

Q&A

Please fill the session-related questions into the Q&A sheet in your registration kit and hand over the sheet to our promoters

MATLAB EXPO 2019

5G New Radio Fundamentals: Understanding the Next Generation of Wireless Technology

Tabrez Khan
Application Engineering

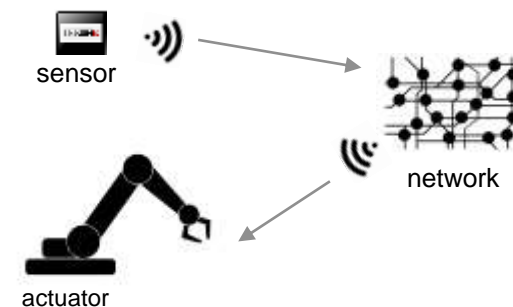


Introduction to 5G Physical Layer

- 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
- mMTC (massive Machine Type Communications)
 - Large number of connections
- URLLC (Ultra-Reliable and Low Latency Communications)
 - Low latency



5G vs LTE: Main Physical Layer Differences

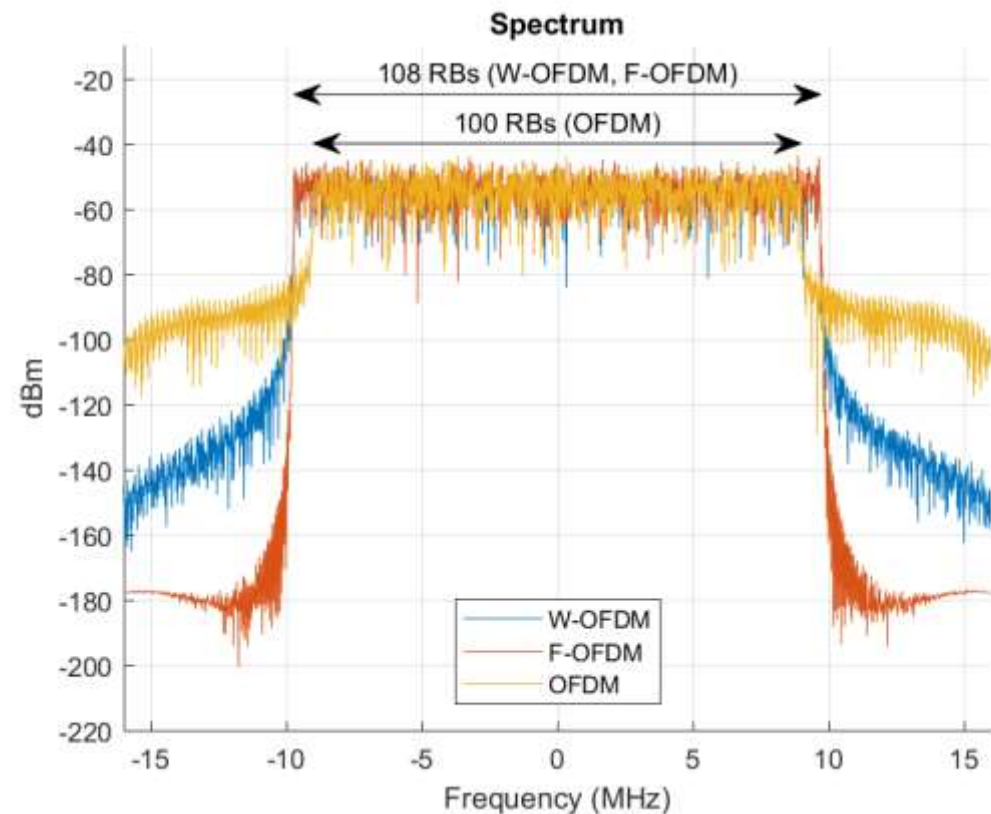
	LTE	5G
Use cases	Mobile broadband access (MTC later)	More use cases: eMBB, mMTC, URLLC
Latency	~10 ms	<1 ms
Band	FR1 (< 6 GHz)	FR1 (<6 GHz), FR2 (23-53 GHz)
Bandwidth	Up to 20 MHz	Up to 100 MHz below 6 GHz Up to 400 MHz above 6 GHz
Subcarrier spacing	Fixed	Variable
Freq allocation	UEs need to decode the whole BW	Use of bandwidth parts
“Always-on” signals	Cell specific RS, PSS,SSS, PBCH	Reduced always-on signals, the only one is the SS block

5G Waveforms, Frame Structure and Numerology

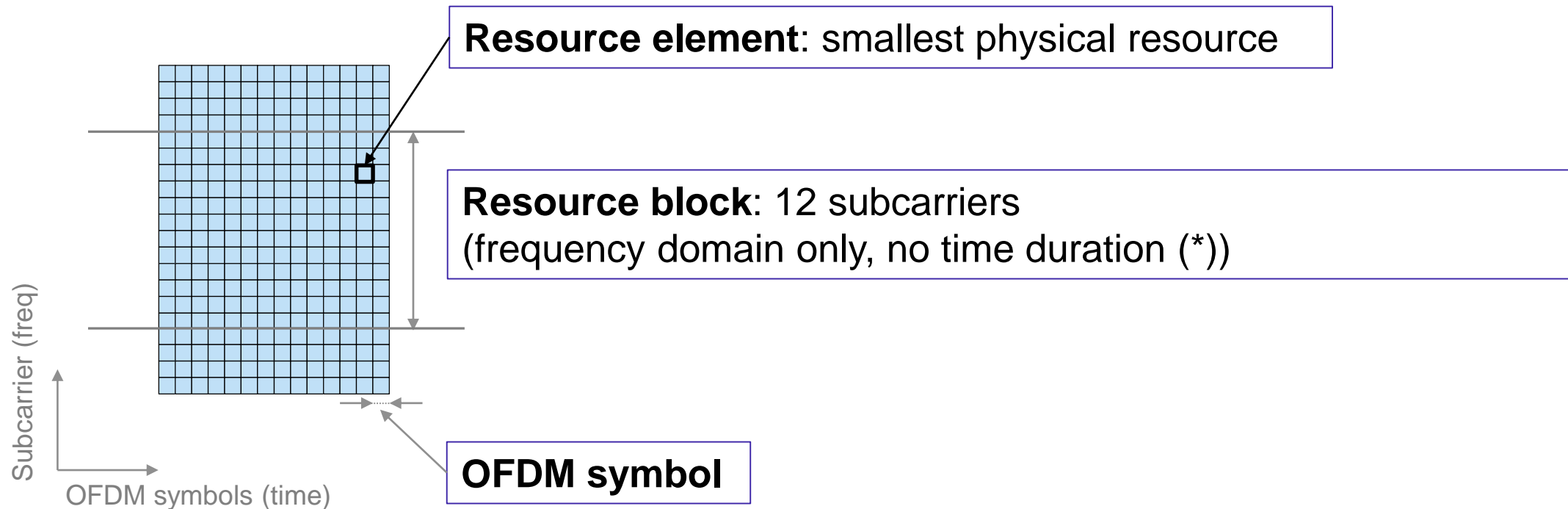
- Waveforms
- Resource elements and blocks
- Frame structure
- Variable subcarrier spacing
- Bandwidth parts

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



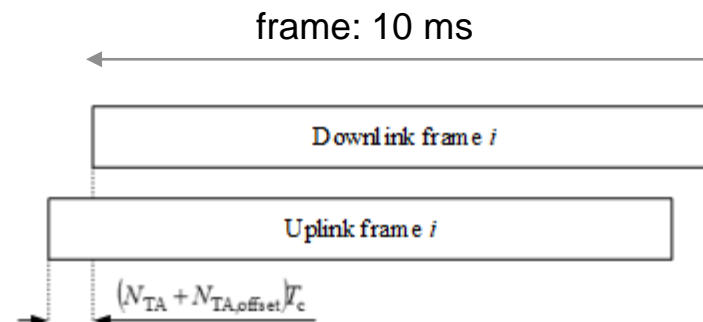
Resource Elements and Resource Blocks



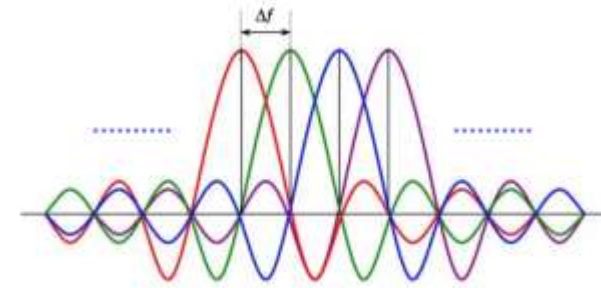
(*) unlike LTE: 1 RB = 12-by-7

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

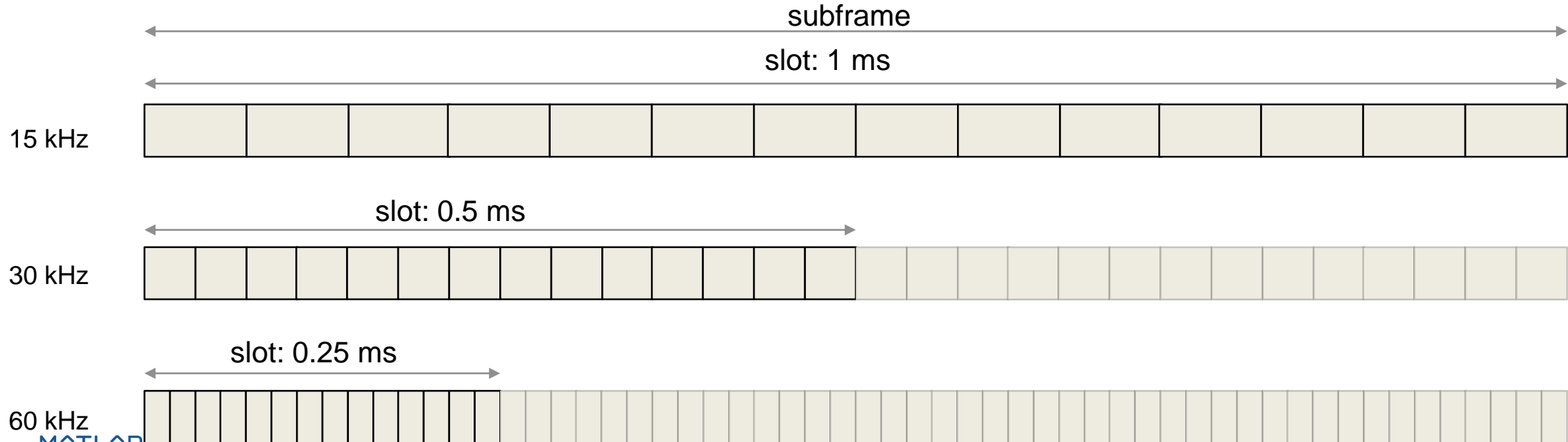


	Slot configuration 0				
Subcarrier spacing (kHz)	15	30	60	120	240
Symbol duration (no CP) (μs)	66.7	33.3	16.6	8.33	4.17
Nominal max BW (MHz)	49.5	99	198	396	397.4
Min scheduling interval (ms)	1	0.5	0.25	0.125	0.0625

- Subcarrier spacing can be a power-of-two multiple of 15kHz
- Waveforms can contain a mix of subcarrier spacings
- This flexibility is required to support different services (eMBB, mMTC, URLLC) and to meet short latency requirements
- Increased subcarrier spacing can also help operation in mmWave frequencies

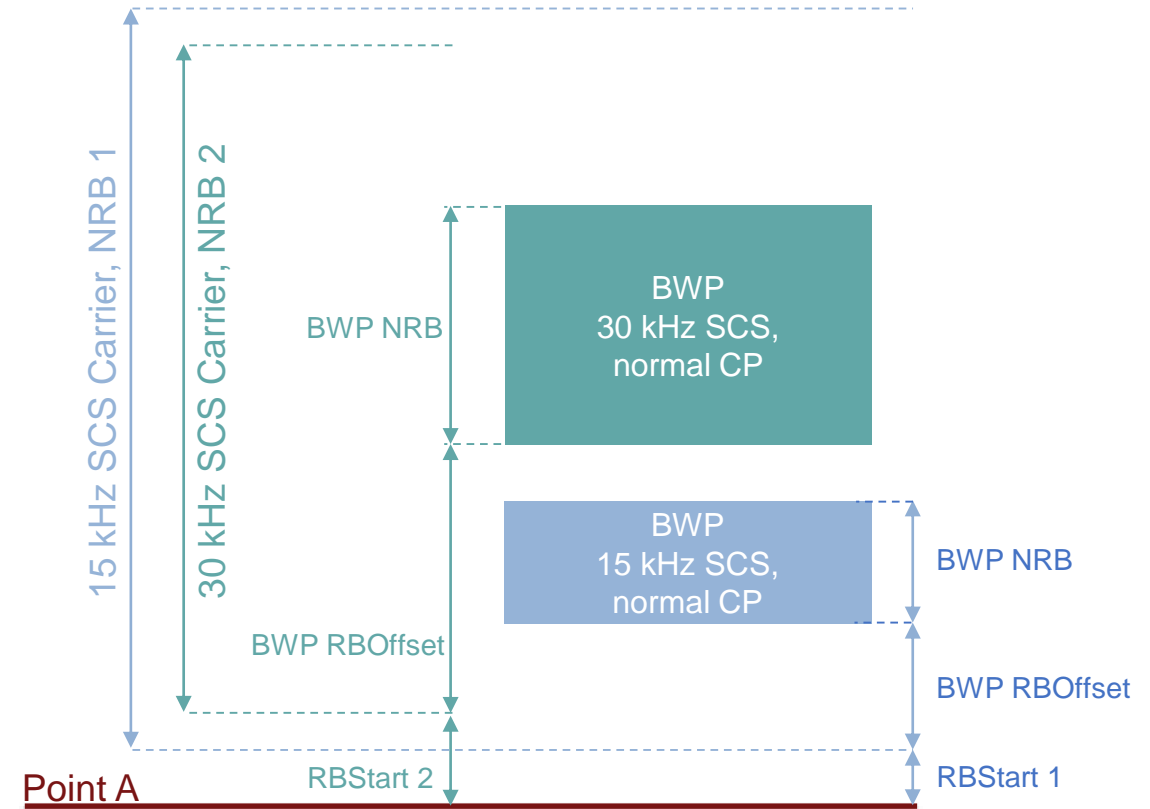
Slots and OFDM Symbols (Normal CP)

Subcarrier spacing (kHz)	Symbols/slot	Slots/frame	Slots/subframe
15	14	10	1
30	14	20	2
60	14	40	4
120	14	80	8
240	14	160	16



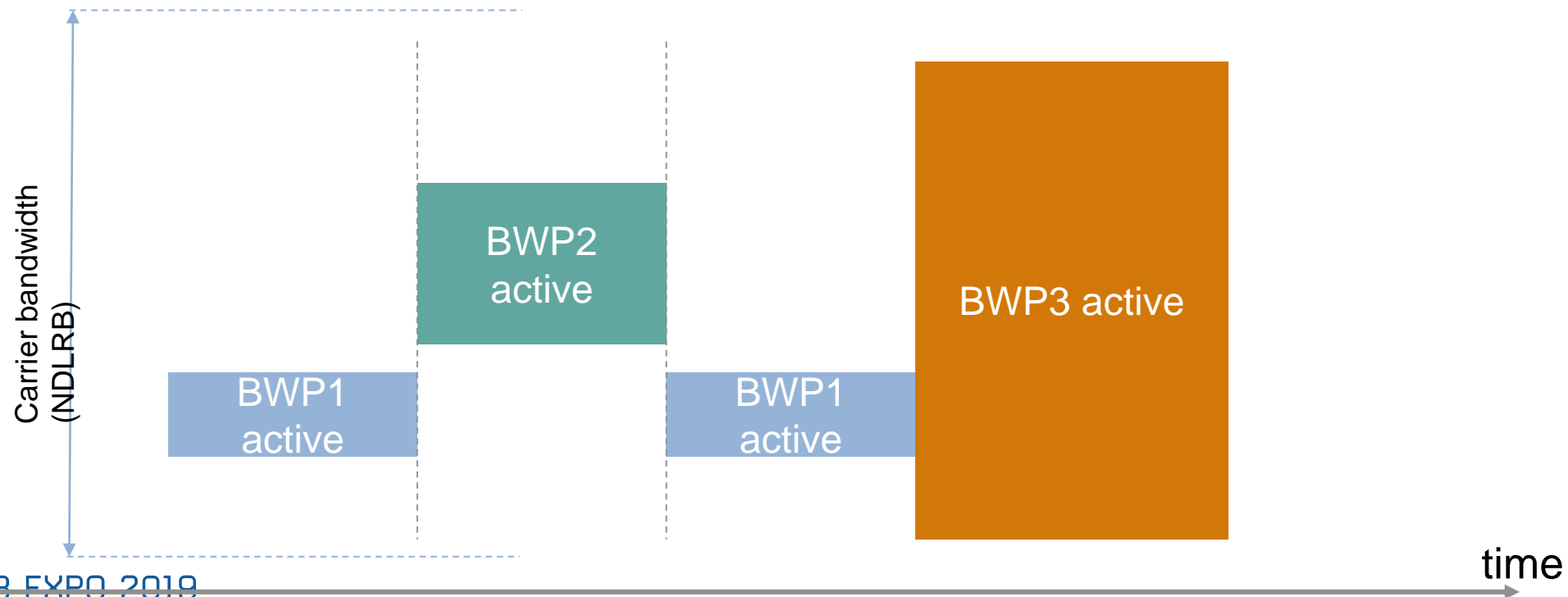
Bandwidth Parts (BWP)

- 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



5G Toolbox – PHY Layer Functions

NR Processing Subsystems

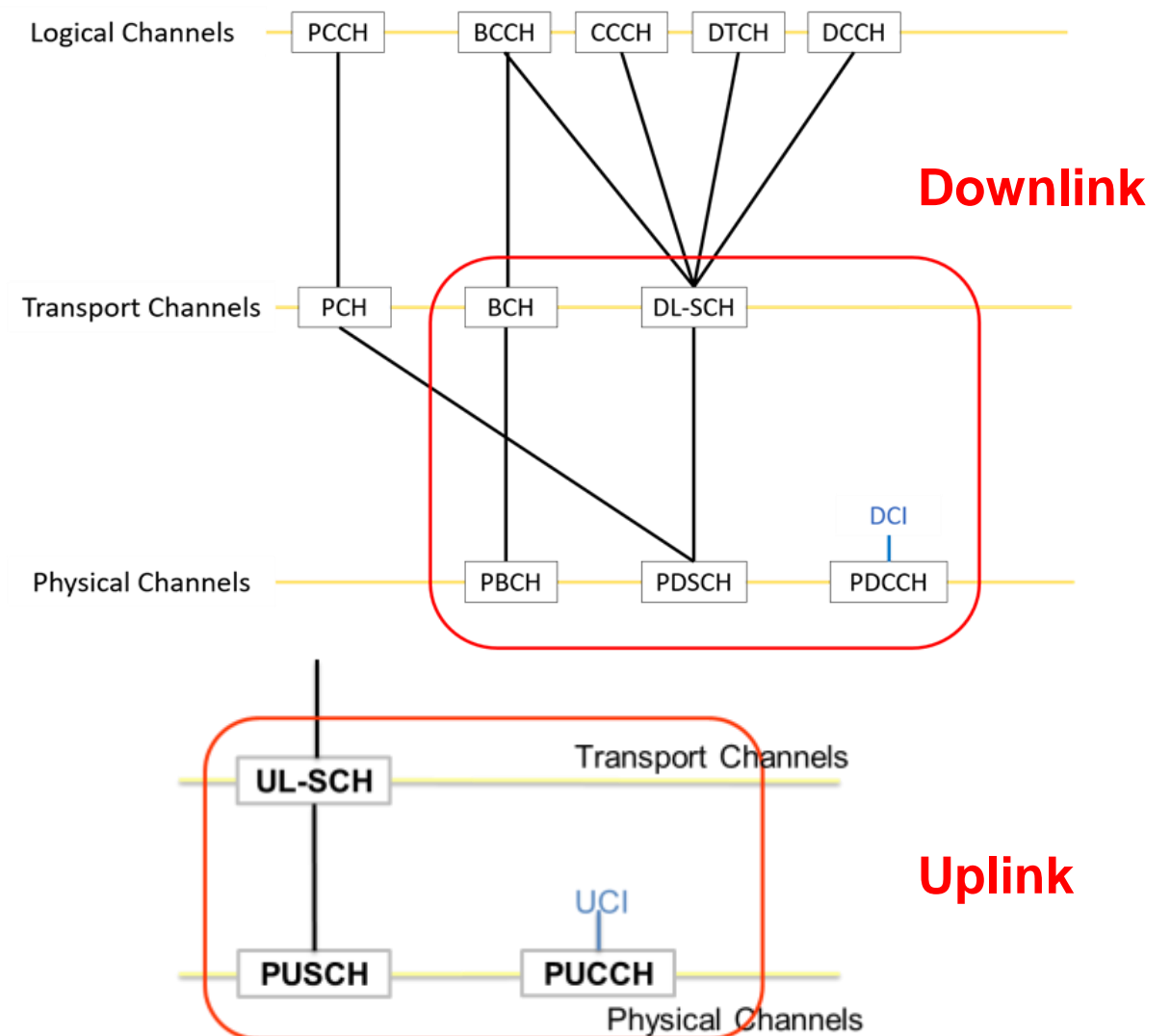
- LPDC & polar coding
- CRC, segmentation, rate matching
- Scrambling, modulation, precoding

NR Downlink and Uplink Channels and Physical Signals

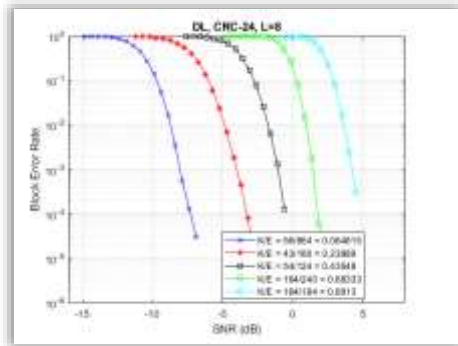
- Synchronization & broadcast signals
- DL-SCH & PDSCH channels
- DCI & PDCCH channels
- UCI, PUSCH, and PUCCH channels

MIMO Propagation channels

- TDL & CDL channel models



5G Toolbox applications & use-cases



End-to-end link-level simulation

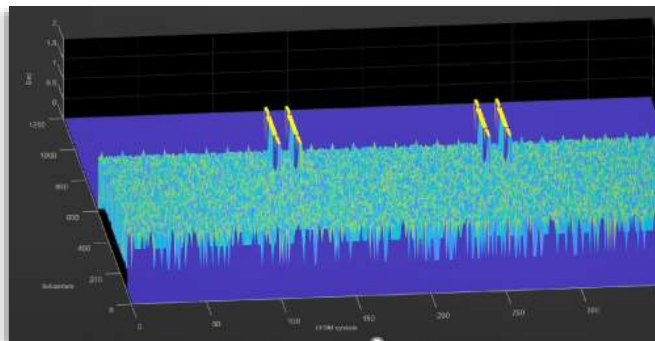
- Transmitter, channel model, and receiver
- Analyze bit error rate (BER), and throughput

Waveform generation and analysis

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

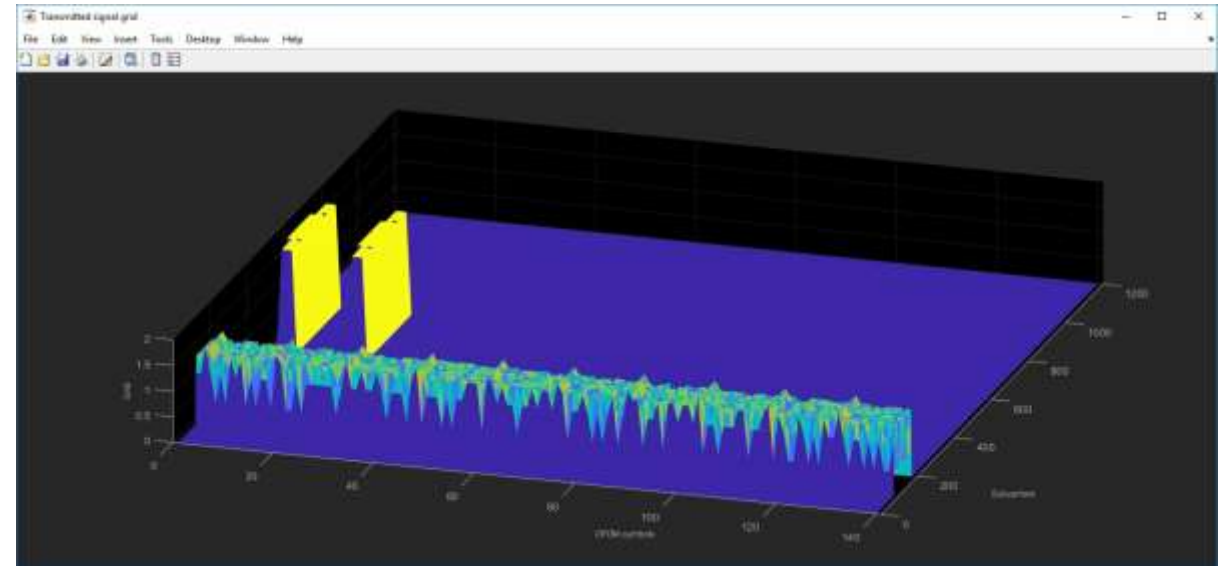
Golden reference design verification

- Customizable and editable algorithms as golden reference for implementation



5G waveform generation

- 5G Toolbox supports downlink & uplink waveform generation
- Generated waveforms feature:
 - mixed numerology
 - multiple bandwidth parts
 - multiple PDSCHs / PUSCHs
 - multiple PDCCHs / PUCCHs
 - fully parameterizable SS bursts
 - multiple CORESETS and search spaces



Power levels have been modified to improve visualization

5G NR Downlink Carrier Waveform Generation

The screenshot shows the MATLAB Documentation browser interface. The browser window has a single tab titled "Example List". The page header includes "Documentation" with sub-tabs for "All", "Examples", and "Functions", and a search bar labeled "Search Help".

The main content area is divided into several sections:

- Waveform Generation**: Generate an NR single carrier downlink waveform, essential downlink channels, and signals for data transmission. [Open Script](#)
- Blocks and Bursts**: Generate multiple synchronization signal blocks (SSBs) to form a synchronization signal burst (SS burst). [Open Live Script](#)
- Information**: Model DCI message encoding, PDCCH processing, and information recovery in NR communications system. [Open Script](#)
- Coding**: Highlights the new polar channel coding technique of NR communications system by modeling the CRC-aided polar (CA-). [Open Script](#)

Below these sections, there is a section for **LDPC Processing for DL-SCH** with a description: "Highlights the LDPC processing chain for the NR downlink shared transport channel." and an [Open Script](#) link.

On the left side, there is a "CONTENTS" sidebar with a "Close" button. It lists navigation options like "Documentation Home" and "Examples", and a "Category" list:

Category	Count
MATLAB	252
5G Toolbox	12
Getting Started with 5G Toolbox	5
Downlink Channels	7
Physical Layer Subcomponents	2
Signal Reception	3
End-to-End Simulation	4
Test and Measurement	1
Communications Toolbox	132
DSP System Toolbox	105
Signal Processing Toolbox	134

Key Reference Application Examples

- **NR Synchronization Procedures**

- **Downlink:**
 - NR PDSCH BLER and Throughput Simulation
 - NR Downlink Waveform Generation

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

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.

Carrier Configuration

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.

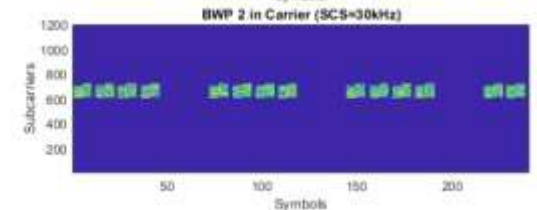
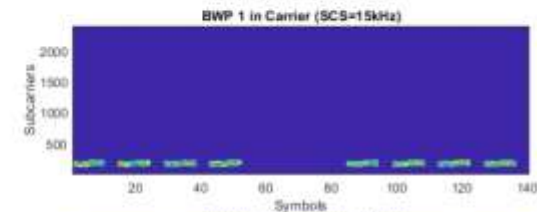
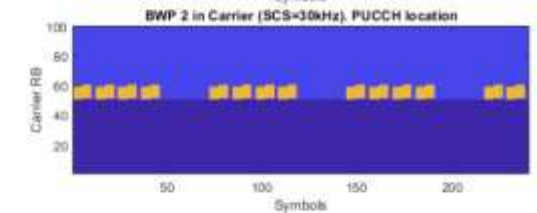
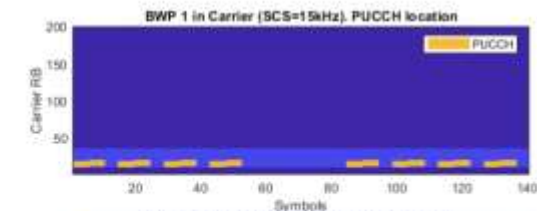
```
carrier = [];
carrier.NULRS = 200; % Carrier width in 15kHz numerology
carrier.NCellID = 0; % Cell identity
carrier.NumSubframes = 10; % Number of 1ms subframes in generated waveform (1,1,4,8 slots per 1m
carrier.DisplayGrids = 1; % Display the resource grids after signal generation
```

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.

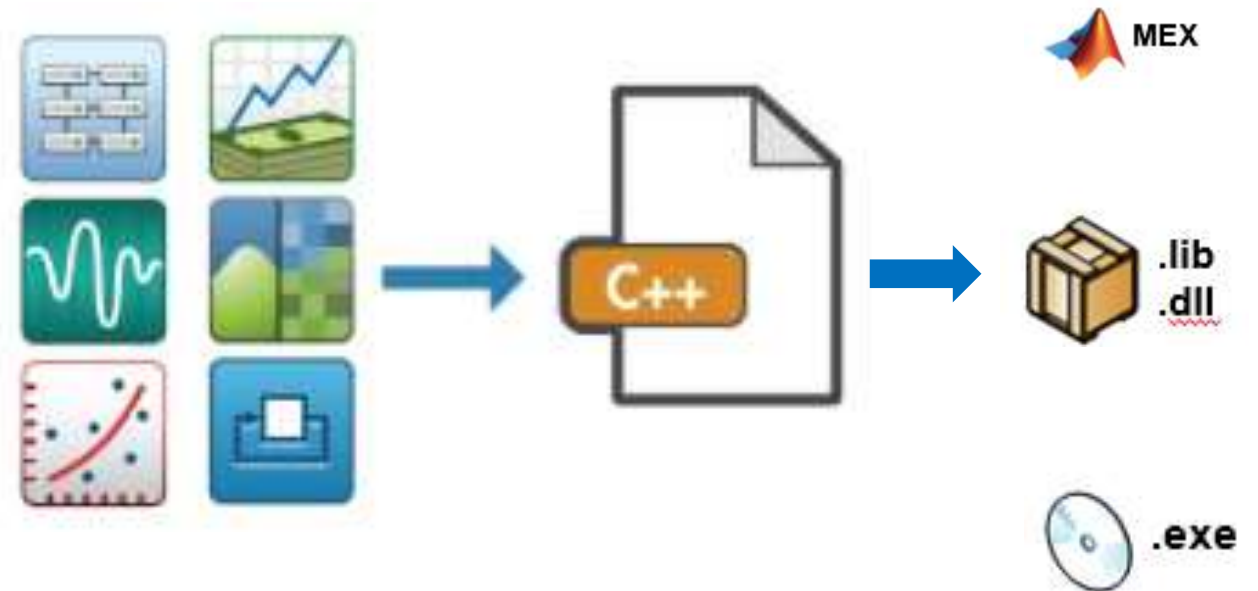
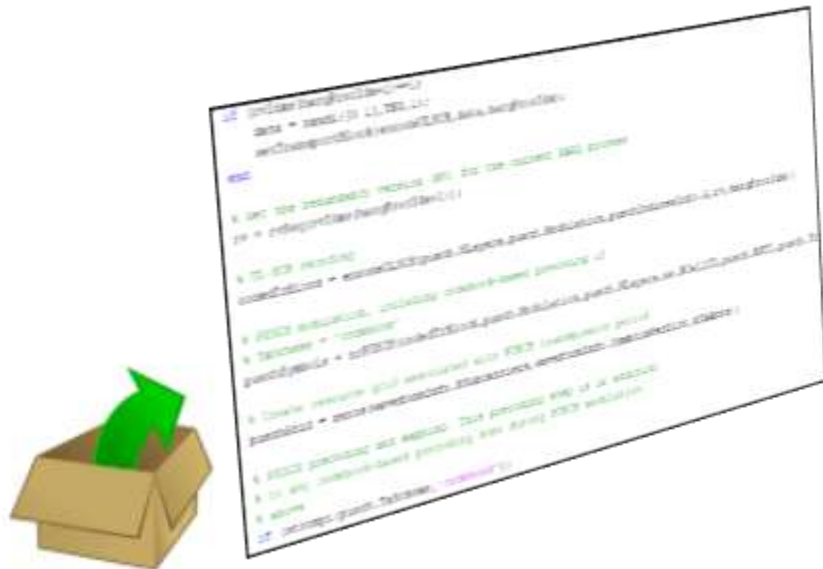
```
% Bandwidth parts configurations
bwp = [];

bwp(1).SubcarrierSpacing = 15; % 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
```

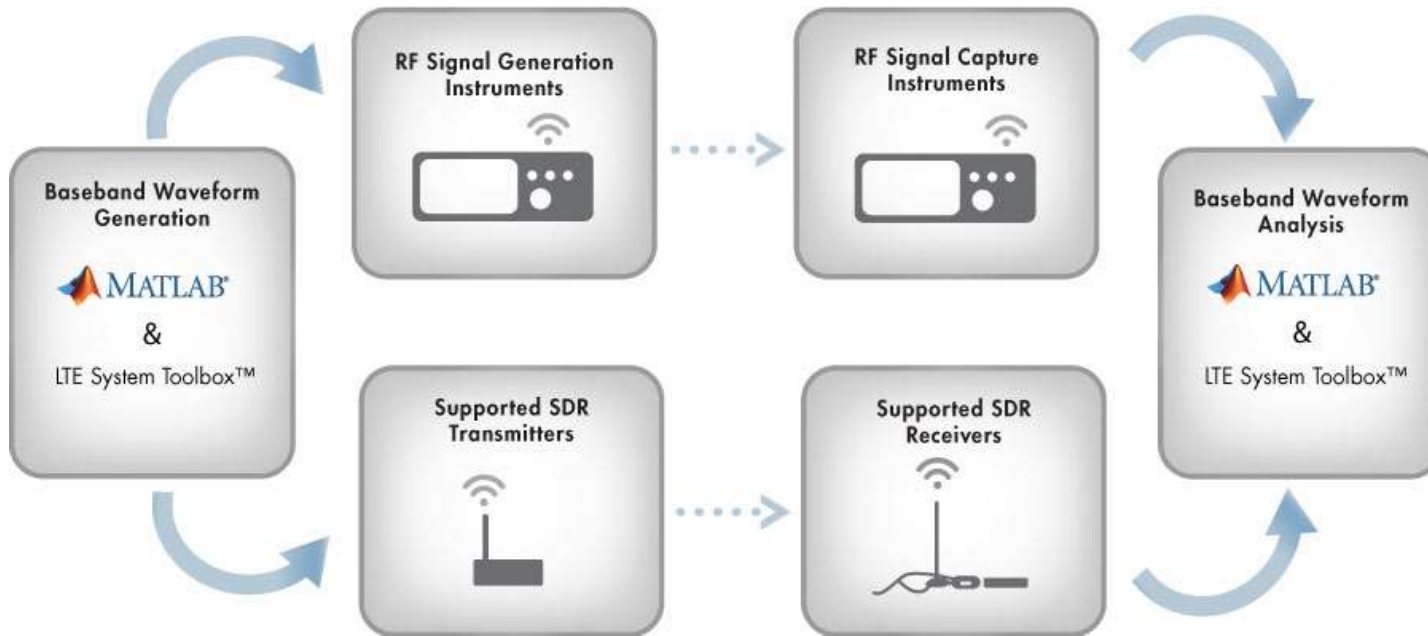


5G Toolbox has open customizable algorithms

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



Over-the-Air Testing with SDR and RF Instruments



Demo Station:
Design and Prototype Wireless Systems



Ettus USRP SDR

RTL-SDR

Pluto SDR

Zynq SDR

RF Signal Generator

Spectrum Analyzer

Call to Action

- Learn more about RF and antenna arrays

Seamless System Design of RF Transceivers and Antennas for Wireless Systems

12:45–13:15

Wireless engineers are pursuing 5G and other advanced technologies to achieve gigabit data rates, ubiquitous coverage, and massive connectivity for many applications such as IoT and V2X. The need to improve performance and coexist with multiple communications standards and devices while reducing the overall area and power imposes challenging requirements on RF front ends. Gaining an insight into such complex systems and performing architectural analysis and tradeoffs require a design model that includes DSP, RF, antenna and channel, as well as impairments.

In this talk, you will learn how to model antenna arrays and integrate them in RF front ends for the development of wireless communications, including:

- Analyzing the performance of antennas with arbitrary geometry
- Performing array analysis by computing coupling among antenna elements
- Modeling the architecture of RF front ends
- Developing baseband and RF beamforming algorithms



Vidya Viswanathan,
MathWorks

5G Customer Successes

MathWorks Qualcomm (UK)

Using MATLAB to Develop 5G RF Front End Components and Algorithms

Sean Lynch, Qualcomm UK Ltd.

Qualcomm UK develops RF Front End components and envelope tracking technology for 5G mobile devices that support over 30 different RF bands. In 5G, the number of possible waveform combinations is 10x greater than LTE, making device validation much more complex and time-consuming.

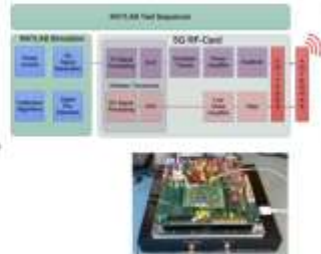
The Qualcomm RF team used MATLAB to build a complete model of the Tx and Rx paths with fixed-point digital blocks and hardware-accurate power amplifier models. They used simulations to predict key system performance measures, optimize design parameters, and automate testing over a range of waveform combinations. The team automatically generated waveform libraries from the MATLAB 5G models, saving time in hardware test development and delivery of waveforms to customers.

Advantages of using MATLAB:

- Fully model and verify the RF transceiver and key analog and RF components
- Release sensitive IP both internally and externally in a secure manner
- Enable a small team to create a scalable and maintainable set of tests
- Eliminate the cost of developing separate test suites for different test instruments

Qualcomm (UK)

"We use MATLAB models to optimize and verify the 5G RF Front End through all phases of development."



MathWorks Huawei (China)

Developing a Radio Frequency System for Wireless at Huawei

Erni Zhu, Huawei

Huawei, in collaboration with MathWorks, developed an intermediate frequency (IF) and radio frequency (RF) system for 5G wireless base stations to achieve greater capacity, higher speed, lower latency, and more energy efficiency.

MATLAB® and Simulink® help Huawei address design and verification challenges including modeling and analysis of hybrid analog/digital systems, accelerating algorithm implementation, test code generation, and automatic verification. Huawei used development time by efficiently creating designs only in HDL, which reduced debugging and verification effort.

Advantages of using MATLAB:

- Perform closed-loop simulation of designs containing both analog/RF and digital components, such as digital predistortion (DPD) for RF power amplifiers
- Quickly develop a flexible, high-performance hardware development platform at the beginning of the R&D process using a seamless interface to IP environments
- Quickly build an automatic verification platform between software and hardware
- Use a single platform for hardware development, including reference models, hardware conversion, and automatic C and HDL code generation
- Base models to define verification of baseband, basepoint, and RF code

Huawei (China)



- ### Customer Value
- Efficient IP development
 - Small teams can do more and work faster
 - Use MATLAB code and Simulink models throughout the development process
 - Unify R&D, test, and hardware development

MathWorks Convida (USA)

Advancing the 5G Wireless Standard at Convida Wireless: An Insider Look

Convida Wireless is a joint venture between Sony Corporation of America and InterDigital that focuses on internal of 5G technologies and advancing the specifications and standards for 5G wireless technology. Three InterDigital engineers – Lakshmi Iyer, Paul Bassett, Jr, and Allan Yungxing Dai – describe their work on behalf of Convida with two 3rd Generation Partnership Project (3GPP) working groups and explain the instrumental role that MATLAB plays in their efforts.

With all the interest 5G is generating in the industry, what aspects of the technology is your team most excited about?

Lakshmi Iyer (LI): One of the big changes in 5G over LTE is that we are targeting ultra-reliable, low-latency communications. We are talking about end-to-end latency of less than a millisecond and highly reliable links. To achieve this, we are aiming for a 99.999 BER of about 100-1000 times lower than the LTE rate of 10 percent.

Paul Bassett, Jr. (PB): Ultra-reliable, low-latency requirements and techniques will make numerous innovations possible, including mass vehicle-to-vehicle communications, new applications for handling emergency situations, and high-definition streaming video, to name a few.

Allan Yungxing Dai (AY): And 5G will support wider bandwidth and higher capacity than 4G by leveraging a beam-centric architecture to enable higher concentrations of mobile users in a given area.

What role does Convida play in the 5G standards working groups? And from a business perspective, what are the benefits of participating in these working groups?

Convida (USA)

MathWorks Nokia (Finland)

5G Development with Model-Based Design at Nokia

Sami Repo, Nokia

Nokia is using Model-Based Design with MATLAB and Simulink to accelerate development of the digital front end (DFE) for 5G base stations. The 5G standard specifies flexible operation across a wide range of frequencies to support faster data rates, greater reliability, and many connected IoT devices.

The DFE provides the high-speed digital processing to and from massive, multi-channel base station antennas and RF transceiver components. The 5G requirements bring new complexity to the design of the DFE. Nokia has found Model-Based Design to be especially beneficial for the design of DFE functions such as channel filtering, up/down conversion, digital pre-distortion, gain control, and carrier combining/demultiplexing that compensate for impairments in the signal chain through the radio channel.

Working with MathWorks tools and technical teams has enabled Nokia to establish Model-Based Design. This brings flexibility, visibility and capability to react through the entire 5G DFE design flow. Nokia now has faster execution, greater understanding of options, and quality improvements.

Advantages of Model-Based Design with MATLAB and Simulink:

- Analyze & explore before building a new system design or changing an existing one
- Understand performance to optimize the system and eliminate unforeseen bottlenecks
- Use models as a common language for communication and automation

Nokia (Finland)

"Working with MathWorks has enabled Nokia to establish Model-Based Design, which has brought flexibility, visibility and capability to react through entire 5G DFE design flow by providing greater understanding of options, faster execution, and quality improvements."



How to learn more

- Go to 5G Toolbox product page
www.mathworks.com/products/5g
[5G Development with MATLAB](#) (ebook)

- Watch Videos & Webinars

[5G: Model, Simulate, Design, and Test 5G Systems with MATLAB](#)
[Waveform Generation and Testing with SDR and RF instruments](#)

MATLAB EXPO 2019

Email: tkhan@mathworks.in

LinkedIn: <https://www.linkedin.com/in/tabrez-khan-8756615a/>



Thank You