Q&A

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MATLAB EXPO 2019

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

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Application Engineering

Introduction to 5G Physical Layer

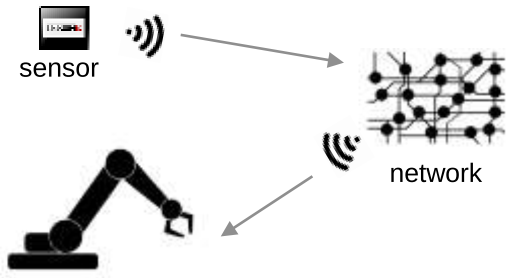
- 5G requirements and use cases
- Key 5G physical layer features
- Physical layer simulation with 5G Toolbox

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

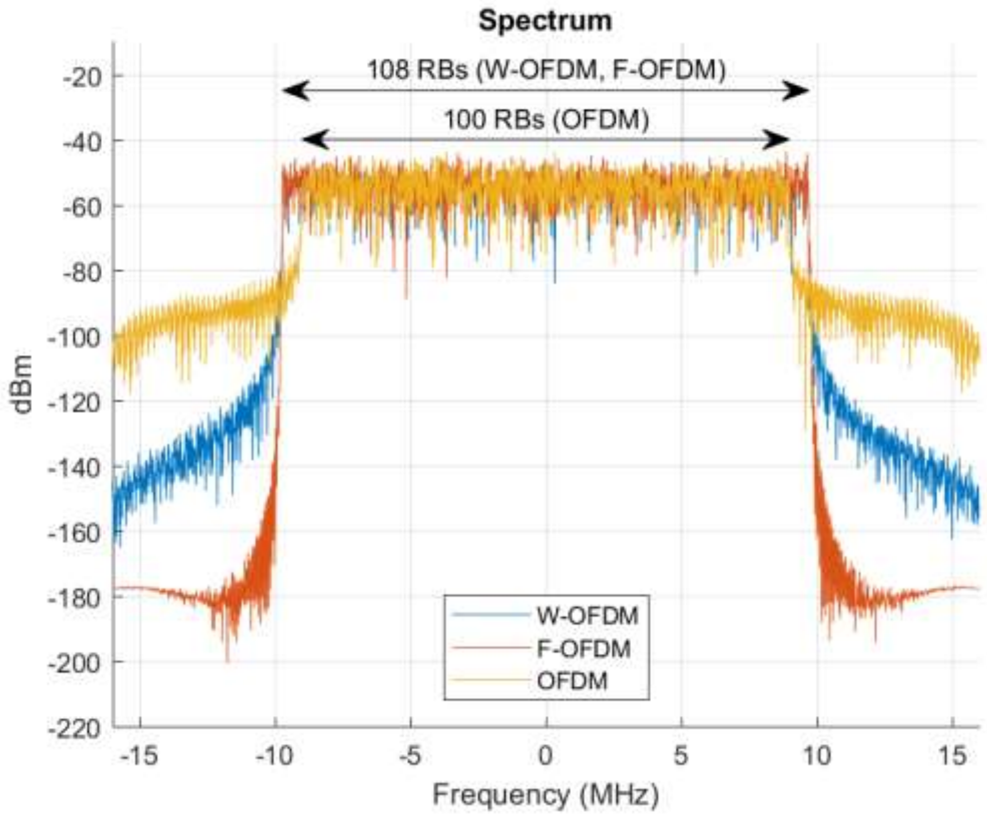
	LTE	5G
Use cases	Mobile broadband access (MTC later)	More use cases: eMBB, mMTC, URLLC
Latency	~10 ms	<1 ms
Band	FR1 (< 6 GHz)	FR1 (<6 GHz), FR2 (23-53 GHz)
Bandwidth	Up to 20 MHz	Up to 100 MHz below 6 GHz Up to 400 MHz above 6 GHz
Subcarrier spacing	Fixed	Variable
Freq allocation	UEs need to decode 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

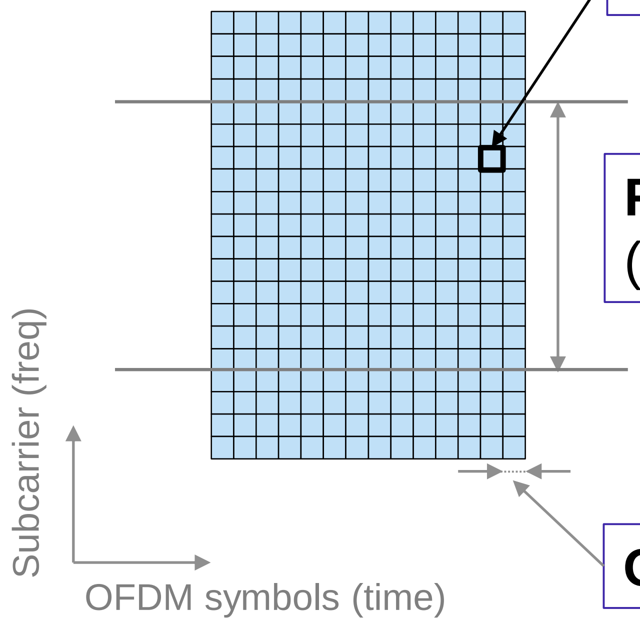
- Waveforms
- Resource elements and blocks
- Frame structure
- Variable subcarrier spacing
- Bandwidth parts

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



Resource element: smallest physical resource

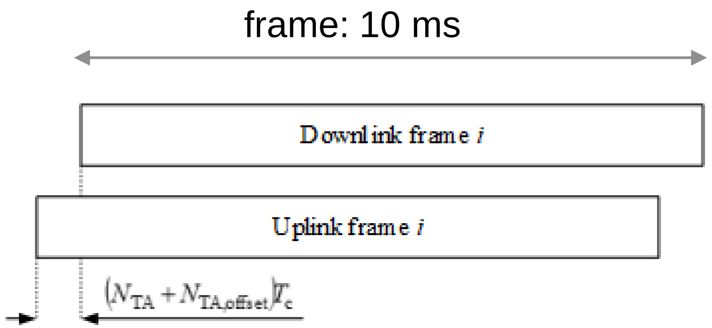
Resource block: 12 subcarriers
(frequency domain only, no time duration (*))

OFDM symbol

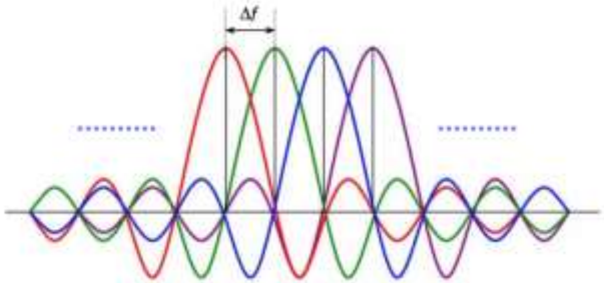
(*) unlike LTE: 1 RB = 12-by-7

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

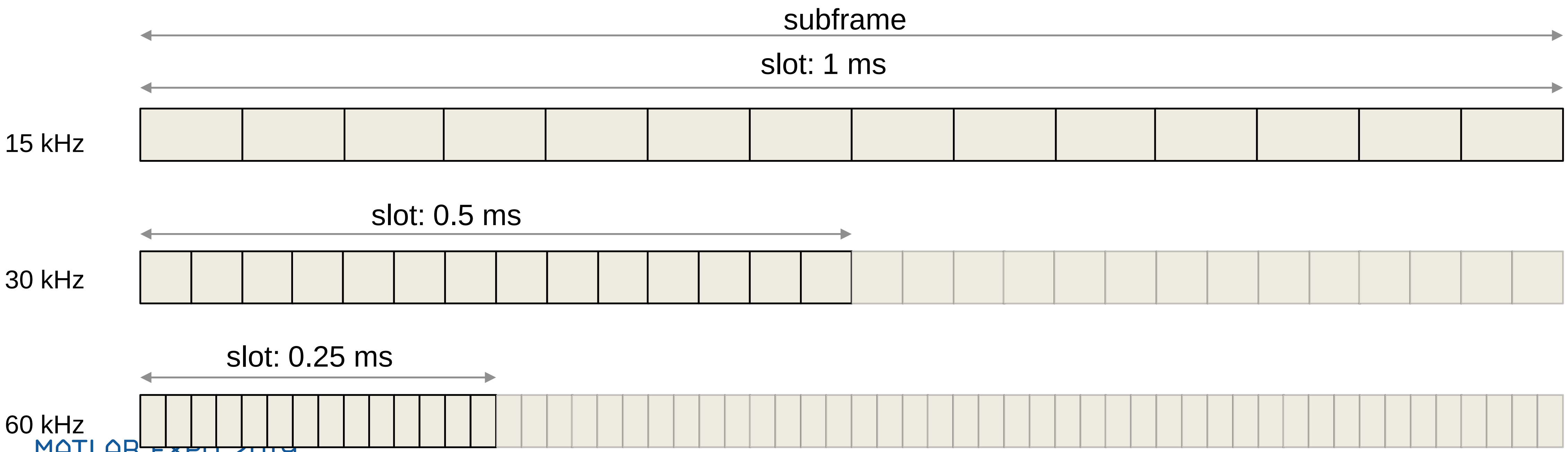


	Slot configuration 0				
Subcarrier spacing (kHz)	15	30	60	120	240
Symbol duration (no CP) (μs)	66.7	33.3	16.6	8.33	4.17
Nominal max BW (MHz)	49.5	99	198	396	397.4
Min scheduling interval (ms)	1	0.5	0.25	0.125	0.0625

- 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

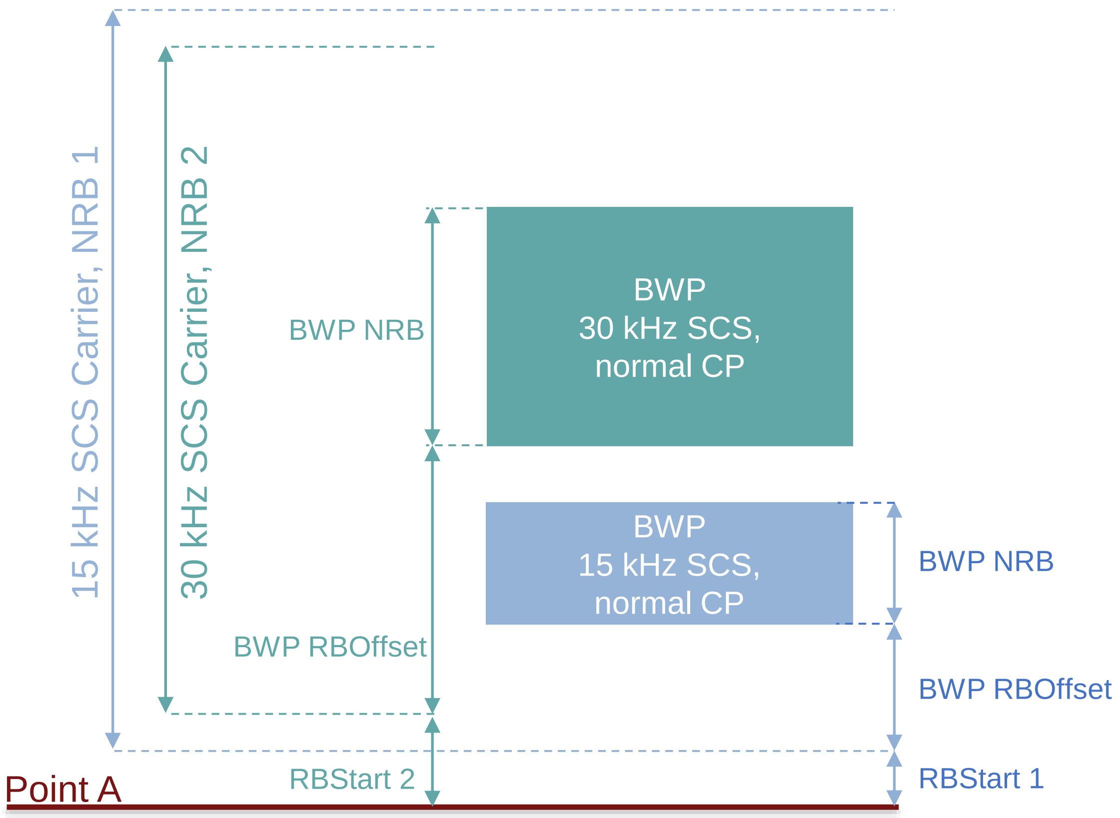
Slots and OFDM Symbols (Normal CP)

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



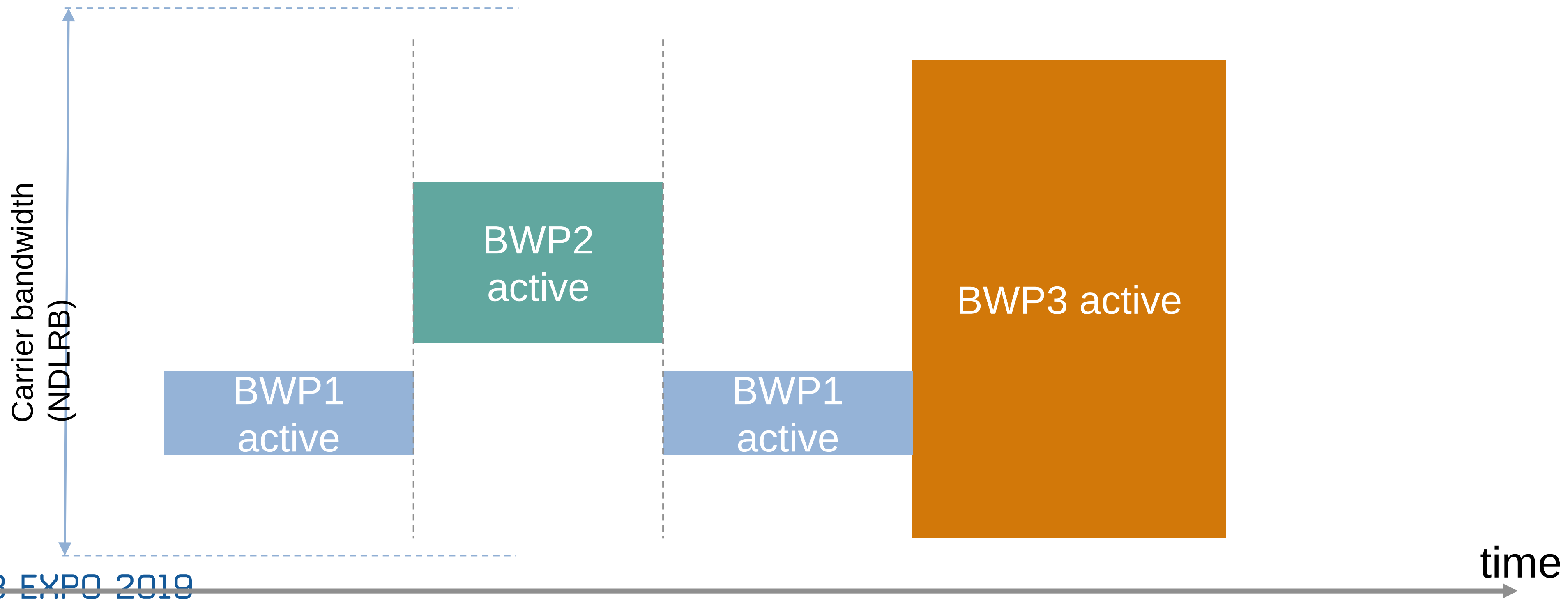
Bandwidth Parts (BWP)

- 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

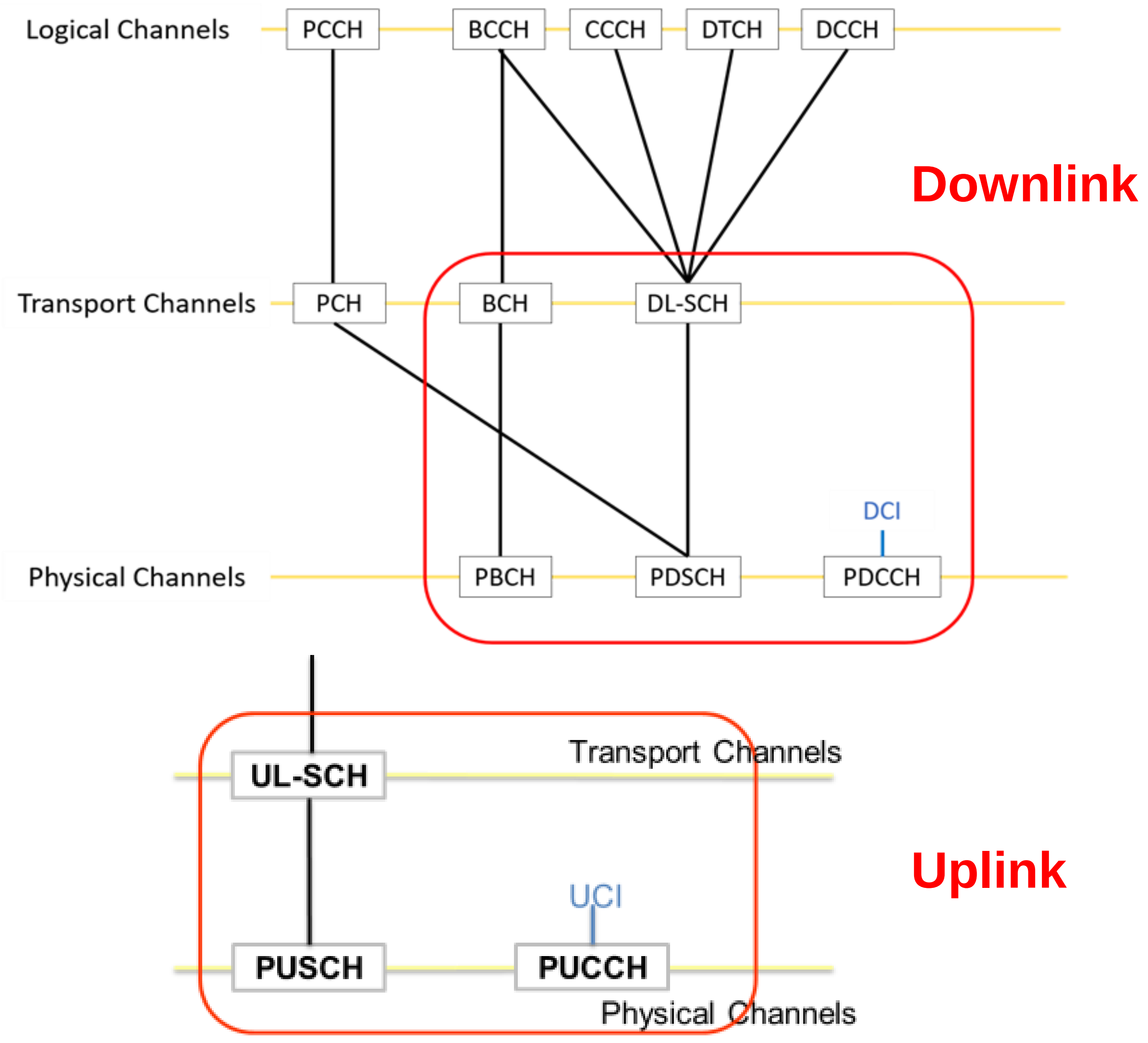
- LPDC & polar coding
- CRC, segmentation, rate matching
- Scrambling, modulation, precoding

NR Downlink and Uplink Channels and Physical Signals

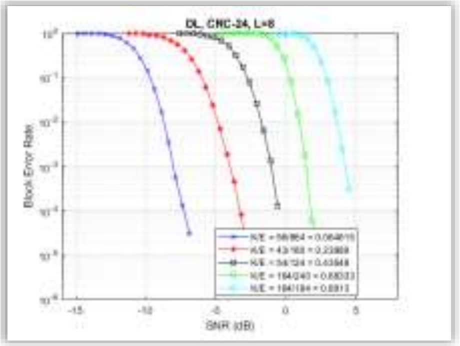
- Synchronization & broadcast signals
- DL-SCH & PDSCH channels
- DCI & PDCCH channels
- UCI, PUSCH, and PUCCH channels

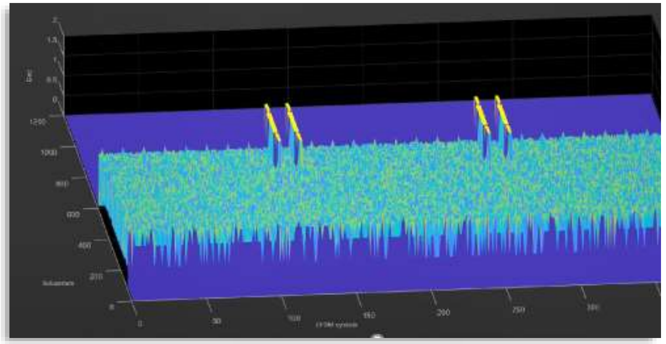
MIMO Propagation channels

- 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

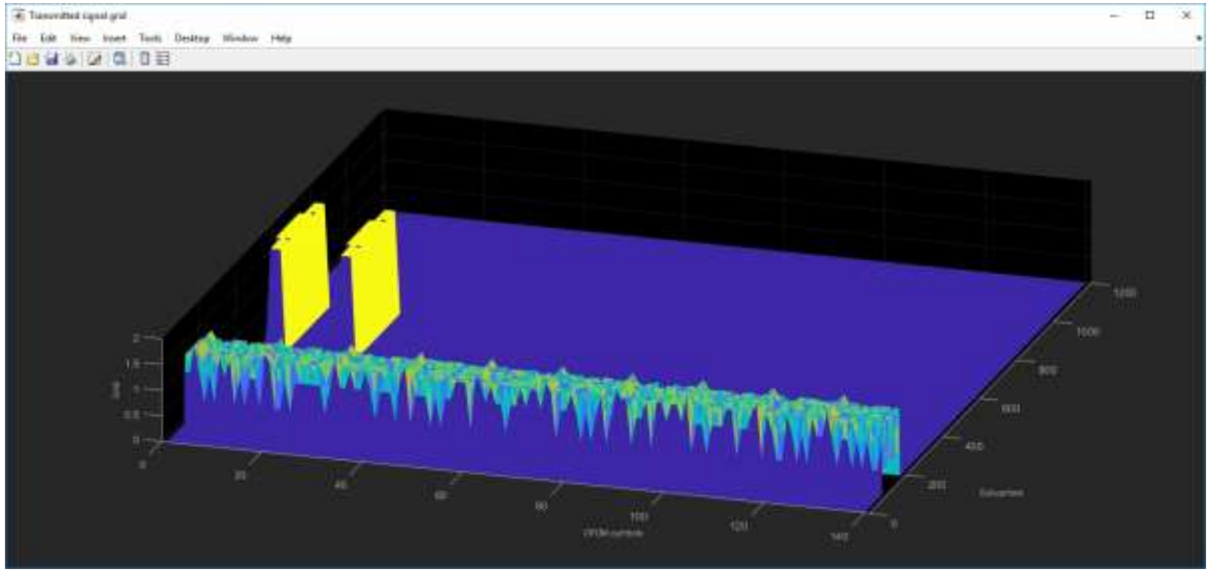
Golden reference design verification

- Customizable and editable algorithms as golden reference for implementation

5G waveform generation

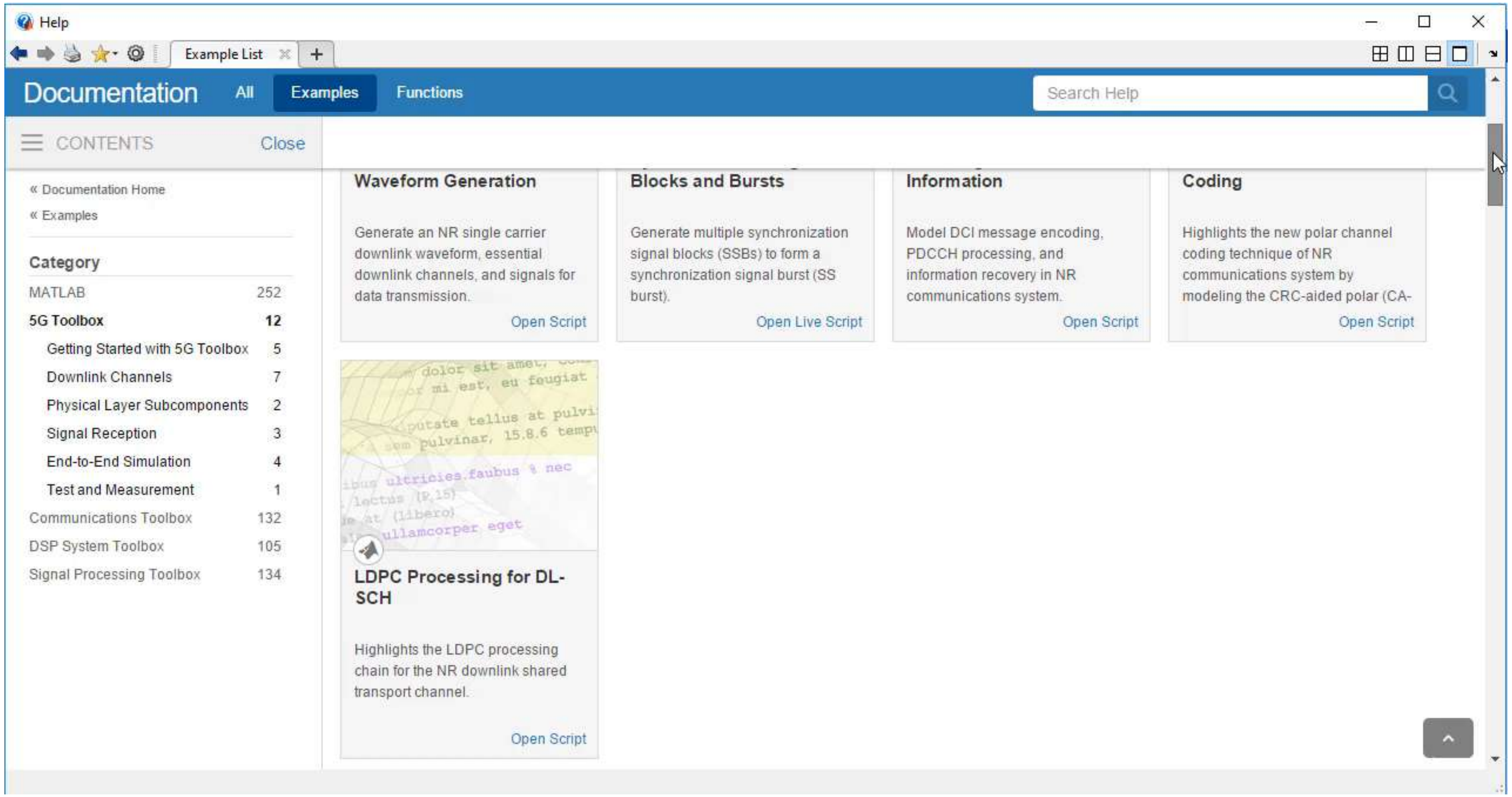
- 5G Toolbox supports downlink & uplink waveform generation

- 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



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).

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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.

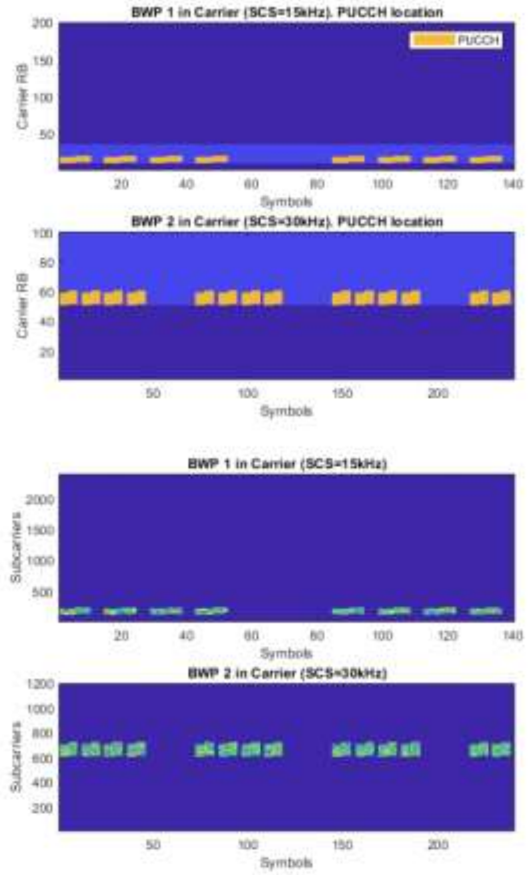
```
carrier = [];
carrier.NULRB = 200;          % Carrier width in 15kHz numerology
carrier.NCellID = 0;          % Cell identity
carrier.NumSubframes = 10;    % Number of 1ms subframes in generated waveform (1,2,4,8 slots per 1m
carrier.DisplayGrids = 1;     % Display the resource grids after signal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

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
```

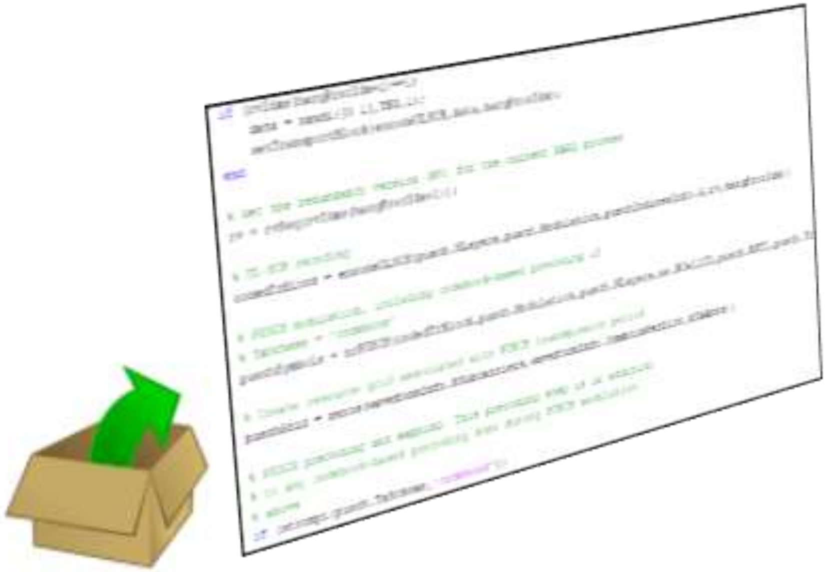


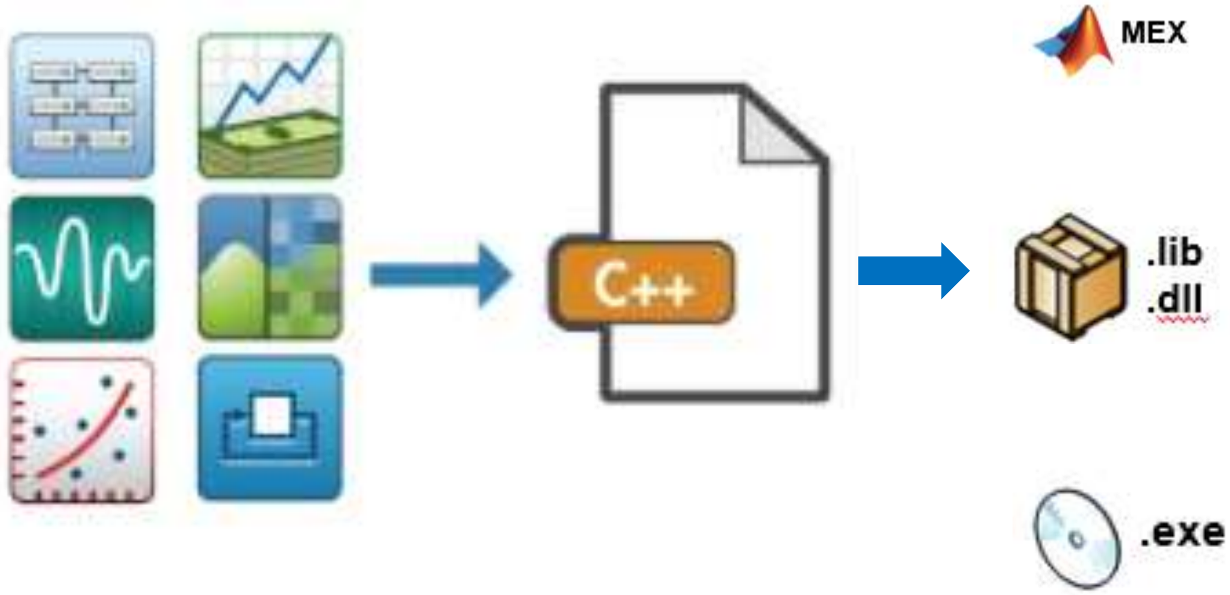
5G Toolbox has open customizable algorithms

- All functions are open, editable, customizable MATLAB code

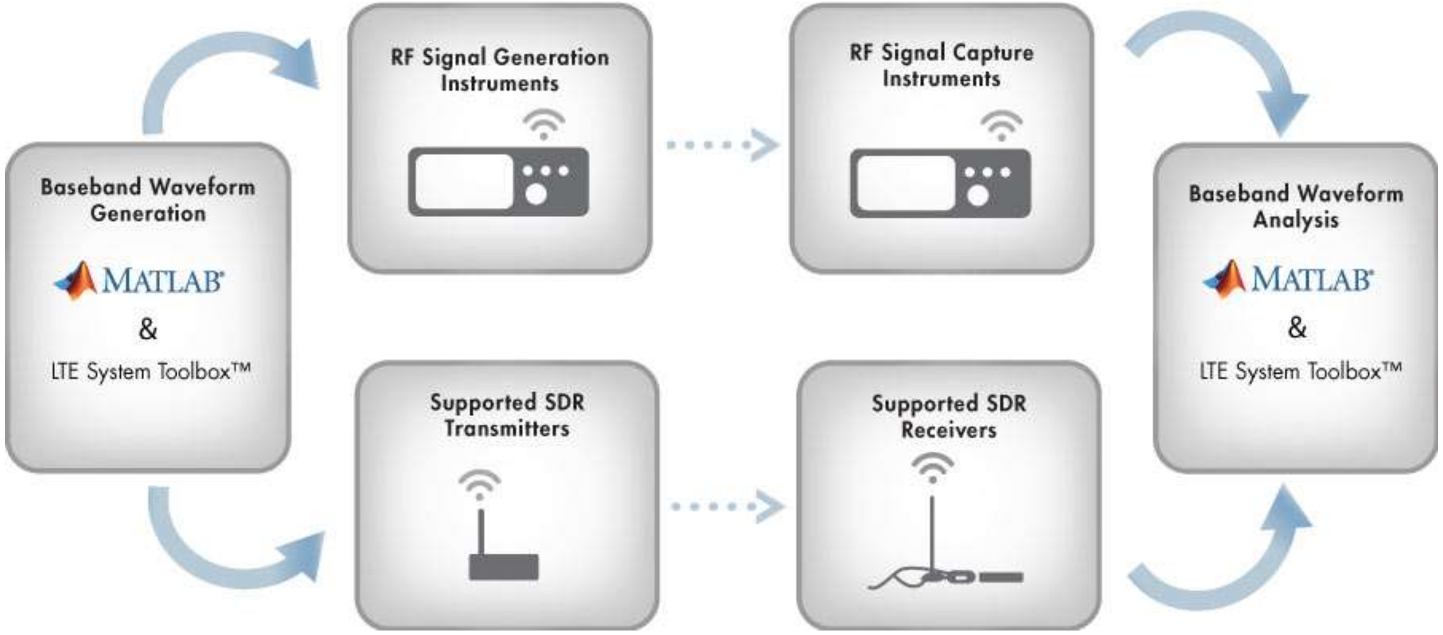
- C/C++ code generation:

Supported with MATLAB Coder





Over-the-Air Testing with SDR and RF Instruments



Ettus USRP SDR

RTL-SDR

Pluto SDR

Zynq SDR

RF Signal Generator

Spectrum Analyzer

Demo Station:
Design and Prototype Wireless Systems

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

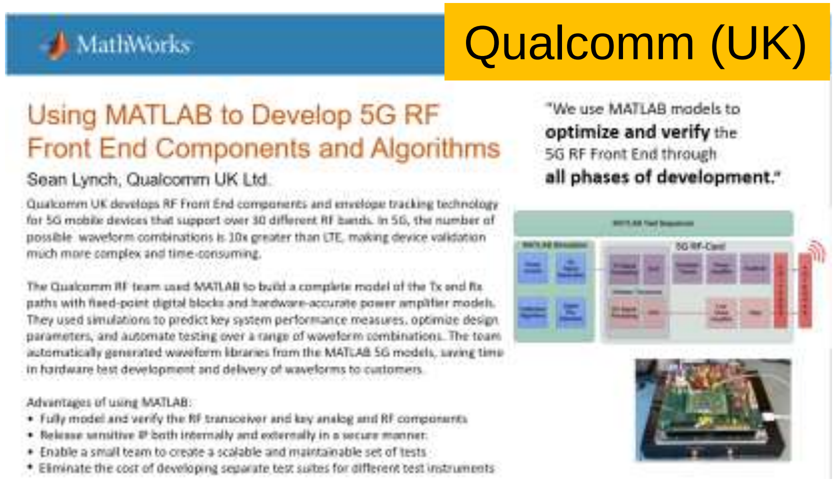
Wireless engineers are pursuing 5G and other advanced technologies to achieve gigabit data rates, ubiquitous coverage, and massive connectivity for many applications such as IoT and V2X. The need to improve performance and coexist with multiple communications standards and devices while reducing the 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.

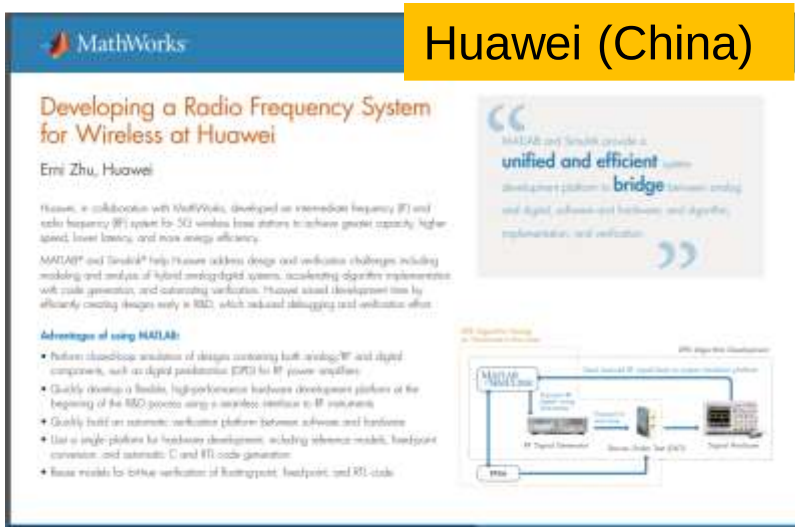
In this talk, you will learn how to model antenna arrays and integrate them in RF front ends for the development of wireless communications, including:

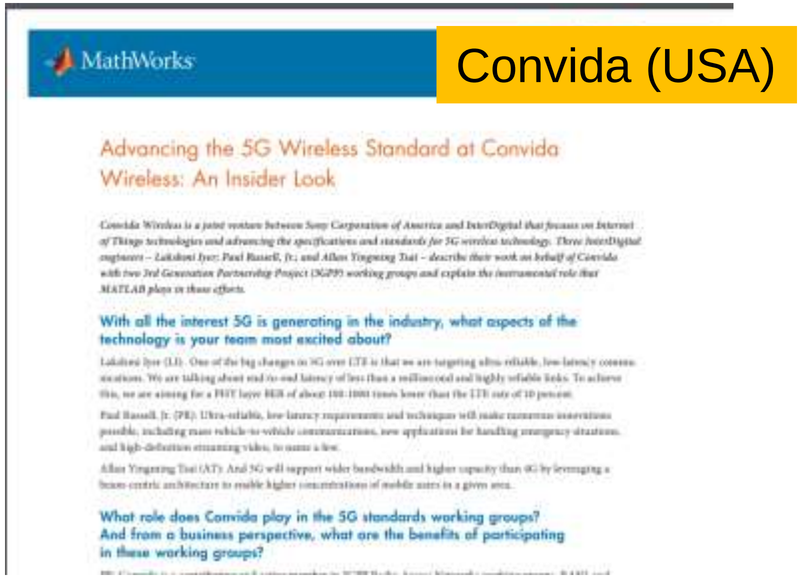
- Analyzing the performance of antennas with arbitrary geometry
- Performing array analysis by computing coupling among antenna elements
- Modeling the architecture of RF front ends
- Developing baseband and RF beamforming algorithms

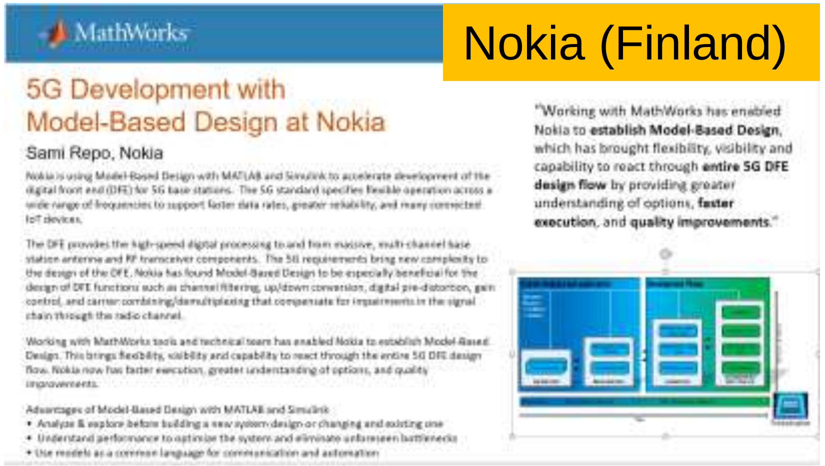
Vidya Viswanathan, MathWorks

5G Customer Successes









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

Available on the 5G Technology web page

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

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Thank You