resource element indices

  

Object	Description
nrPDSCHConfig	PDSCH configuration parameters
nrPDSCHReservedConfig	PDSCH reserved physical resource block (PRB) configuration parameters

The nrPDSCH and nrPDSCHDecode functions now enable you to specify carrier and PDSCH configuration parameters by using the nrCarrierConfig and nrPDSCHConfig objects, respectively.

## Enhanced support for PUSCH indices and PUSCH configuration

You can now use this function and object to configure and generate physical uplink shared channel (PUSCH) resource element indices. These enhancements replace the example-specific implementation in previous releases.

Function	Description
nrPUSCHIndices	Generate PUSCH resource element indices

  

Object	Description
nrPUSCHConfig	PUSCH configuration parameters

The `nrPUSCH` and `nrPUSCHDecode` functions now enable you to specify carrier and PUSCH configuration parameters by using the `nrCarrierConfig` and `nrPUSCHConfig` objects, respectively.

## Enhanced support for PDCCH resources, CORESET, and search spaces

You can now use these functions to generate physical downlink control channel (PDCCH) resources and PDCCH DM-RS resources. These enhancements replace the example-specific implementation in previous releases.

Function	Description
<code>nrPDCCHResources</code>	Generate PDCCH and PDCCH DM-RS resources
<code>nrPDCCHSpace</code>	Generate PDCCH resources for all candidates and aggregation levels

You can now use these objects to configure the control resource element set (CORESET), the PDCCH, and the search space set. These enhancements replace the example-specific implementation in previous releases.

Object	Description
<code>nrCORESETConfig</code>	CORESET configuration parameters
<code>nrPDCCHConfig</code>	PDCCH configuration parameters
<code>nrSearchSpaceConfig</code>	Search space set configuration parameters

For more information on how to configure the CORESET, the PDCCH, and the search space set, see [Downlink Control Processing and Procedures](#).

## Enhanced support for SRS

You can now use these functions and this object to model the sounding reference signal (SRS). These enhancements replace the example-specific implementation in previous releases.

Function	Description
<code>nrSRS</code>	Generate uplink SRS symbols
<code>nrSRSIndices</code>	Generate uplink SRS resource element indices

  

Object	Description
<code>nrSRSConfig</code>	SRS configuration parameters

For more information on how to configure and generate the SRS for uplink transmission, see [NR SRS Configuration](#).

You can use the SRS for synchronization, channel estimation, and uplink channel state information (CSI) estimation. For an example, see [NR Uplink Channel State Information Estimation Using SRS](#).

## Specify RNTI for polar and DCI decoding

The `nrPolarDecode` and `nrDCIDeCode` functions now enable you to specify the radio network temporary identifier (RNTI) used for masking the CRC parity bits at the transmit end.

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## **Uplink FRC generation**

Generate standard-compliant 5G NR uplink fixed reference channels (FRCs) for frequency range 1 (FR1) and frequency range 2 (FR2). For more information, see 5G NR-TM and FRC Waveform Generation.

## **Characterize the impact of RF impairments in NR transmitter and receiver**

Characterize the impact of radio frequency (RF) impairments, such as in-phase and quadrature (IQ) imbalance, phase noise, and power amplifier (PA) nonlinearities in the performance of a NR RF transmitter. For more information, see Modeling and Testing an NR RF Transmitter.

Characterize the impact of RF impairments in the RF reception of an NR waveform when coexisting with a long-term evolution (LTE) interference. For more information, see Modeling and Testing an NR RF Receiver with LTE Interference.

## **Measure EVM of NR-TM**

Measure the error vector magnitude (EVM) of NR test models (NR-TM) with phase noise and memoryless nonlinearity impairments. For an example, see EVM Measurement of 5G NR-TM Waveforms.

## **Measure CSI-RSRP, CSI-RSSI, CSI-RSRQ and report CQI using CSI-RS**

Measure the channel state information (CSI) reference signal received power (CSI-RSRP), the CSI received signal strength indicator (CSI-RSSI), and the CSI reference signal received quality (CSI-RSRQ). For an example, see 5G NR CSI-RS Measurements.

Calculate and compare CQI values using CSI-RS with practical and perfect channel estimation. For an example, see 5G NR CQI Reporting.

## **System-level simulation updates**

### **Schedule 5G NR PUSCH and PDSCH resources for TDD mode with symbol based scheduling**

Schedule PUSCH and PDSCH resources in time division duplexing (TDD) mode with radio link control (RLC) layer functionality in unacknowledged mode (UM). You can use slot or symbol based scheduling, choose from various MAC scheduling strategies, and evaluate the scheduling performance. For more information, see NR TDD Symbol Based Scheduling Performance Evaluation.

### **Schedule 5G NR PUSCH and PDSCH resources for FDD mode**

Schedule PUSCH and PDSCH resources in frequency division duplexing (FDD) mode with RLC UM and MAC logical channel prioritization (LCP) procedure. You can choose from various MAC scheduling strategies and evaluate the scheduling performance. For more information, see NR FDD Scheduling Performance Evaluation.

### **Use RLC and LCP for 5G NR PUSCH FDD scheduling**

PUSCH scheduling in frequency division duplexing (FDD) mode now includes radio link control (RLC) layer functionality in UM and MAC LCP procedure. For more information, see NR PUSCH FDD Scheduling.

### **Generate data for deep learning data synthesis**

Train a convolutional neural network (CNN) for 5G channel estimation using Deep Learning Toolbox™ and data generated with 5G Toolbox. For an example, see Deep Learning Data Synthesis for 5G Channel Estimation.

### **Functionality being removed or changed**

#### **Polar decoding metric update**

*Behavior change*

In releases R2019b and before, the function `nrPolarDecode` uses the exact form of the expression  $\log(1 + e^x)$  for the internal metric evaluation of polar decoding. Because the exact form leads to numerical instability for high SNR ranges, polar decoding now uses an approximation. The function `nrPolarDecode` approximates  $\log(1 + e^x)$  as 0 for  $x < 0$  and as  $x$  for  $x \geq 0$ .

Polar decoding is a common component in the broadcast channel, downlink control information, and uplink control information decoding. Therefore, the polar metric approximation affects the results of the `nrBCHDecode`, `nrDCIDeCode`, and `nrUCIDeCode` functions, resulting in a marginal degradation of the BLER performance in a link-level simulation.

# R2019b

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**Version: 1.2**

**New Features**

**Bug Fixes**

## Receiver Design and Synchronization: Perform practical timing and channel estimation

When processing received signals, use these functions to perform practical timing or channel estimation.

Functions	Description
<code>nrTimingEstimate</code>	Practical timing estimation
<code>nrChannelEstimate</code>	Practical channel estimation

The NR PDSCH Throughput and NR PUSCH Throughput examples now include practical timing and channel estimation in addition to perfect timing and channel estimation.

## LDPC decoder enhancements and support for layered belief propagation and min-sum approximation

Low-density parity-check (LDPC) decoding now uses multicore processing. Additional LDPC decoding algorithms, such as layered belief propagation, normalized min-sum approximation, and offset min-sum approximation, are also available. These enhancements apply to these decoders: `nrLDPCDecode` function, `nrDLSCHDecoder` System object, and `nrULSCHDecoder` System object.

## Support for CSI-RS

Use these functions and objects to model standard-compliant channel state information reference signals (CSI-RS).

Functions	Description
<code>nrCSIRS</code>	Generate CSI-RS symbols
<code>nrCSIRSIndices</code>	Generate CSI-RS resource element indices

  

Objects	Description
<code>nrCSIRSConfig</code>	CSI-RS configuration parameters
<code>nrCarrierConfig</code>	Carrier configuration parameters

## 5G NR-TM waveform generation

Generate standard-compliant 5G NR test models (NR-TMs) for frequency range 1 (FR1) and frequency range 2 (FR2). For NR-TM waveform generation, you can specify the NR-TM name, the channel bandwidth, the subcarrier spacing, and the duplexing mode. For an example, see 5G NR-TM and FRC Waveform Generation.

## NR downlink ACLR measurement

Measure the adjacent channel leakage ratio (ACLR) for 5G NR test models in FR1 and FR2. For an example, see 5G NR Downlink ACLR Measurement.



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## **System-Level Simulation: Schedule 5G NR PUSCH resources**

Schedule physical uplink shared channel (PUSCH) resources in FDD mode and evaluate scheduling performance. You can choose from various MAC scheduling strategies. For more information, see NR PUSCH FDD Scheduling.

## **Enhanced 5G NR waveform generation, including CSI-RS, SRS, and PT-RS**

Downlink waveform generation now includes CSI-RS and physical downlink shared channel (PDSCH) phase tracking reference signal (PT-RS). For more information, see 5G NR Downlink Carrier Waveform Generation.

Uplink waveform generation now includes sounding reference signal (SRS) and PUSCH PT-RS. For more information, see 5G NR Uplink Carrier Waveform Generation.



# R2019a

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**Version: 1.1**

**New Features**

**Bug Fixes**

## Support for uplink physical channels PUSCH and PUCCH

Use these functions to model the physical uplink shared channel (PUSCH) and the physical uplink control channel (PUCCH) formats 0, 1, 2, 3, and 4.

New Feature	Description
nrPUSCH	Generate PUSCH modulation symbols
nrPUSCHCodebook	Generate PUSCH precoding matrix
nrPUSCHDecode	Decode PUSCH modulation symbols
nrPUSCHDescramble	Perform PUSCH descrambling
nrPUSCHPRBS	Generate PUSCH scrambling sequence
nrPUSCHScramble	Perform PUSCH scrambling
nrPUCCH0	Generate PUCCH format 0 modulation symbols
nrPUCCH1	Generate PUCCH format 1 modulation symbols
nrPUCCH2	Generate PUCCH format 2 modulation symbols
nrPUCCH3	Generate PUCCH format 3 modulation symbols
nrPUCCH4	Generate PUCCH format 4 modulation symbols
nrPUCCHPRBS	Generate PUCCH pseudorandom scrambling sequence
nrPUCCHHoppingInfo	Get PUCCH hopping information
nrLowPAPRS	Generate low peak-to-average power ratio (low-PAPR) sequence
nrTransformPrecode	Generate transform precoded symbols
nrTransformDeprecode	Generate transform decoded symbols

For more information, see Uplink Physical Channels.

## Support for uplink shared channel (UL-SCH) and uplink control information (UCI)

### UL-SCH

These functions and System objects support UL-SCH encoding and decoding.

New Feature	Description
nrULSCH	Apply UL-SCH encoder processing chain
nrULSCHDecoder	Apply UL-SCH decoder processing chain
nrULSCHInfo	Get uplink shared channel (UL-SCH) information

For more information, see Uplink Transport Channels.

### UCI

These functions support UCI encoding and decoding, including support for polar coding and channel coding of small block lengths.

New Feature	Description
nrUCIEncode	Encode uplink control information (UCI)
nrUCIDecode	Decode uplink control information (UCI)

For more information, see Uplink Control Information.

### Parity-check support for polar coding

Polar coding functions nrPolarEncode and nrPolarDecode now support parity-check polar coding.

### Addition of new downlink shared channel (DL-SCH) System objects

Use these System objects for DL-SCH encoding and decoding. These System objects replace the example-specific DL-SCH implementations in the previous release.

New Feature	Description
nrDLSCH	Apply DL-SCH encoder processing chain
nrDLSCHDecoder	Apply DL-SCH decoder processing chain

### 5G NR uplink waveform generation

You can now generate a 5G NR uplink waveform, including physical signals and channels. You can also parameterize and generate multiple bandwidth parts (BWP), and multiple instances of the PUSCH and PUCCH channels over different BWPs. For an example, see 5G NR Uplink Carrier Waveform Generation.

### 5G NR PUSCH link-level reference simulation

You can measure the PUSCH throughput for various propagation conditions and parameter sets. For an example, see NR PUSCH Throughput.



# R2018b

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**Version: 1.0**

**New Features**

## **Introducing 5G Toolbox**

5G Toolbox provides standard-compliant functions and reference examples for the modeling, simulation, and verification of 5G communications systems. The toolbox supports link-level simulation, golden reference verification and conformance testing, and test waveform generation.

With the toolbox you can configure, simulate, measure, and analyze end-to-end communications links. You can modify or customize the toolbox functions and use them as reference models for implementing 5G systems and devices.

The toolbox provides reference examples to help you explore baseband specifications and simulate the effects of RF designs and interference sources on system performance. You can generate waveforms and customize test benches to verify that your designs, prototypes, and implementations comply with the 3GPP 5G New Radio (NR) standard.

## **Standard-compliant models for 3GPP 5G NR Release 15**

5G Toolbox provides standard-compliant functions and reference examples for the modeling, simulation, and verification of 5G communications systems. For more information, see Scope of 5G Toolbox.

## **Link-level simulation with reference examples, including 5G NR PDSCH throughput simulation**

5G Toolbox provides standard-compliant functions for end-to-end physical layer transmit and receive processing. You can measure the PDSCH throughput for various propagation conditions and parameter sets. For an example, see NR PDSCH Throughput.

## **OFDM waveform generation with NR subcarrier spacings and frame numerologies**

With 5G Toolbox, you can generate NR waveforms, including physical signals and channels. The process includes all the stages from channel coding to OFDM modulation. You can explore the effect of different subcarrier spacings and frame numerologies.

## **TR 38.901 propagation channel models, including tapped delay line (TDL) and clustered delay line (CDL)**

5G Toolbox provides TDL and CDL channel modeling capabilities. For more details, see the `nrCDLChannel` and `nrTDLChannel` System objects.

## **Downlink transport and physical channels (shared, control, broadcast); synchronization and demodulation reference signals**

5G Toolbox provides functions to model transport and physical channels, including shared, control, and broadcast channels. You can also model synchronization and demodulation reference signals. For more information, see Downlink Channels.



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## **Signal processing functions, including channel coding (LDPC and polar codes), channel estimation, synchronization, and equalization**

5G Toolbox provides low-level functions that model subcomponents in the processing chain for transport channels, physical channels, and physical signals. For more information, see Physical Layer Subcomponents. The toolbox also provides signal reception capability. Using 5G Toolbox functions, you can perform channel estimation, timing estimation, synchronization, and minimum mean-squared error (MMSE) equalization. For more information, see Signal Reception.

## **C and C++ code generation support**

All 5G Toolbox functions and System objects support ANSI®/ISO® compliant C/C++ code generation.

