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Technische Grundlagen des neuen 5G-Funkstandards

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Introduction to 5G PHY

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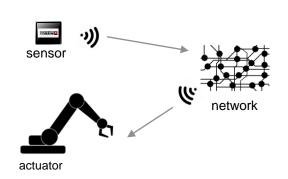


- 5G requirements and use cases
- Key 5G physical layer features
- Physical layer simulation with 5G Toolbox

5G Use Cases and Requirements

- eMBB (enhanced Mobile Broadband)
 - High data rates
 - Increased bandwidth efficiency
- mMTC (massive Machine Type Communications)
 - Large number of connections
 - Energy efficiency and low-power operation
- URLLC (Ultra-Reliable and Low Latency Communications)
- Low latency MATLAB EXPO 2019











5G vs LTE: Main Physical Layer Differences

	LTE	5G
Use cases	Mobile broadband access (MTC later)	More use cases: eMBB, mMTC, URLLC
Latency	~10 ms	<1 ms
Band	Below 6 GHz	Up to 60 GHz
Bandwidth	Up to 20 MHz	Up to 100 MHz below 6 GHz Up to 400 MHz above 6 GHz
Subcarrier spacing	Fixed	Variable
Freq allocation	UEs need to decode the whole BW	Use of bandwidth parts
"Always on" signals	Used: Cell specific RS, PSS,SSS, PBCH	Avoid always on signals, the only one is the SS block



5G Physical Layer Features

Transport Channels, Physical Channels, and Physical Signals	Uplink Control
5G Waveforms, Frame Structure and Numerology	DMRS
Downlink Data	Synchronization Signal Block
Uplink Data	Initial Acquisition Procedures: Cell Search & RACH
Downlink Control	Signals for Channel Sounding
CORESETs	Hybrid Beamforming

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To learn about all topics, visit online videos: <u>URL</u>



5G Transport Channels, Physical Channels, and Physical Signals





Transport Channels

- Offer information transport services to MAC layer
- Carry control/signalling and data
- Define the scrambling, channel coding, interleaving and rate matching to apply to the information

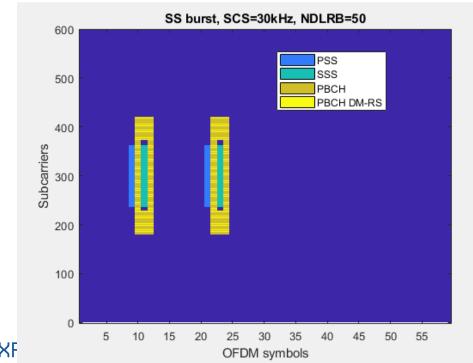
DL Transport Channels	UL Transport Channels
DL-SCH	UL-SCH
DL shared channel	UL shared channel
DCI	UCI
Downlink control information	Uplink control information
BCH	RACH
Broadcast channel	Random access channel
PCH Paging channel MATLAB EXPO 2019	

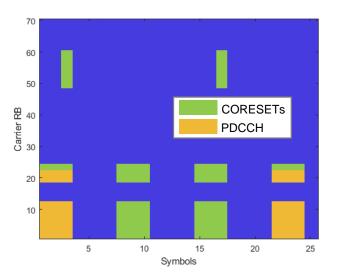


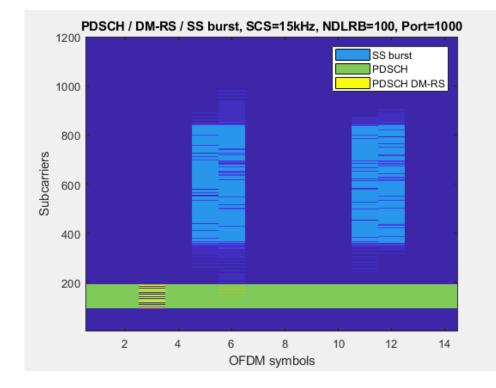
Physical layer channels and signals

- Shared, control and broadcast channels
 - Downlink: DL-SCH / PDSCH, PDCCH, BCH / PBCH
 - Uplink: UL-SCH, PUSCH, PUCCH
- Synchronisation and reference signals

- PSS, SSS, DM-RS







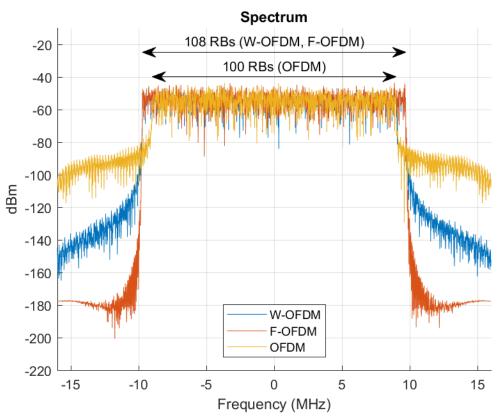
5G Waveforms, Frame Structure and Numerology

- Waveforms
- Resource elements and blocks
- Frame structure
- Variable subcarrier spacing
- Bandwidth parts



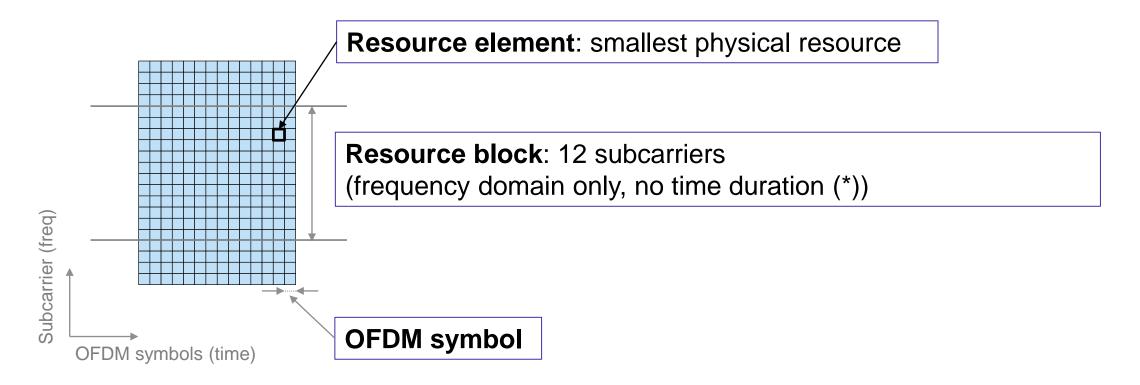
Waveforms

- OFDM with cyclic prefix: CP-OFDM
- Increased spectral efficiency with respect to LTE, i.e. no 90% bandwidth occupancy limitation
- Need to control spectral leakage:
 - F-OFDM
 - Windowing
 - WOLA





Resource Elements and Resource Blocks

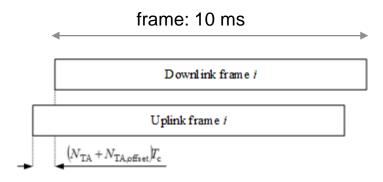


(*) unlike LTE: 1 RB = 12-by-7



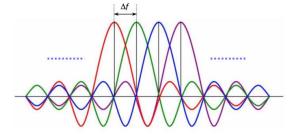
Frame Structure

- 10ms frames
- 10 subframes per frame
- Variable number of slots per subframe
- 14 OFDM symbols per slot (normal CP)
- Variable number of OFDM symbols per subframe (different from LTE)





Variable Subcarrier Spacing



	Slot configuration 0				
Subcarrier spacing (kHz)	15	30	60	120	240
Symbol duration (no CP) (µs)	66.7	33.3	16.6	8.33	4.17
Nominal max BW (MHz)	49.5	99	198	396	397.4
Min scheduling interval (ms)	1	0.5	0.25	0.125	0.0625

- Subcarrier spacing can be a power-of-two multiple of 15kHz
- Waveforms can contain a **mix of subcarrier spacings**
- Addresses the following issues
 - Support different services (eMBB, mMTC, URLLC) and to meet short latency requirements
 - Increased subcarrier spacing can also help operation in mmWave frequencies

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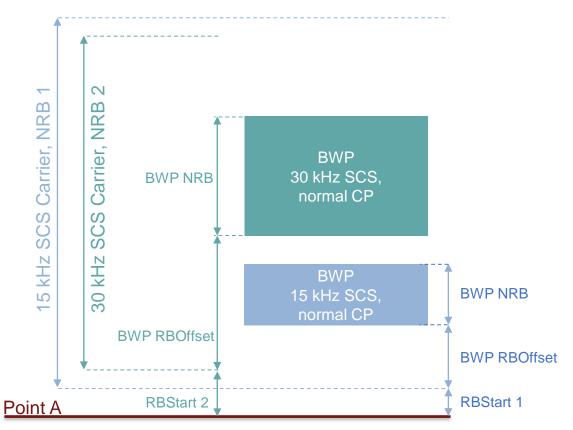
Slots and OFDM Symbols (Normal CP)

	Subcarrier spacing (kHz) Symbols/slot		Slots/frame	Slots/subframe
	15	14	10	1
	30	14	20	2
	60	14		4
	120	14	80	8
	240	14	160	16
	subframe			
	4	slot: 1 ms		
15 kHz				
	slot: 0.5 ms			
30 kHz				
	slot: 0.25 ms			
60 kHz MATLAB				



Bandwidth Parts (BWP)

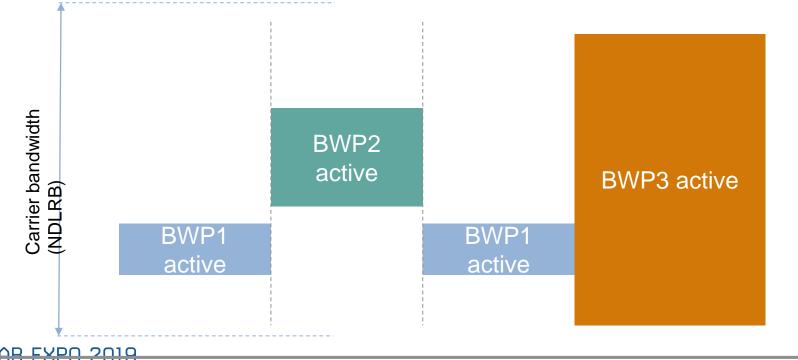
- Carrier bandwidth divided into BWPs
- A BWP is characterized by
 - Subcarrier spacing
 - Cyclic prefix
- Addresses the following issues:
 - Some devices may not be able to receive the full BW
 - Bandwidth adaptation: reduce energy consumption when only narrow bandwidth is required





Bandwidth Parts (BWP)

- A UE can be configured with up to 4 bandwidth parts
- Only one bandwidth part is active at a time
- UE is not expected to receive data outside of active bandwidth part





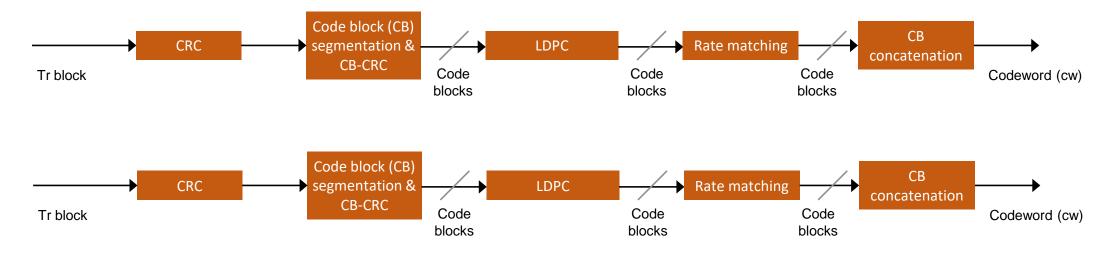
Downlink Data in 5G NR





Downlink Shared Channel (DL-SCH)

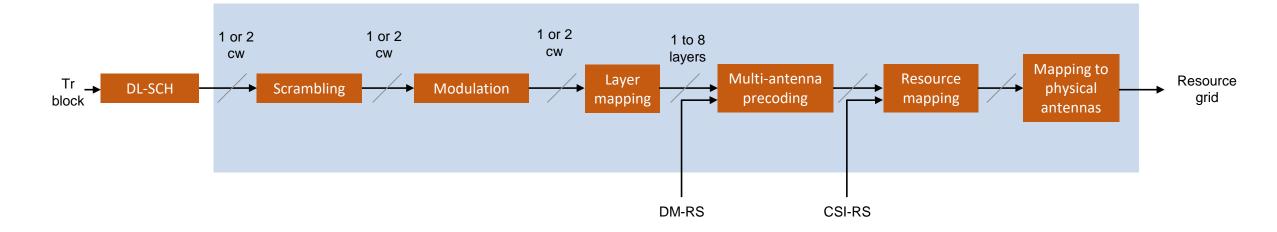
- Carries user data
- Can also carry the System Information Block (SIB)
- Up to 2 codewords and 8 layers
- Mapped to the PDSCH
- Main difference with LTE: use of LDPC coding





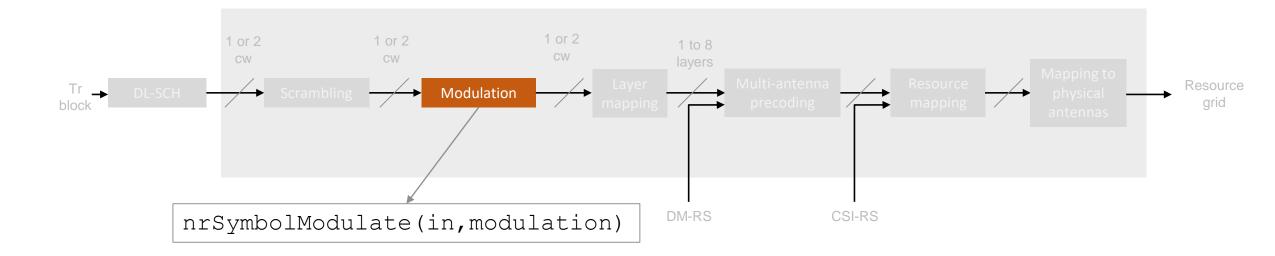
Physical Downlink Shared Channel (PDSCH)

- Highly configurable
- Parameters are configured by:
 - DCI (Downlink Control Information)
 - RRC (Radio Resource Control)





PDSCH Modulation Schemes

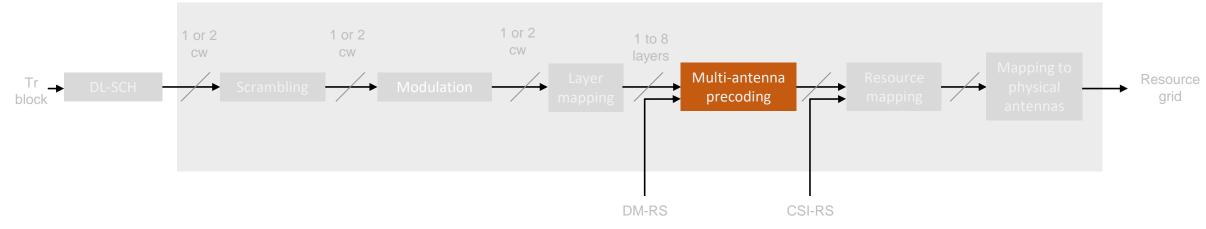


Modulation scheme	Modulation order
QPSK	2
16QAM	4
64QAM	6
256QAM	8

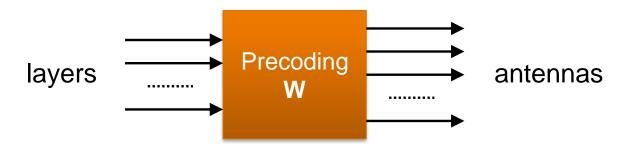
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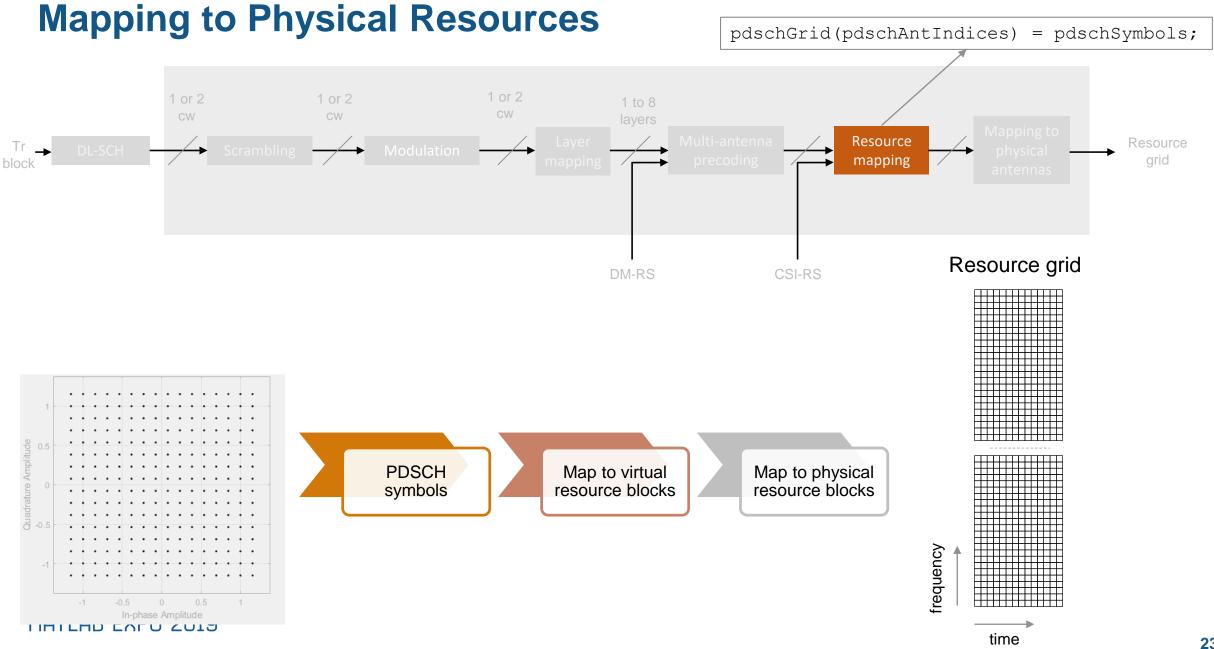
PDSCH Multi-antenna Precoding



- Achieves beamforming and spatial multiplexing
- Maps layers to antenna port
- Uses a precoding matrix W_{Nantennas x Nlayers}
- DM-RS has to go through the same precoding operation

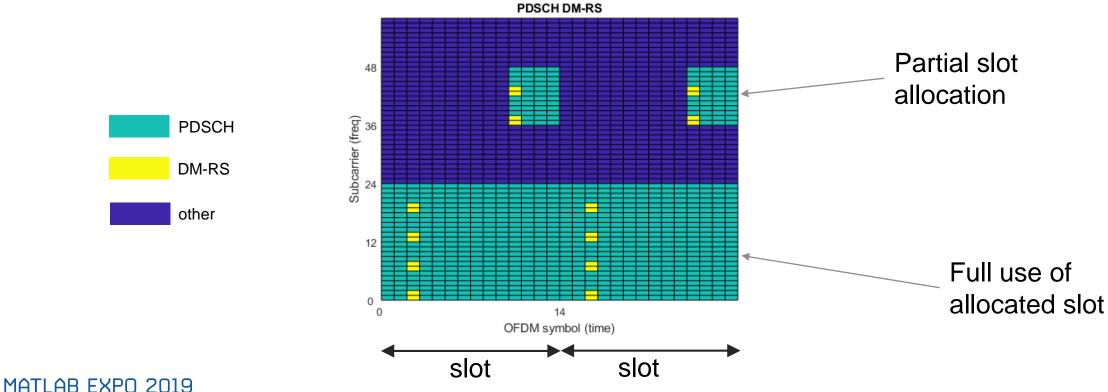






PDSCH Allocation Example

- Can use a full slot or part of a slot
- Partial slot allocation: good for low latency applications



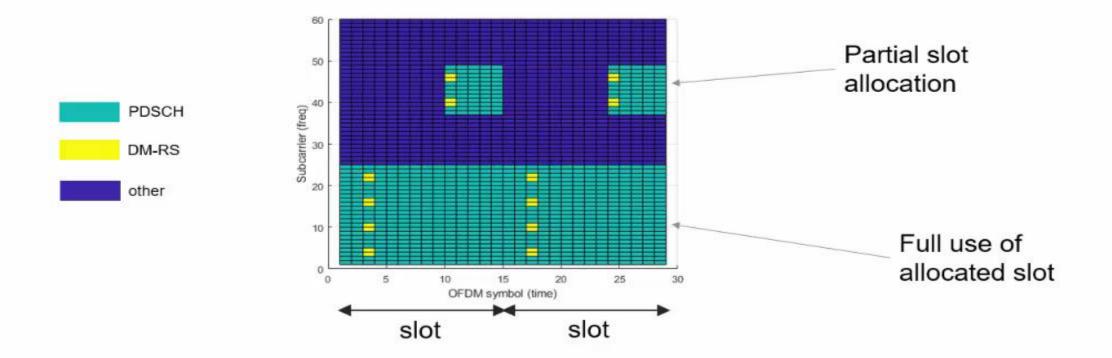


Demonstration

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PDSCH Allocation Example

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Introducing 5G Toolbox

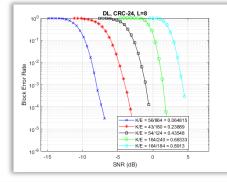


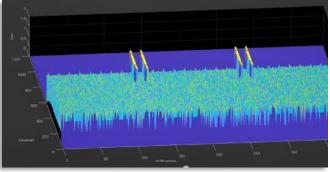






5G Toolbox applications & use-cases







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End-to-end link-level simulation

- Transmitter, channel model, and receiver
- Analyze bit error rate (BER), and throughput

Waveform generation and analysis

 Parameterizable waveforms with New Radio (NR) subcarrier spacings and frame numerologies

Golden reference design verification

 Customizable and editable algorithms as golden reference for implementation



5G Toolbox – PHY Layer Functions

NR Processing Subsystems

- LPDC & polar coding
- CRC, segmentation, rate matching
- Scrambling, modulation, precoding

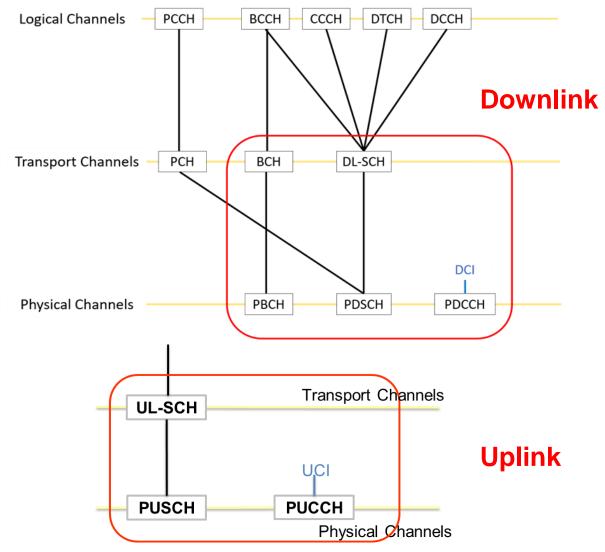
NR Downlink and Uplink Channels and Physical Signals

- Synch & broadcast signals
- DL-SCH & PDSCH channels
- DCI & PDCCH channels
- UCI, PUSCH, and PUCCH channels

MIMO Prop channels

TDL & CDL channel models

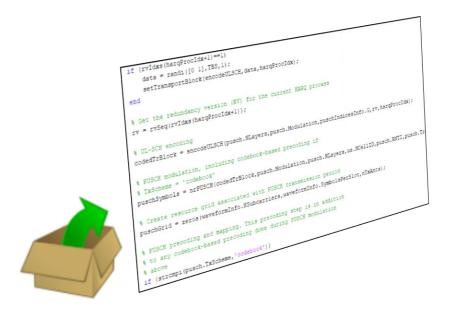


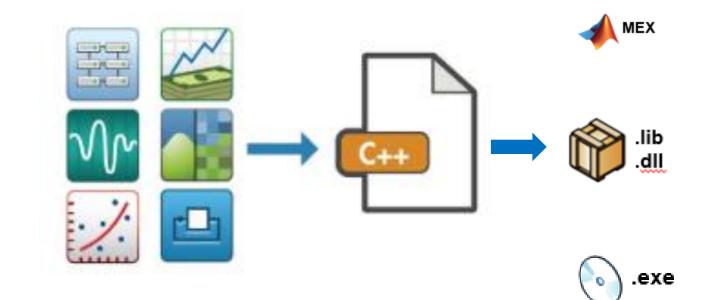




5G Toolbox has open customizable algorithms

 All functions are open, editable, customizable MATLAB code C/C++ code generation:
 Supported with MATLAB Coder





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Key Reference Application Examples

- NR Synchronization Procedures
- Downlink:
 - NR PDSCH BLER and Throughput Simulation
 - NR Downlink Waveform Generation Carrier Configuration

5G NR Uplink Carrier Waveform Generation

This example implements a 5G NR uplink carrier waveform generator using 5G Toolbox(TM). Copyright 2018 The MathWorks, Inc.

Introduction

This example shows how to parameterize and generate a 5G New Radio (NR) uplink waveform. The following channels and signals are generated;

* PUSCH and its associated DM-RS

* PUCCH and its associated DM-RS

This example supports the parameterization and generation of multiple bandwidth parts (BWP). Multiple instances of the PUSCH and PUCCH channels can be generated over the different BWPs.

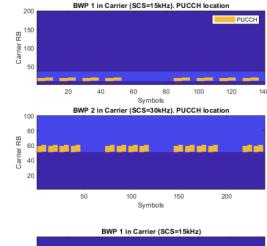
This section sets the overall carrier bandwidth in resource blocks, the cell ID, and the length of the generated waveform in subframes. You can visualize the generated resource grids by setting the [DisplayGrids] field to 1.

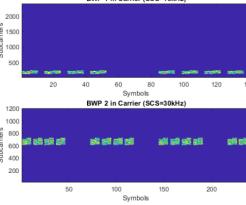
```
carrier = [];
carrier.NULRB = 200; % Carrier width in 15kHz numerology
carrier.NCellID = 0; % Cell identity
carrier.NumSubframes = 10; % Number of 1ms subframes in generated waveform (1,2,4,8 slots per 1m
carrier.DisplayGrids = 1; % Display the resource grids after signal generation
```

Bandwidth Parts

A BWP is formed by a set of contiguous resources sharing a numerology on a given carrier. This example supports the use of multiple BWPs using a struct array. Each entry in the array represents a BWP. Each BWP can have different subcarrier spacings (SCS), use different cyclic prefix (CP) lengths and span different bandwidths. The [RBOffset] parameter controls the location of the BWP in the carrier. This is expressed in terms of the BWP numerology. Different BWPs can overlap with each other.

% Bandwidth parts configurations bwp = [];	
<pre>bwp(1).SubcarrierSpacing = 15;</pre>	% BWP Subcarrier Spacing
bwp(1).CyclicPrefix = 'Normal';	% BWP Cyclic prefix for 15 kHz
bwp(1).NRB = 25;	% Size of BWP
bwp(1).RBOffset = 10;	% Position of BWP in carrier





- Uplink:
 - NR PUSCH BLER and Throughput Simulation
 - NR Uplink Waveform Generation



How to learn more

- View the "5G PHY Overview" instructional videos <u>https://mathworks.com/videos/series/5g-explained.html</u>
- 5G Toolbox product information <u>www.mathworks.com/products/5g</u>
 - Watch the 5G Toolbox video
 - Review the 5G Toolbox documentation
- 'MATLAB for 5G' overview of product range
 - www.mathworks.com/solutions/wireless-communications/5g
- Ask MathWorks for a trial license!!!

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ik Ibox	- 1	SG Toolbox ^{+w} provides standard-compliant functions and reference examples for the modeling, simulation, and verification of SG communications systems. The toolbox supports link-level simulation, golden reference verification and conformance testing, and test waveform generation.
ing Started with 5G Too	lbox	With the toolbox you can configure, simulate, measure, and analyze end-to-end communications links. You
nlink Channels		can modify or customize the toolbox functions and use them as reference models for implementing 5G systems and devices.
sical Layer Subcompor	ients	The toolbox provides reference examples to help you explore baseband specifications and simulate the
al Reception -to-End Simulation		effects of RF designs and interference sources on system performance. You can generate waveforms and
and Measurement		customize test benches to verify that your designs, prototypes, and implementations comply with the 3GPP 5G New Radio (NR) standard.
e Generation and Depl	oyment	
ace Blockset		Getting Started
ace Toolbox		Learn the basics of 5G Toolbox
a Toolbox		Downlink Channels
System Toolbox		5G NR downlink channel processing for physical signals and channels, transport channels, and control information
ated Driving System To	olbox	
rmatics Toolbox		Physical Layer Subcomponents
unications Toolbox		Low-level subcomponents for 5G NR channel processing

5G Tool

Documentation AII E	xamples Functions Se
CONTENTS Close	
« Documentation Home	▲ 5G Toolbox
	Simulate, analyze, and test the physical layer of 5G communications systems
MATLAB	5G Toolbox™ provides standard-compliant functions and reference examples for the modeling, simulation,
Simulink 5G Toolbox	and verification of 5G communications systems. The toolbox supports link-level simulation, golden reference
	verification and conformance testing, and test waveform generation.
Getting Started with 5G Toolbox	With the toolbox you can configure, simulate, measure, and analyze end-to-end communications links. You
Downlink Channels	can modify or customize the toolbox functions and use them as reference models for implementing 5G systems and devices.
Physical Layer Subcomponents	
Signal Reception	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
End-to-End Simulation	customize test benches to verify that your designs, prototypes, and implementations comply with the 3GPP
Test and Measurement	5G New Radio (NR) standard.
Code Generation and Deployment	
Aerospace Blockset	Getting Started
Aerospace Toolbox	Learn the basics of 5G Toolbox
Antenna Toolbox	Deverile Observale
Audio System Toolbox	Downlink Channels 5G NR downlink channel processing for physical signals and channels, transport channels, and control infor
Automated Driving System Toolbox	so fire commune processing to provide signals and chambles, transport chambles, and control mon
Bioinformatics Toolbox	Physical Layer Subcomponents
	Low level subcomponents for 5G NP channel processing

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