5G Toolbox™ Release Notes

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The MathWorks, Inc.
1 Apple Hill Drive
Natick, MA 01760-2098

5G Toolbox™ Release Notes

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Version: 2.5

New Features

Bug Fixes

5G Waveform Generator app updates

You can now use the **5G Waveform Generator** app to:

- Initialize physical uplink shared channel (PUSCH) RA-RNTI scrambling for *msgA* on PUSCH during a two-step random access channel (RACH) procedure, as defined in Release 16 of TS 38.211 Section 6.3.1.1.
- Enable low peak-to-average-power ratio (PAPR) physical downlink shared channel (PDSCH) demodulation reference signal (DM-RS) sequences, as defined in Release 16 of TS 38.211 Section 7.4.1.1.
- Enable low PAPR PUSCH DM-RS sequences, as defined in Release 16 of TS 38.211 Section 6.4.1.1.
- Configure the frequency position of the control resource set (CORESET) by setting the RB offset.
- Configure physical downlink control channel (PDCCH) DM-RS transmission in the entire CORESET by setting the precoder granularity.
- Configure the number of subframes in an NR test model (NR-TM).
- Specify a different power level for each synchronization signal (SS) block in a burst.
- Configure an additional channel or signal in a 5G NR downlink or uplink waveform by customizing a duplicate copy of an existing channel or signal configuration.
- Open a copy of an NR-TM, downlink FRC, or uplink FRC preset definition as a 5G NR downlink or uplink waveform configuration. Use this feature to customize the standard-defined preset definitions.
- Transmit your waveforms over the air at full radio device rate. For a list of radios that support full device rates, see “Supported Radio Devices” (Wireless Testbench). This feature requires “Wireless Testbench”. For an example, see “Transmit App-Generated Wireless Waveform Using Radio Transmitters”.

TS 38.101 HST channel modeling

Use the `nrHSTChannel` System object™ to send an input signal through a high-speed train (HST) channel to obtain the channel-impaired signal. The object implements the HST single tap, HST-DPS, and HST-SFN channel profiles from TS 38.101-4 Annex B.

CDL and TDL channel model updates

The `info` function of the `nrCDLChannel` and `nrTDLChannel` System objects now also returns the maximum channel delay. This delay consists of the maximum path delay and the channel filter delay.

Support for O-RAN fronthaul CU-plane message generation

Use the `nrORANBlockCompress` and `nrORANBlockDecompress` functions to perform O-RAN fronthaul block compression and decompression. The functions implement the block floating point (BFP), block scaling, and μ-law compression and decompression methods, as defined in TS O-RAN.WG4.CUS Annex A.1, A.2, and A.3.

For an example of how to generate fronthaul control and user plane (CU-Plane) messages for O-RAN conformance tests, as defined in TS O-RAN.WG4.CONF, see “Generate CU-Plane Messages for O-RAN Fronthaul Test”.

CORESET enhancements

The `nrCORESETConfig` configuration object now enables you to specify the precoder granularity and RB offset through the `PrecoderGranularity` and `RBOffset` object properties, respectively.

SS burst configuration updates

The `Power` property of the `nrWavegenSSBurstConfig` object now enables you to specify a different power level for each SS block in a burst. You can use this feature to model the power level effect of beam sweeping on different blocks in the burst.

Enhanced support for RSRP, RSSI, and RSRQ measurements

- Use the `nrCSIRSMeasurements` function to 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), as defined in TS 38.215 Sections 5.1.2 and 5.1.4.
- Use the `nrSSBMeasurements` function to measure the synchronization signal (SS) reference signal received power (SS-RSRP), the SS received signal indicator (SS-RSSI), and the SS reference signal received quality (SS-RSRQ), as defined in TS 38.215 Sections 5.1.1 and 5.1.3.

These functions replace the example-specific implementation in previous releases.

Enhanced support for PRACH detection

- Use the `nrPRACHDetect` function to detect the physical random access channel (PRACH). This function replaces the example-specific implementation in previous releases.
- The “5G NR PRACH Detection and False Alarm Test” example now enables you to run a false alarm conformance test, as defined in TS 38.141-1.

Reference simulation to measure NR PDSCH throughput using CSI feedback

Use the “NR PDSCH Throughput Using Channel State Information Feedback” reference simulation to measure the PDSCH throughput of a 5G NR adaptive link. The simulation adjusts the modulation and coding scheme (MCS), precoding matrix, and number of layers based on the CSI feedback that the UE reports.

EVM measurement updates

- The “EVM Measurement of 5G NR Downlink Waveforms with RF Impairments” example now shows how to estimate the I/Q imbalances in a 5G NR PDSCH waveform that contains PDCCH.
- The “EVM Measurement of 5G NR PUSCH Waveforms” example now shows how to estimate the I/Q imbalances of a 5G NR PUSCH waveform.

Type II codebooks for CSI computation

The “5G NR Downlink CSI Reporting” example now supports type II codebooks for the computation of CSI parameters.

Train deep Q-network (DQN) agent for beam selection

The “Train DQN Agent for Beam Selection” example shows how to train a DQN reinforcement learning agent to increase beam selection accuracy in a 5G NR communications system by selecting the beam with the highest signal strength while reducing beam transition cost.

Compress CSI feedback with autoencoder neural network

The “CSI Feedback with Autoencoders” example shows how to use an autoencoder neural network to compress CSI feedback in a 5G NR communications system. This approach eliminates the use of a quantized codebook and can improve overall system performance.

Simulate 5G LDPC BLER using the cloud or a cluster

The “5G LDPC Block Error Rate Simulation Using the Cloud or a Cluster” example shows how to use the cloud or a cluster for block error rate (BLER) simulation of low-density parity-check (LDPC) coding for the 5G NR downlink shared transport channel (DL-SCH).

System-level simulation updates

Use the `nrMACPDUDecode` function to decode the medium access control (MAC) protocol data units (PDUs).

R2022a

5G Waveform Generator app updates

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

- OFDMA channel noise generator (OCNG) for downlink FRC waveform generation, as defined in Release 16 of TS 38.101 Annex A.5.
- Resource grid visualization of conflicts across channels and signals.
- Instant resource grid and channel view plot updates during configuration of NR-TM and NR uplink and downlink FRC waveforms.
- Resource element (RE) mapping visualization. Use the RE mapping plot to visualize reference signal allocation within the resource block that contains the selected channel. You can visualize demodulation reference signal (DM-RS), phase tracking reference signal (PT-RS), channel state information reference signal (CSI-RS), and sounding reference signal (SRS) resources.
- NR waveform transmission over the air by using a software-defined radio (SDR) hardware. To transmit a waveform on one of the supported SDRs (ADALM-Pluto, USRP™, USRP embedded series, and Xilinx® Zynq-based radios), you must install the associated add-on. For more information, see Transmit Using SDR.

Enhanced support for TR 38.901 channel model

- The `nrPathLossConfig` and `nrPathLoss` features now support the indoor factory with high Tx and high Rx (InF-HH) scenario, as defined in TR 38.901 Table 7.2-4.
- The `nrCDLChannel` System object now enables you to model the fast fading channel, as defined in TR 38.901 Section 7.5, using the `XPR`, `RayCoupling`, and `InitialPhases` object properties.

Release 16 updates to PUSCH scrambling

These features now support physical uplink shared channel (PUSCH) RA-RNTI scrambling initialization for *msgA* on PUSCH during a two-step random access channel (RACH) procedure, as defined in Release 16 of TS 38.211 Section 6.3.1.1.

- `nrPUSCHConfig` and `nrWavegenPUSCHConfig` objects through the `NRAPID` object property
- `nrPUSCH` and `nrPUSCHDecode` functions through the `NRAPID` object property of the `pusch` input argument
- `nrPUSCHScramble`, `nrPUSCHDescramble`, and `nrPUSCHPRBS` functions through the optional `nrapid` input argument

Release 16 updates to PDSCH DM-RS and PUSCH DM-RS

PDSCH DM-RS

- Use the `DMRSDownlinkR16` property of the `nrPDSCHDMRSConfig` object to enable low peak-to-average-power ratio (PAPR) physical downlink shared channel (PDSCH) DM-RS sequences, as defined in Release 16 of TS 38.211 Section 7.4.1.1.
- The `NIDNSCID` property of the `nrPDSCHDMRSConfig` object now supports dynamic ID selection.
- PDSCH DM-RS symbol generation now supports type B mapping DM-RS symbol positions, as defined in Release 16 of TS 38.211 Tables 7.4.1.1.2-3 and 7.4.1.1.2-4.

PUSCH DM-RS

- Use the DMRSUplinkR16 and DMRSUplinkTransformPrecodingR16 properties of the nrPUSCHDMRSConfig object to enable low PAPR PUSCH DM-RS sequences, as defined in Release 16 of TS 38.211 Section 6.4.1.1.
- The NIDNSCID property of the nrPUSCHDMRSConfig object now supports dynamic ID selection.

Enhancements to PDCCH support

The nrPDCCHConfig and nrWavegenPDCCHConfig objects now enable you to position the physical downlink control channel (PDCCH) in the associated control resource set (CORESET) by using the CCEOffset property of the objects.

Enhanced computational performance in end-to-end simulations

Internal optimizations of the nrRateMatchLDPC, nrRateRecoverLDPC, nrEqualizeMMSE, and nrExtractResources functions now enable faster end-to-end simulations. The achievable speedup depends on the configuration parameters of the simulation. For example, running the simulation in the NR PDSCH Throughput example with 1000 subframes is on average 30% faster in comparison to previous releases.

Dynamic spectrum sharing for 5G NR and LTE coexistence

The Dynamic Spectrum Sharing for 5G NR and LTE Coexistence example shows how to generate coexisting LTE and 5G NR waveforms for dynamic spectrum sharing.

Model RF impairments in MATLAB

The EVM Measurement of 5G NR Downlink Waveforms with RF Impairments example shows how to model and analyze RF impairments in MATLAB®, including phase noise, in-phase and quadrature (I/Q) imbalance, filter effects, and memoryless nonlinearity.

EVM measurement enhancements

The EVM Measurement of 5G NR Downlink Waveforms with RF Impairments example shows how to:

- Measure the error vector magnitude (EVM) of the PDCCH in addition to the PDSCH.
- Estimate and correct for carrier frequency offsets.

The EVM Measurement of 5G NR PUSCH Waveforms example now shows how to estimate and correct the carrier frequency offset of 5G NR PUSCH waveforms.

Neural network for beam selection deep learning example

The Neural Network for Beam Selection example shows how to use a neural network to reduce the overhead in the beam selection task by using only the location of the receiver rather than the knowledge of the communication channels.

System-level simulation updates

- Use the `nrMACSubPDU` function to generate a medium access control (MAC) subprotocol data unit (subPDU) for uplink or downlink direction.
- Use the `nrMACBSRDecode` function to decode the buffer status report (BSR) control element (CE) and receive logical channel group (LCG) IDs and the buffer size range.
- The NR Cell Performance Evaluation with Beam Management example shows how to beamform the downlink data based on the layer-1 reference signal received power (L1-RSRP) feedback from the user equipment (UE).

Functionality being removed or changed

SR bit output value in PUCCH format 0 decoding has changed

Behavior change

For physical uplink control channel (PUCCH) format 0, the `nrPUCCHDecode` function now returns `0` instead of `[]` for the scheduling request (SR) bit value when the detection metric is below the discontinuous transmission (DTX) detection threshold.

Detection threshold in PUCCH format 1 decoding has changed

Behavior change

For PUCCH format 1, the `nrPUCCHDecode` function now uses 0.22 instead of 0.36 as the default DTX detection threshold.

nrWavegenCSIRSConfig object enables CSI-RS by default

Behavior change

The `Enable` property of the `nrWavegenCSIRSConfig` object now defaults to `1` instead of `0`. As a result, the `nrWavegenCSIRSConfig` object now enables CSI-RS by default. To preserve the behavior of the `nrDLCarrierConfig` object from previous releases, in which CSI-RS is disabled by default, the `CSIRS` property of the `nrDLCarrierConfig` object now defaults to `{nrWavegenCSIRSConfig('Enable',0)}` instead of `{nrWavegenCSIRSConfig}`.

R2021b

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
`nrWavegenPUCCH0Config`	PUCCH format 0 configuration parameters for 5G waveform generation
`nrWavegenPUCCH1Config`	PUCCH format 1 configuration parameters for 5G waveform generation
`nrWavegenPUCCH2Config`	PUCCH format 2 configuration parameters for 5G waveform generation
`nrWavegenPUCCH3Config`	PUCCH format 3 configuration parameters for 5G waveform generation
`nrWavegenPUCCH4Config`	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.

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

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
`nrULCarrierConfig`	5G uplink waveform configuration parameters
`nrSCSCarrierConfig`	Subcarrier spacing (SCS) carrier configuration parameters
`nrWavegenBWPConfig`	Bandwidth part configuration parameters for 5G waveform generation
`nrWavegenPUSCHConfig`	Physical uplink shared channel (PUSCH) configuration parameters for 5G waveform generation (including uplink control information (UCI) and Release 16 CG-UCI parameters)
`nrWavegenSRSConfig`	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
`nrPRS`	Generate PRS symbols
`nrPRSIndices`	Generate PRS resource element indices

Object	Description
`nrPRSConfig`	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.

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

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 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
`nrULSCHMultiplex`	Perform UL-SCH data and control multiplexing
`nrULSCHDemultiplex`	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 *pdcch-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
pcapWriter	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

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
nrPDCCHResources	Generate PDCCH and PDCCH DM-RS resources
nrPDCCHSpace	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
nrCORESETConfig	CORESET configuration parameters
nrPDCCHConfig	PDCCH configuration parameters
nrSearchSpaceConfig	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
nrSRS	Generate uplink SRS symbols
nrSRSIndices	Generate uplink SRS resource element indices

Object	Description
nrSRSConfig	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.

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

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
`nrTimingEstimate`	Practical timing estimation
`nrChannelEstimate`	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
`nrCSIRS`	Generate CSI-RS symbols
`nrCSIRSIndices`	Generate CSI-RS resource element indices

Objects	Description
`nrCSIRSConfig`	CSI-RS configuration parameters
`nrCarrierConfig`	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.

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

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 deprecoded 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

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.

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.