MATLAB EXPO 2018

What's Behind 5G Wireless Communications?

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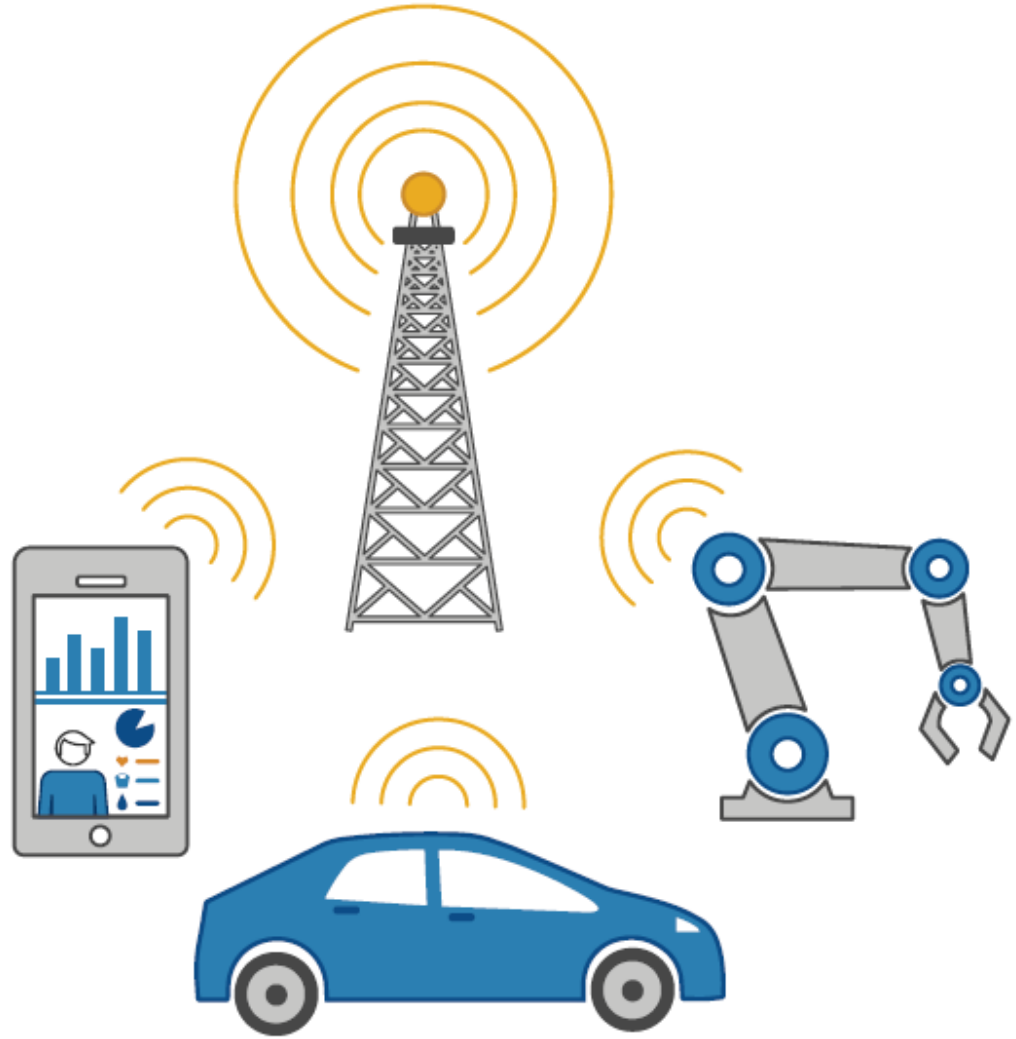
Agenda

- 5G goals and requirements
- Modeling and simulating 5G PHY signals
- 5G development workflow

3GPP Standardization Timeline

5G Applications and Requirements

- 4K, 8K, 360° Video
- Virtual Reality
- Internet of Things
- Connected Vehicles

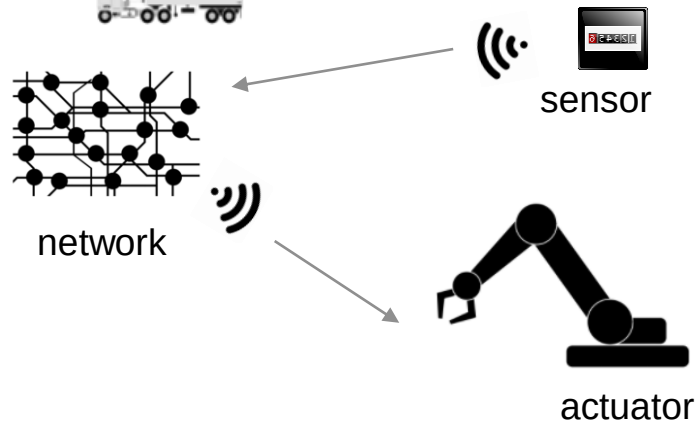


5G Technology Use Cases

- eMBB (enhanced Mobile Broadband)

- mMTC (massive Machine Type Communications)

- URLLC (Ultra-Reliable and Low Latency Communications)



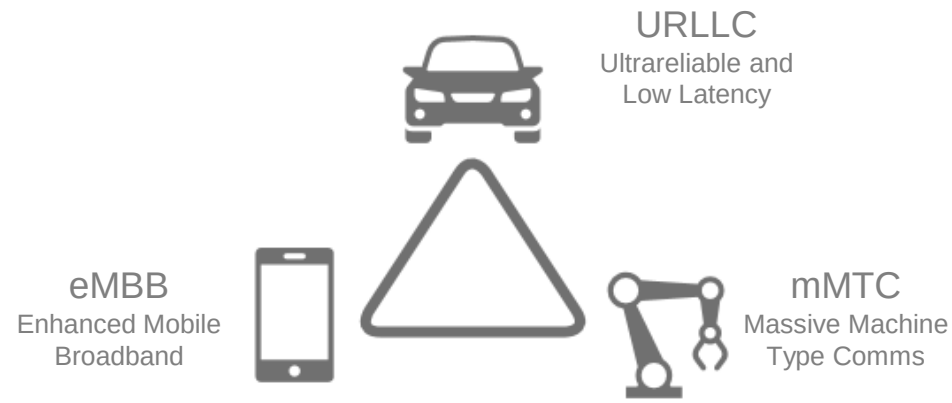
5G and LTE Standard Support

36.xxx

- LTE-M
- NB-IoT
- Public safety
- C-V2X
- Spectrum sharing

38.xxx

- eMBB
- URLCC
- NR IoT
- NR C-V2X

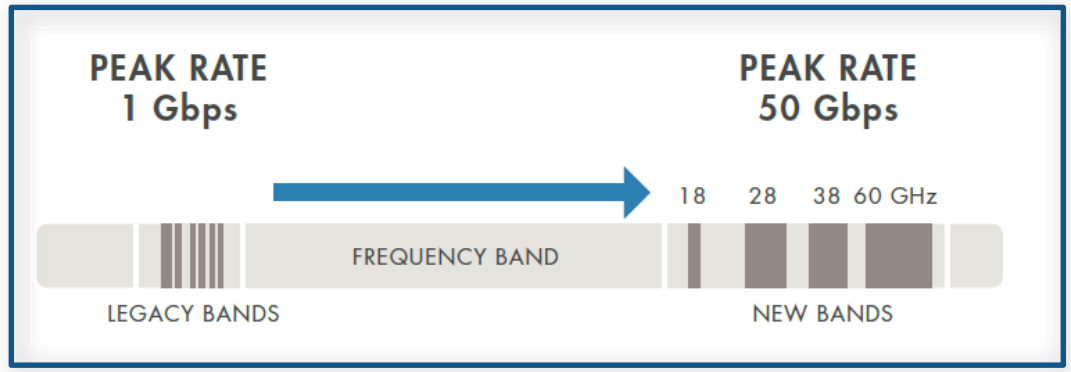


Achieving High Broadband Data Rates, Low Latency, High Efficiency

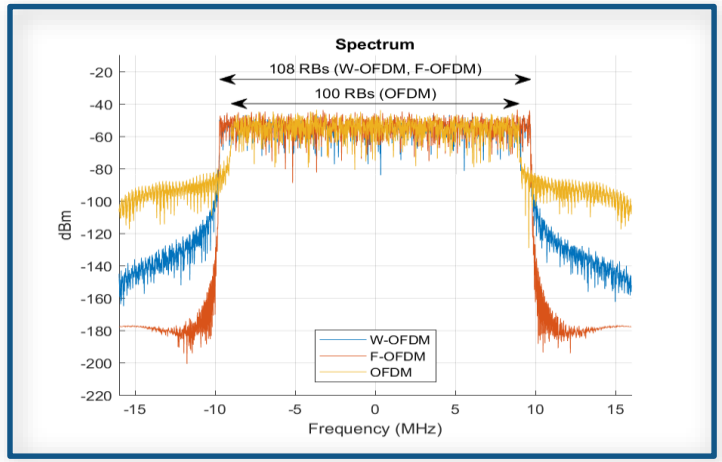
Technical Solutions

- Increased bandwidth
- Better spectral efficiency
- Flexible air interface
- Densification

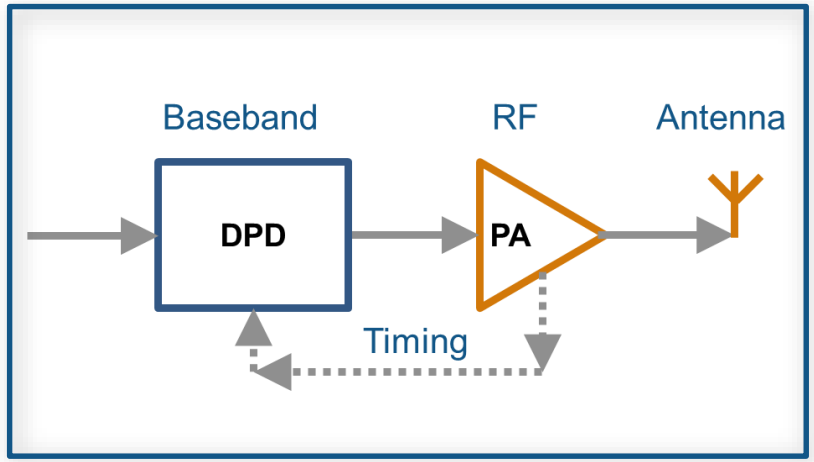
Higher Frequency Bands



New Physical Layer



New RF Architectures

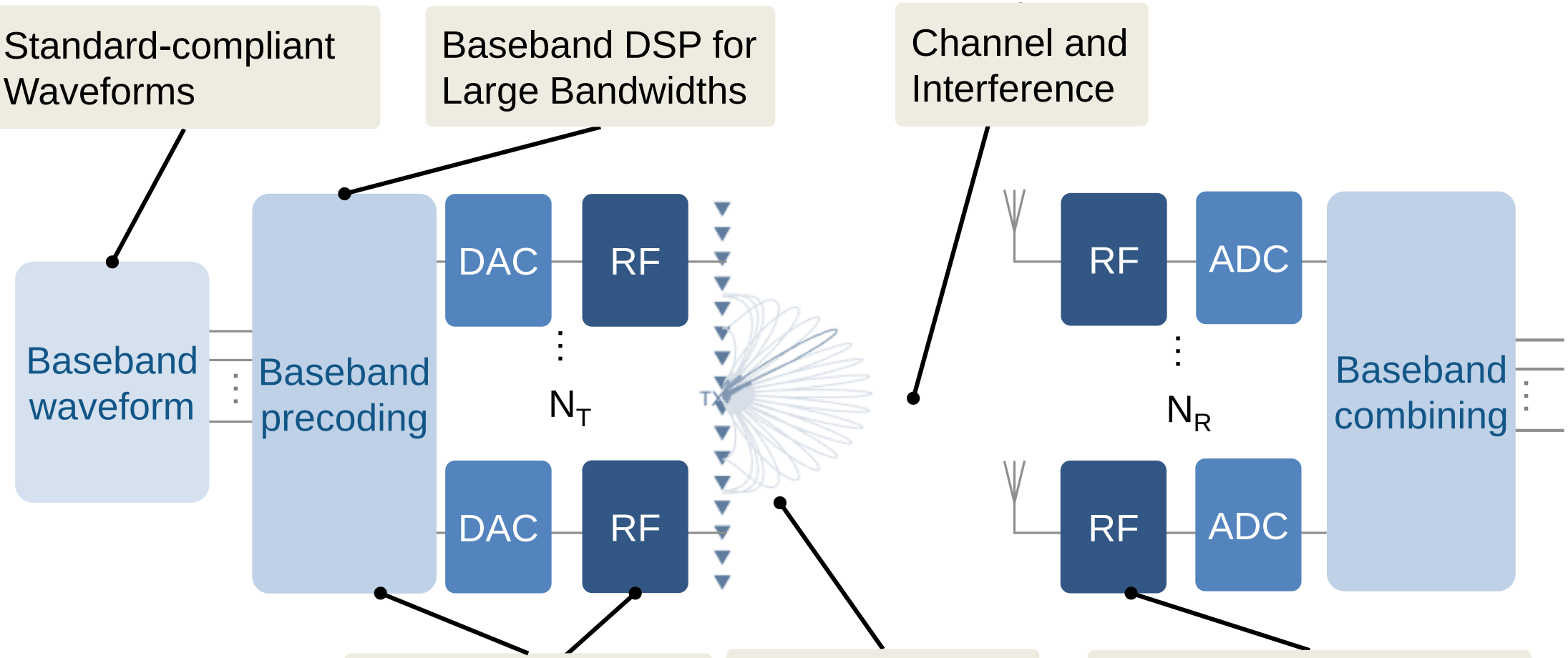


Massive MIMO

Massive MIMO antenna array for a Huawei 5G field trial.

Multi-Domain Engineering for 5G

Subsystems must be designed and tested together



Agenda

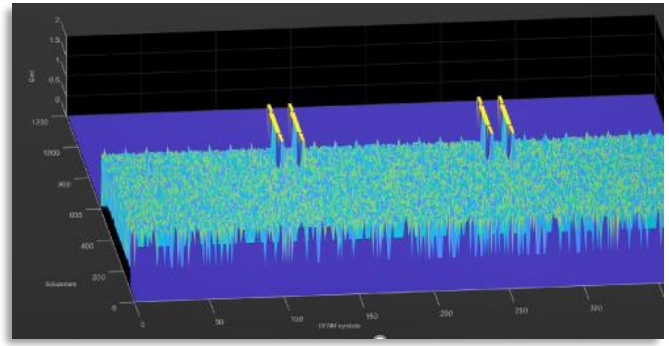
- 5G goals and requirements
- Modeling and simulating 5G PHY signals → Introducing 5G Toolbox!
- 5G development workflow

Introducing 5G Toolbox

R2018b

Supports 3GPP Rel. 15
Based on Version 15.2.0 (June 2018)

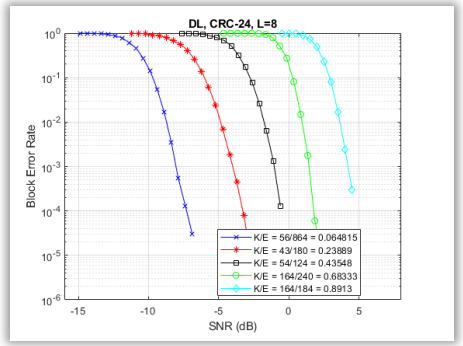
5G Toolbox Applications & Use-Cases



Waveform Generation and Analysis

- New Radio (NR) subcarrier spacings and frame numerologies

End-to-End Link-Level Simulation



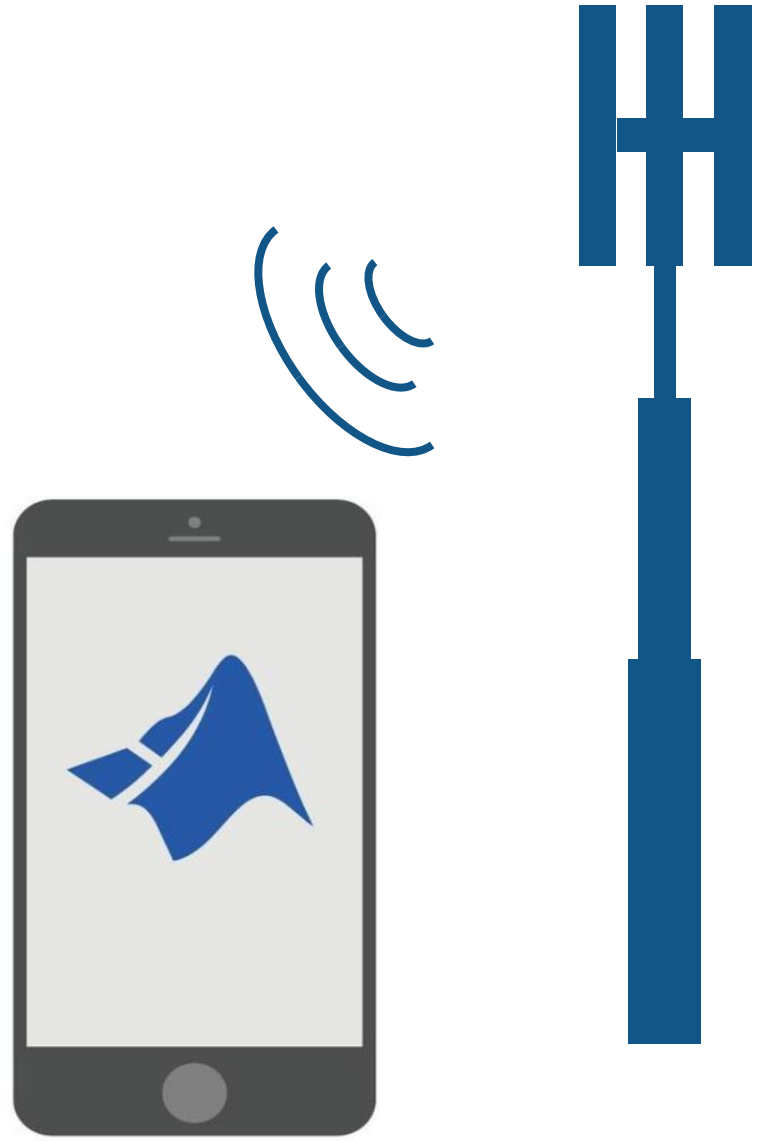
- Transmitter, channel model, and receiver
- Analyze bit error rate (BER), and throughput

Golden Reference Design Verification

- Customizable and editable algorithms as golden reference for implementation

5G Toolbox

- Waveform generation
- Downlink processing - Transmit and receive
- Physical channels and signals
- TDL and CDL channel models
- Link-level simulation & throughput measurements
- Synchronization Bursts
- Cell search procedures
- Reference designs as detailed examples



5G Waveform Generation

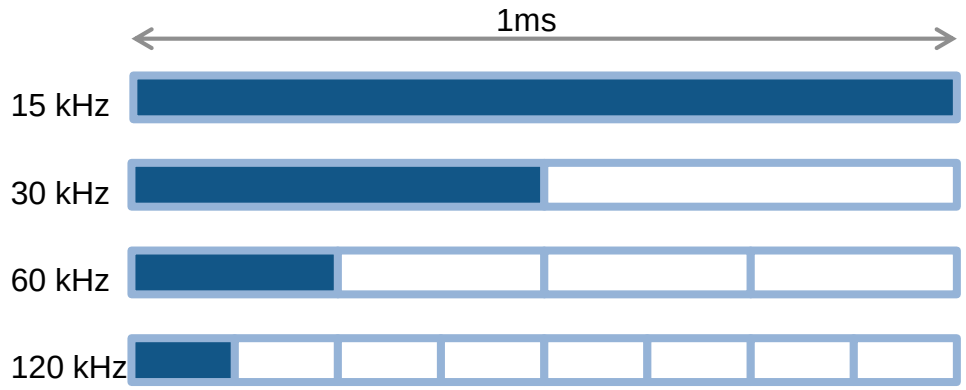
- 5G Toolbox supports Downlink waveform generation
  - OFDM Waveform with cyclic prefix: CP-OFDM

- Generated waveforms feature:
  - Mixed numerology
  - Multiple bandwidth parts
  - Multiple PDSCHs
  - Fully parameterizable SS bursts
  - Multiple CORESETS and search spaces

Numerology and Subcarrier Spacing

- Subcarrier spacing can be a power-of-two multiple of 15kHz
- 5G Toolbox supports variable subcarrier spacings
- Waveforms generated by 5G Toolbox can contain a mix of subcarrier spacings

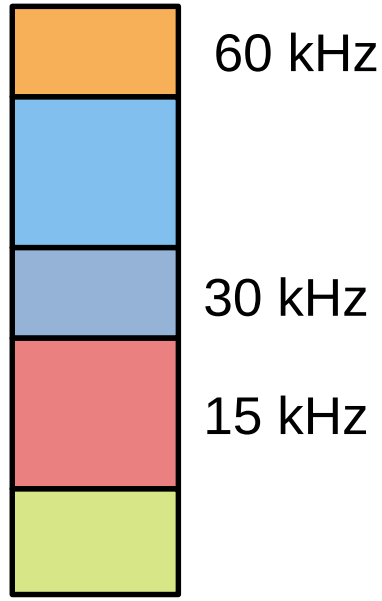
μ	$\Delta f = 2^m * 15kHz$	Slots/ms	Max Bandwidth (MHz)
0	15	1	49.50
1	30	2	99
2	60	4	198
3	120	8	396
4	240	16	397.44
5	480	32	397.44



Bandwidth Parts and Mixed Numerology

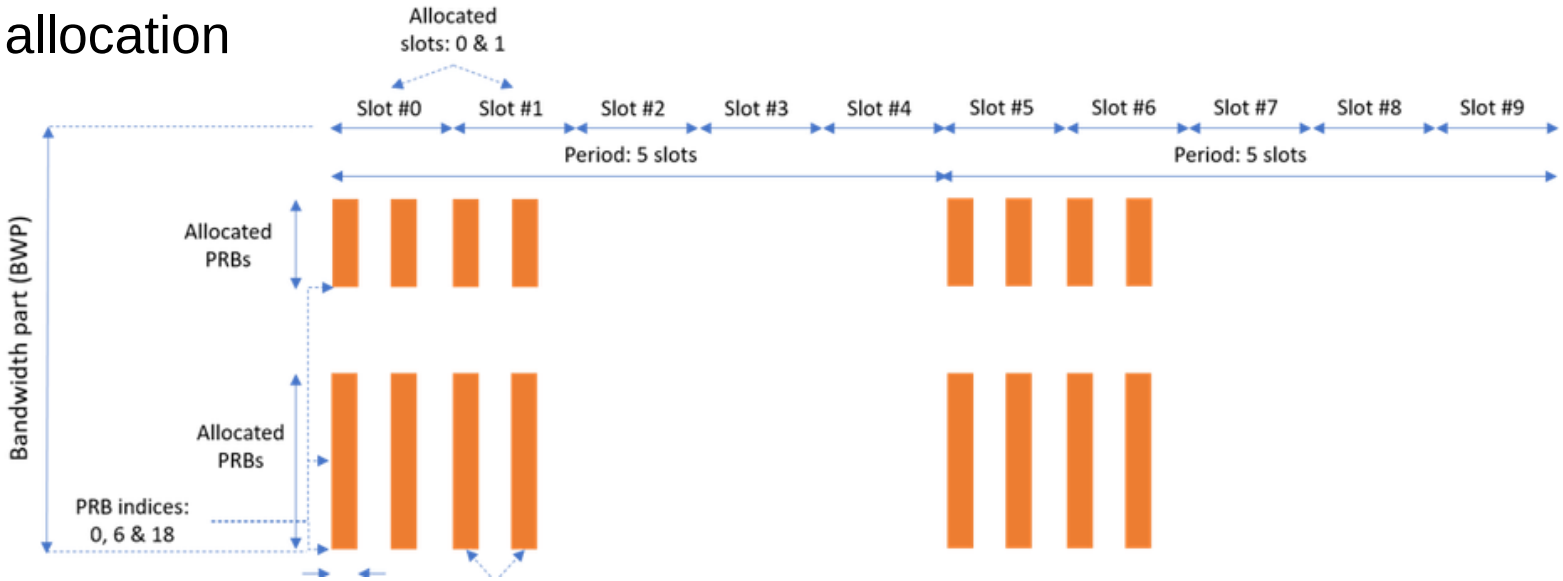
- Bandwidth divided into Carrier Bandwidth Parts (CBP)
  - Consecutive resource blocks
- Each CBP has its own subcarrier spacing
- Each UE can be associated with up to 4 CBPs in DL

- 5G Toolbox supports different CBPs
- Waveforms generated by 5G Toolbox can contain multiple CBPs



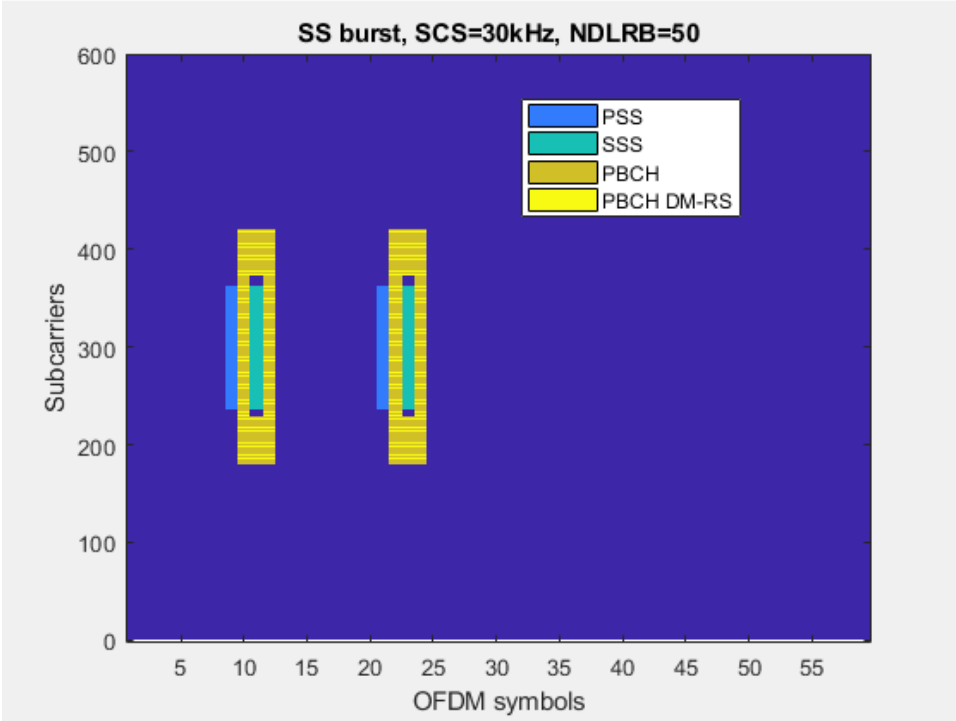
CORESET and Search Space Configuration

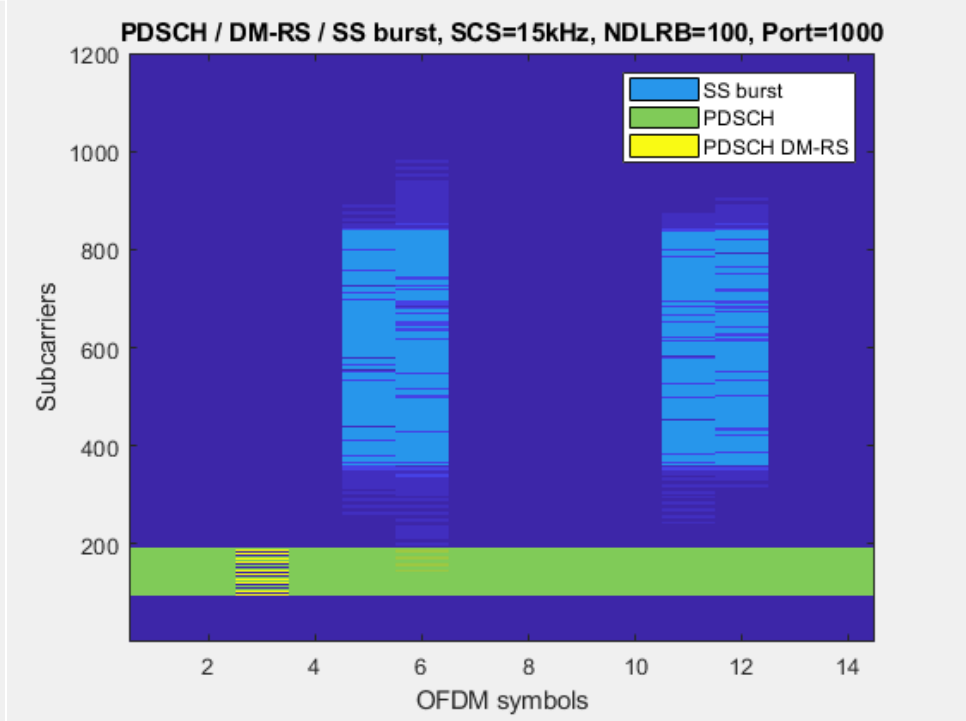
- 5G Toolbox allows you to specify COntrol REsource SET (CORESET)
  - Possible locations (in time and frequency) of the control channel for a given numerology
  - Allocated OFDM symbols in a slot
  - The allocated slots within a period
  - Periodicity of the allocation
  - CORESET duration in symbols, either 1, 2 or 3
  - The first PRB of the allocation



Downlink Physical Layer Channels and Signals

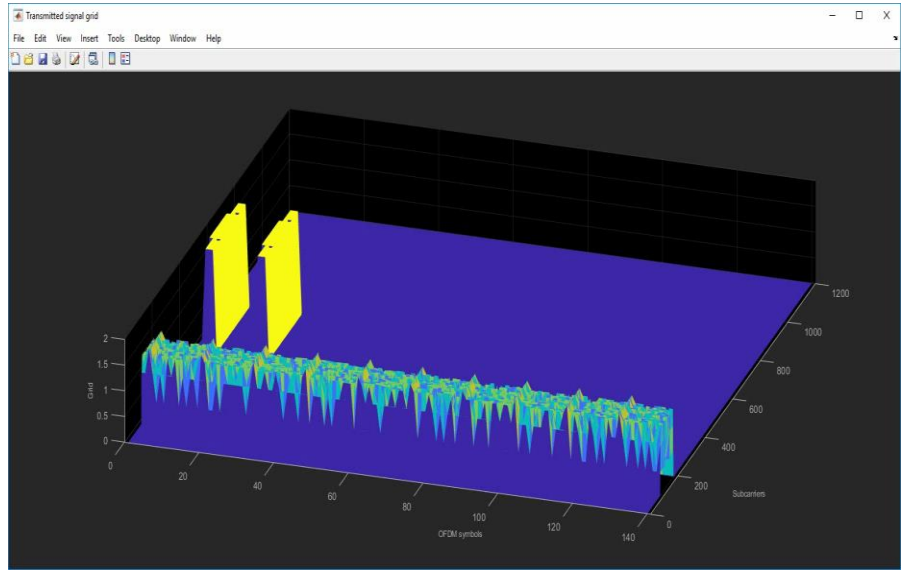
- Shared, control, and broadcast channels
  - PDSCH, PDCCH, PBCH
- Synchronization and reference signals
  - PSS, SSS, DM-RS





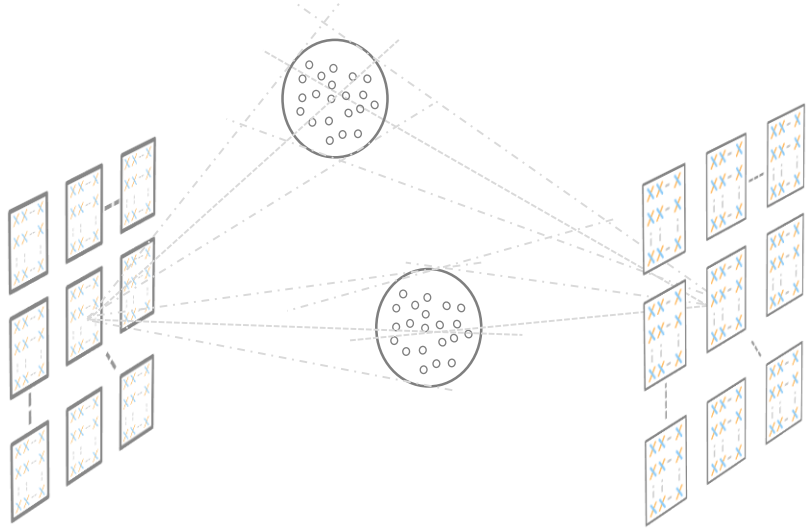
Synchronization

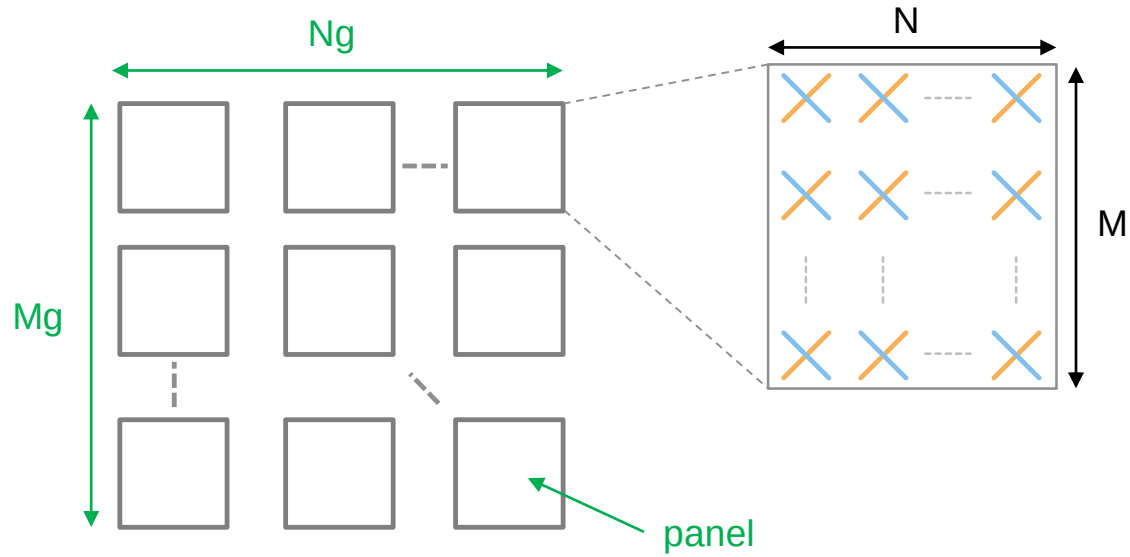
- Construct synchronization signal (SS) bursts
- Pass waveform through fading channel
- Synchronize to receive waveform using
  - Primary synchronization signal (PSS)
  - Secondary synchronization signal (SSS)
  - PBCH demodulation reference signal (PBCH DM-RS)
- Perform PBCH decoding and parsing



5G Channel Models

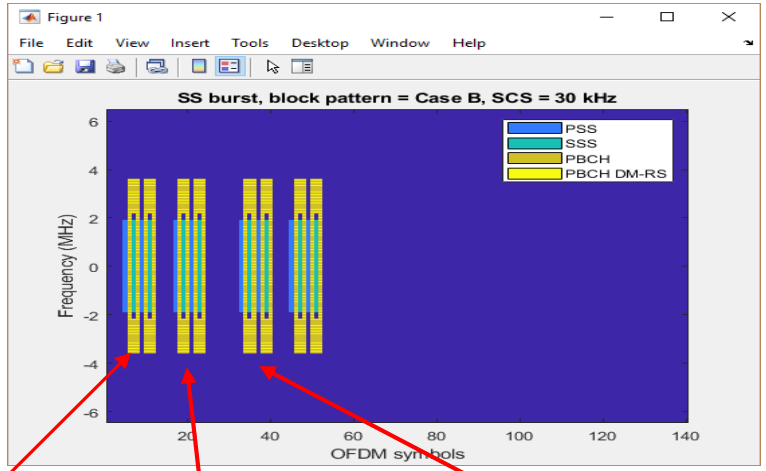
- Implementation of 5G channel models TR 38.901
  - Delay profile: TDL and CDL profiles: A, B, C, D, E or custom
  - Channel delay spread
  - Doppler shift
  - MIMO correlation
  - CDL: spatial channel model, including antenna array geometry [M, N, P, Mg, Ng]

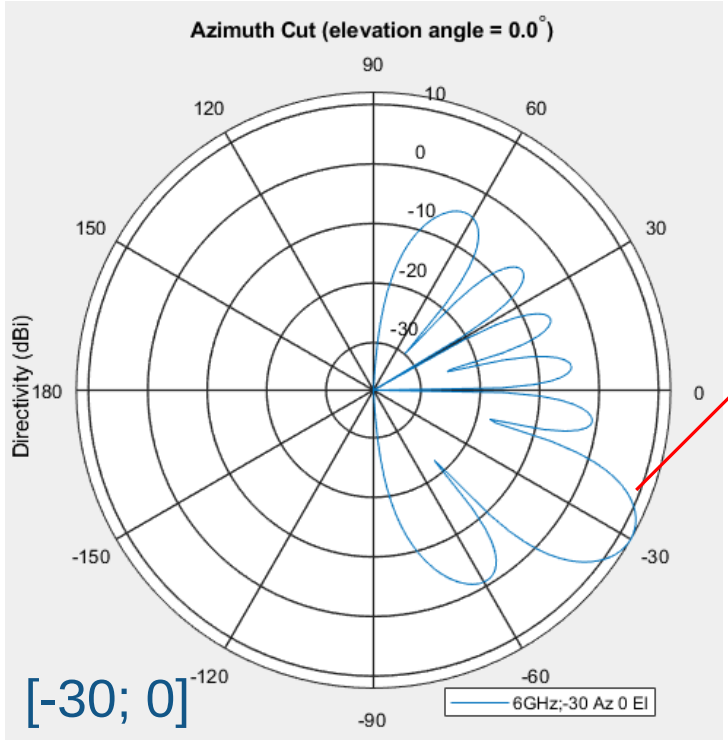




5G mmWave Beam Search

- 6 GHz link
- 30 kHz spacing
- 8 antennas





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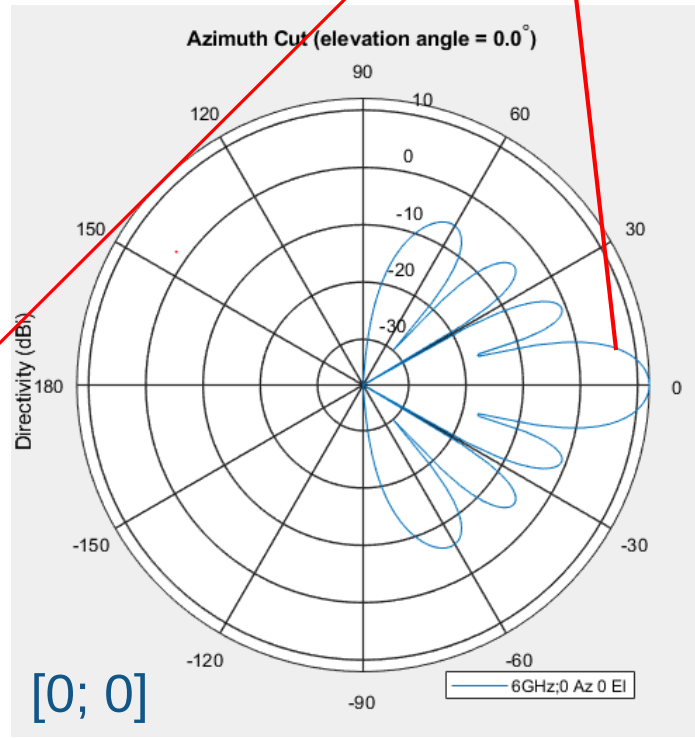

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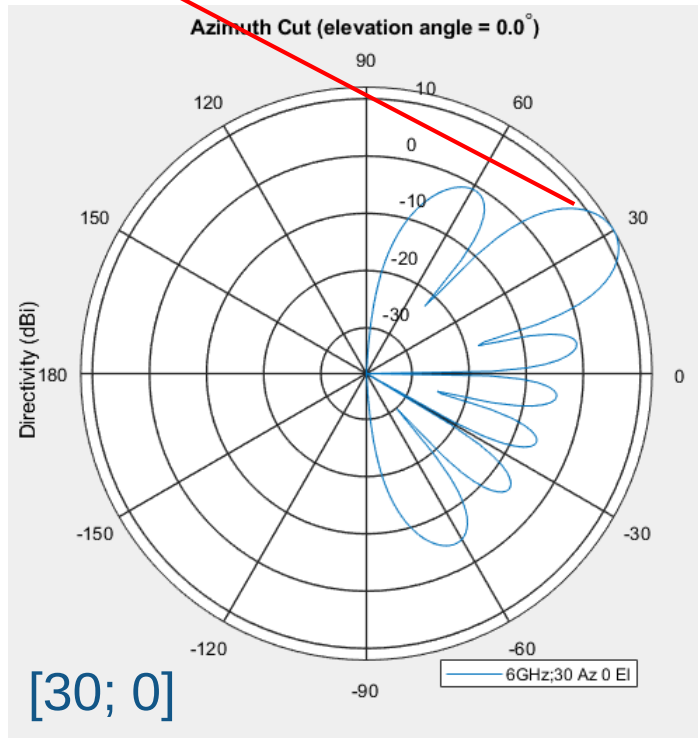

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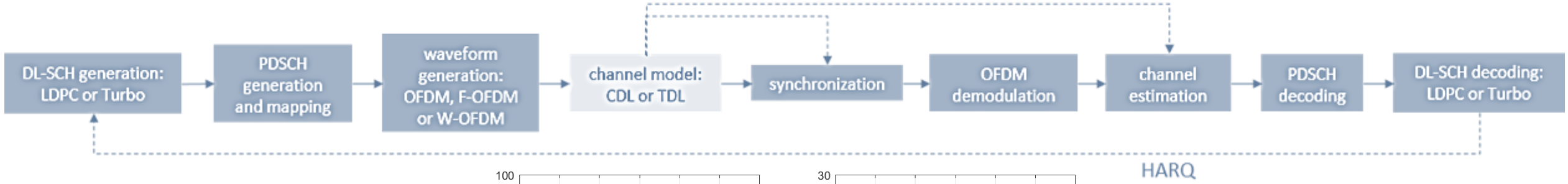
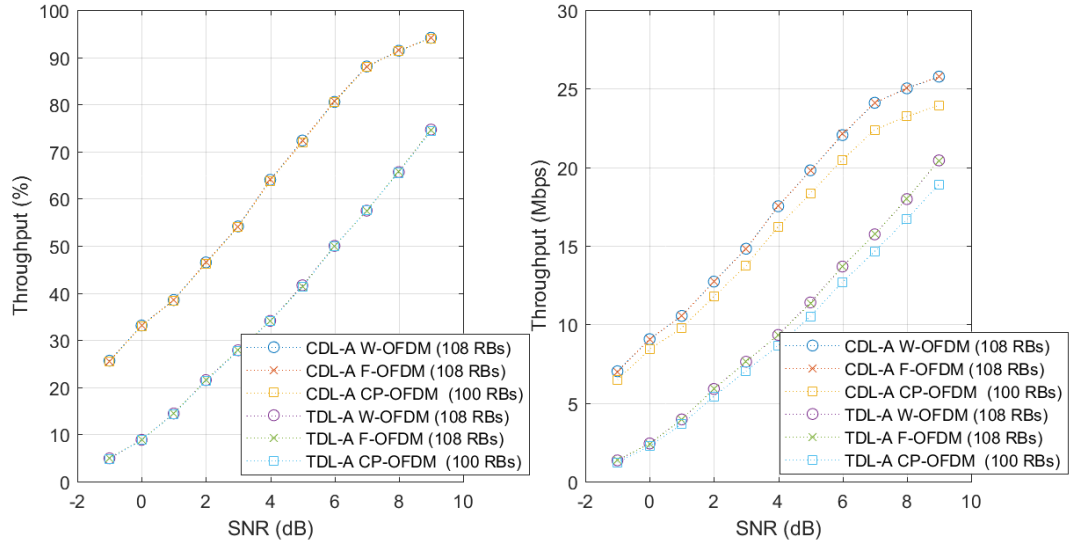
5G End-To-End Link Level Simulation

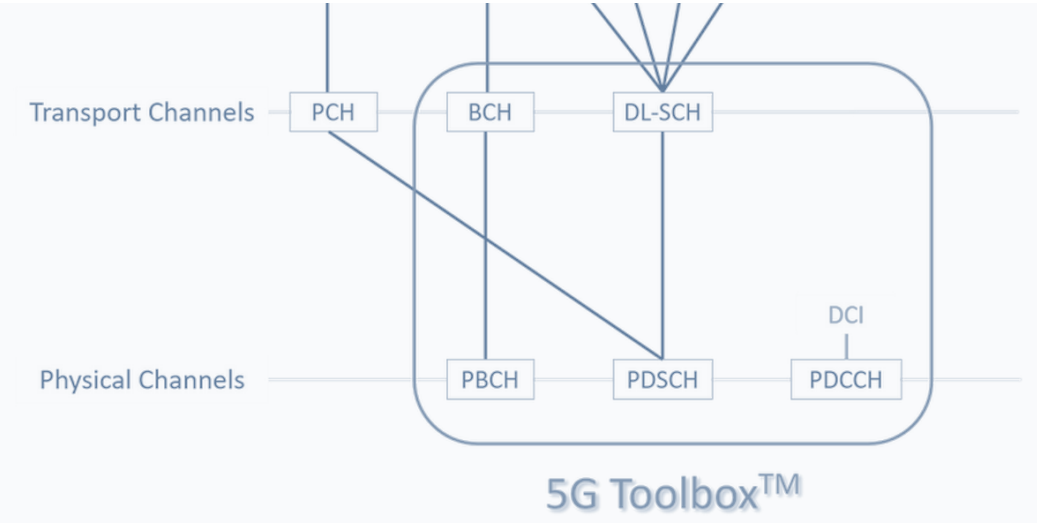
- Physical layer reference model
- Evaluate impact of algorithm designs on link performance
- Verify algorithm implementation and performance

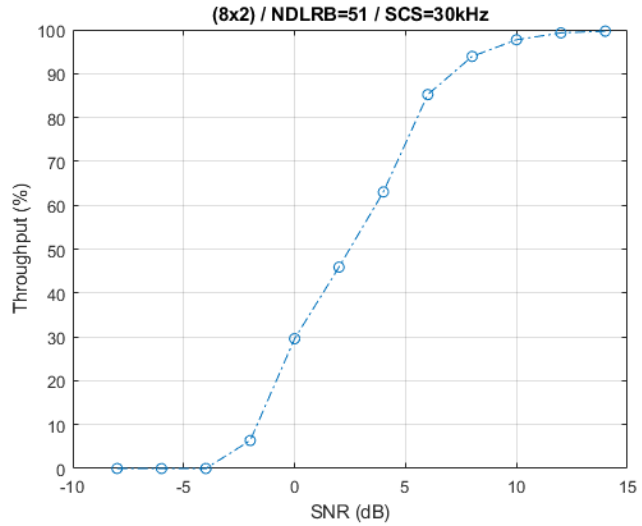


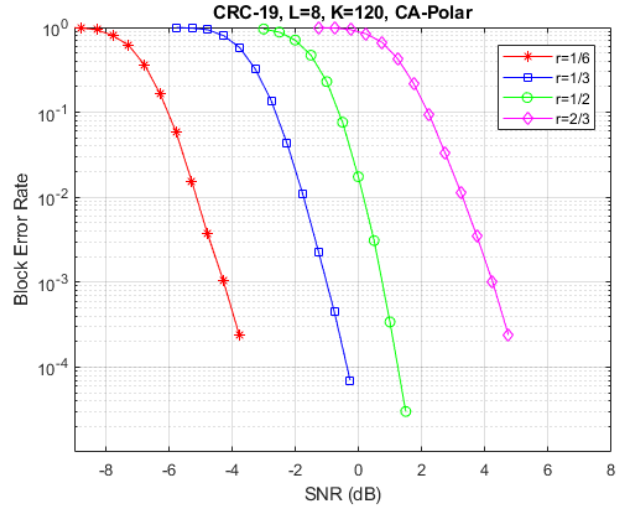


Transport Channel Processing

- Cyclic redundancy check (CRC) encoding and decoding
- DL-SCH: Low-density parity-check (LDPC) encoding, decoding, rate matching, and rate recovery
  - LDPC code block segmentation and de-segmentation
- DCI and BCH: Polar encoding, decoding, rate matching, and rate recovery

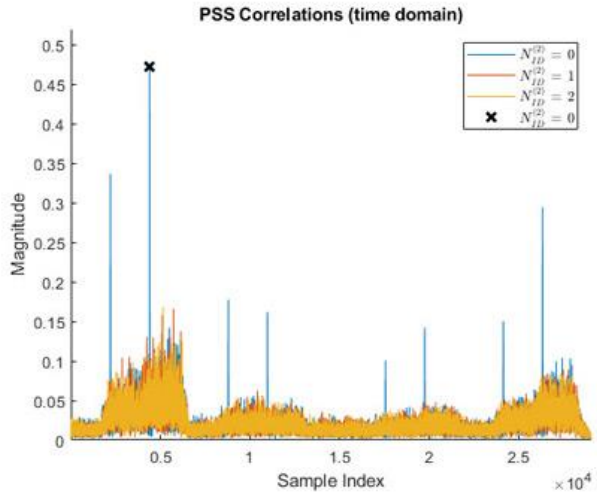


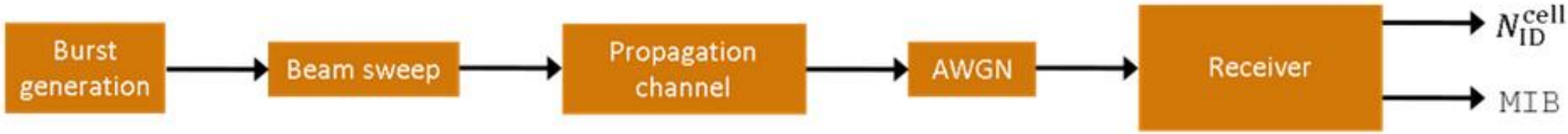




Cell Search and Selection Procedures

- Obtain cell ID and initial system information including Master Information Block (MIB)
- Perform the following steps:
  - Burst generation
  - Beam sweep
  - TDL propagation channel model and AWGN
  - Receiver synchronization and demodulation



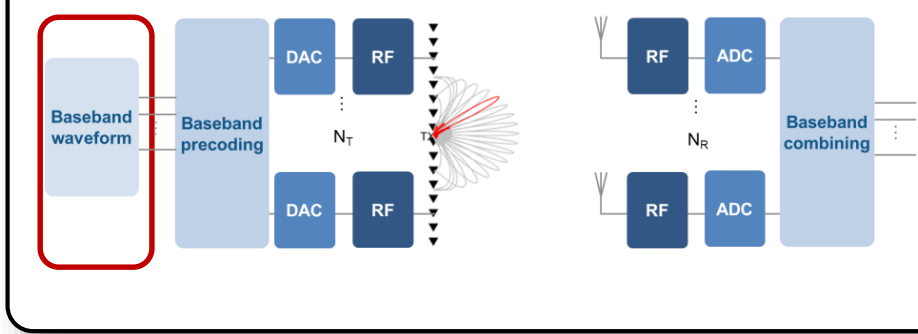


It’s Not Only About 5G …

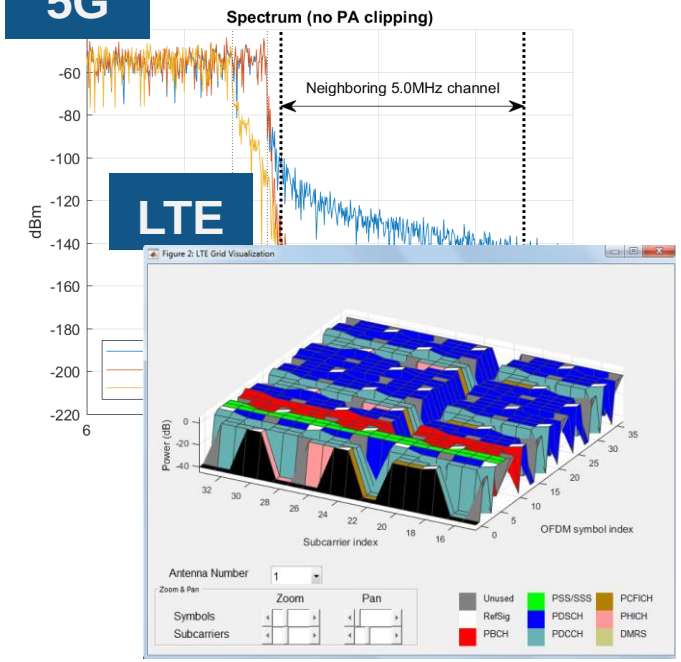
Waveform Generation

- Test with standard-compliant waveforms
- Generate all physical channels and signals
- Off-the-shelf and full custom waveforms

Standard compliance

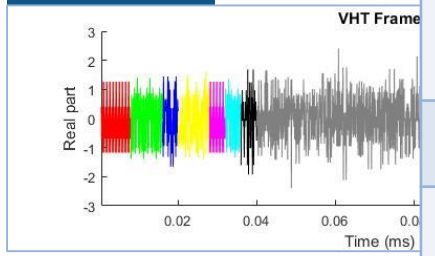


5G



3GPP
✓ LTE & LTE-Advanced
✓ V2X Sidelink
✓ D2D Sidelink
✓ **LTE-M**
✓ **NB-IoT**

WLAN



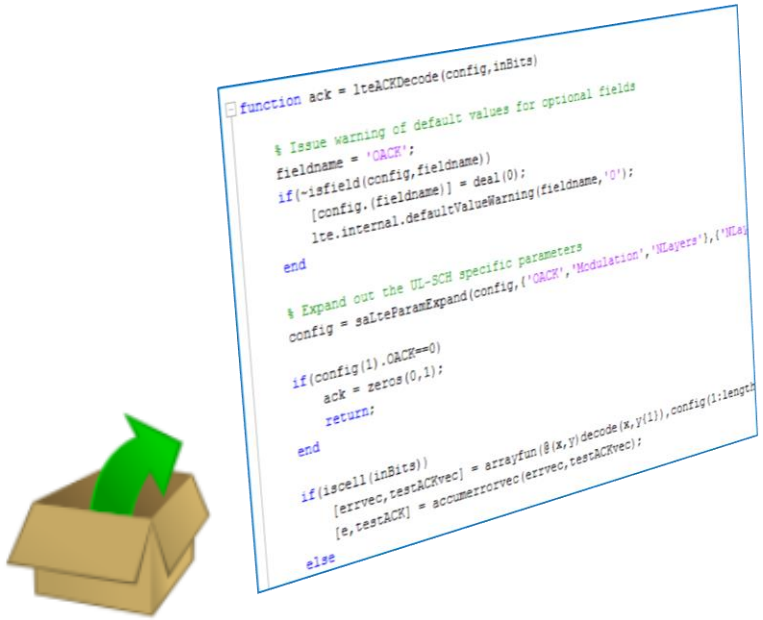
IEEE 802.11
✓ **802.11ax (draft)**
✓ 802.11ad
✓ 802.11ah
✓ 802.11ac
✓ 802.11a/b/g/n
✓ 802.11p/j

Agenda

- 5G goals and requirements
- Modeling and simulating 5G PHY signals
- 5G development workflow

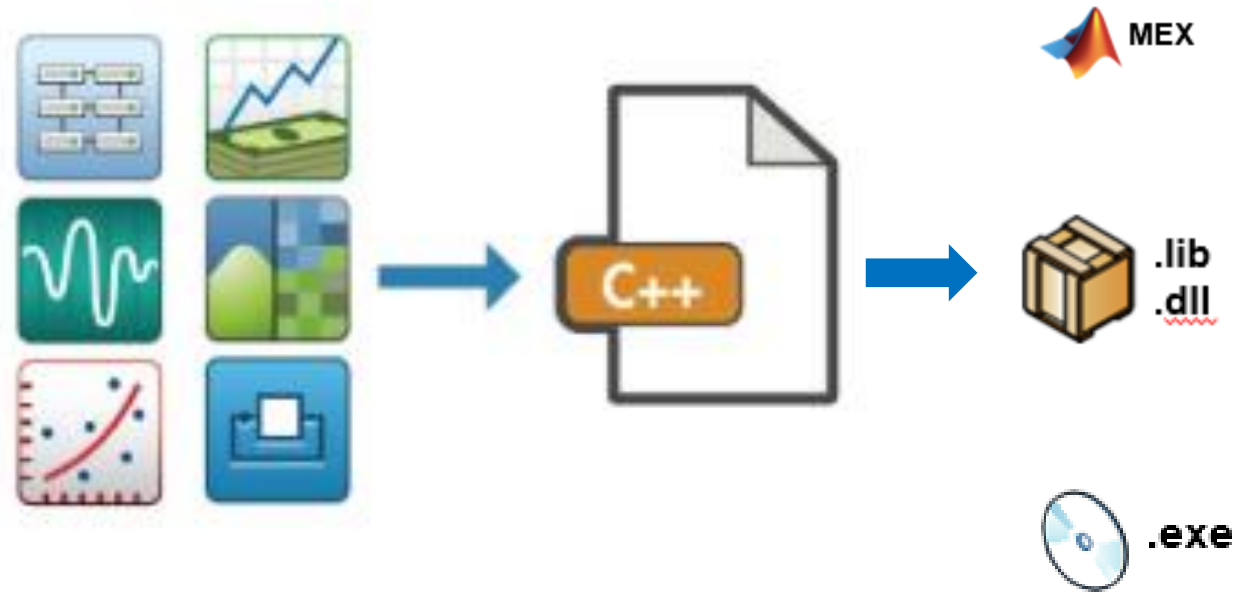
5G Toolbox Has Open Customizable Algorithms

- All functions are open, editable, customizable MATLAB code



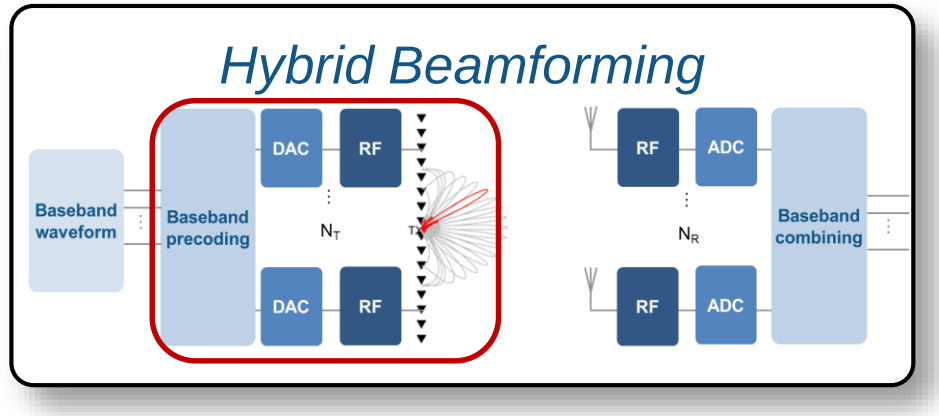
```
function ack = lteACKDecode(config,inBits)

    % Issue warning of default values for optional fields
    fieldname = 'OACK';
    if(~isfield(config,fieldname))
        [config.(fieldname)] = deal(0);
        lte.internal.defaultValueWarning(fieldname,'0');
    end

    % Expand out the UL-SCH specific parameters
    config = saLteParamExpand(config,{'OACK','Modulation','NLayers'},{'NLa

    if(config(1).OACK==0)
        ack = zeros(0,1);
        return;
    end

    if(iscell(inBits))
        [errvec,testACKvec] = arrayfun(@(x,y)decode(x,y(1)),config(1:length
        [e,testACK] = accumerrorvec(errvec,testACKvec);
    else
```

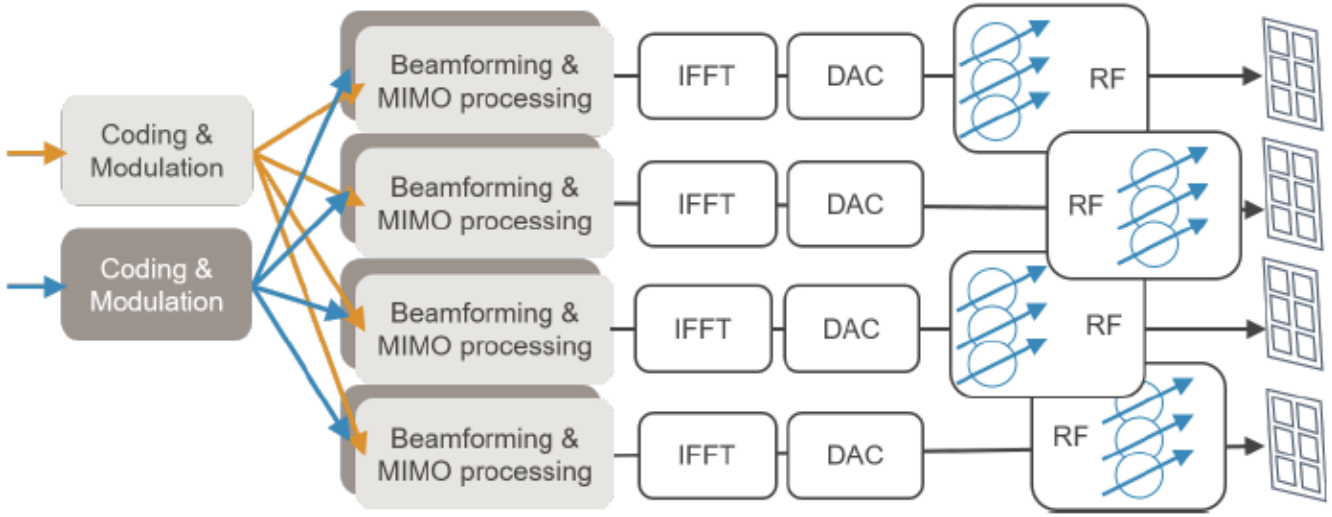
- C/C++ code generation supported with MATLAB Coder



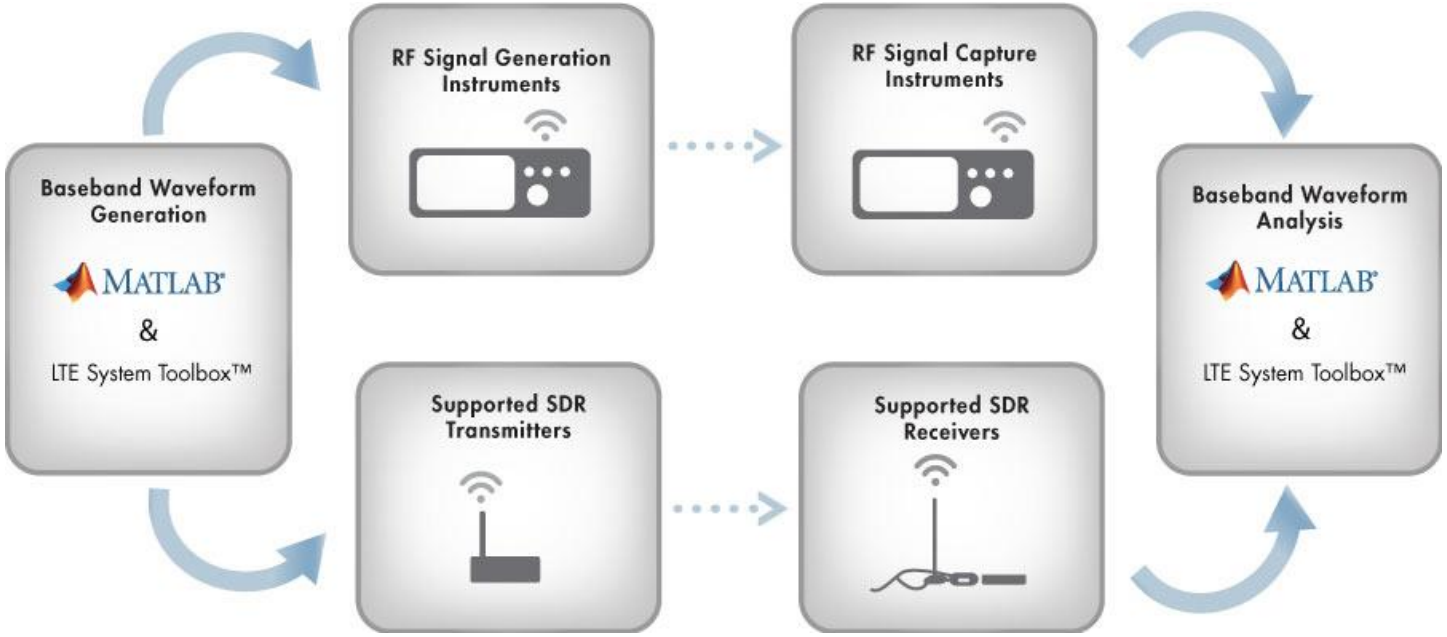
Hybrid Beamforming for Massive MIMO

- Beamforming partitioned between digital and RF
  - Each Tx and Rx element has phase control
  - Subarrays handle amplitude and additional phase
  - Number of transmit antennas can be >> N_S (N_{RF})
- Model and optimize beamforming architecture
- Model imperfections in the signal chain





Over-the-Air Testing with SDR and RF Instruments



Ettus USRP SDR

RTL-SDR

Pluto SDR

Zynq SDR

RF Signal Generator

Spectrum Analyzer

Summary

- 5G Toolbox enables you to simulate, analyse, test 5G wireless communications systems
- Standard-compliant MATLAB functions based on Rel. 15 of 3GPP 5G NR standard
  - Waveform generation
  - Downlink Physical Channels and Signals
  - Link-level simulation including PDSCH Throughput Simulation
  - Cell search procedure with MIB decoding
  - LDPC and Polar Coding algorithms
  - TR 38.901 CDL and TDL Propagation Channels
- MATLAB & Simulink provide a complete Wireless Design Environment