MATLAB EXPO 2018

What’s Behind 5G Wireless Communications?

M.Sc. Fatih Genç, FİGES

Agenda

- **5G goals and requirements**
- **Modeling and simulating key 5G technologies**
  - Release 15: Enhanced Mobile Broadband
  - IoT and V2X
- **5G development workflow**

3GPP Standardization Timeline

Dec-17

Release 15
- Non-standalone
- 5G New Radio with LTE core network

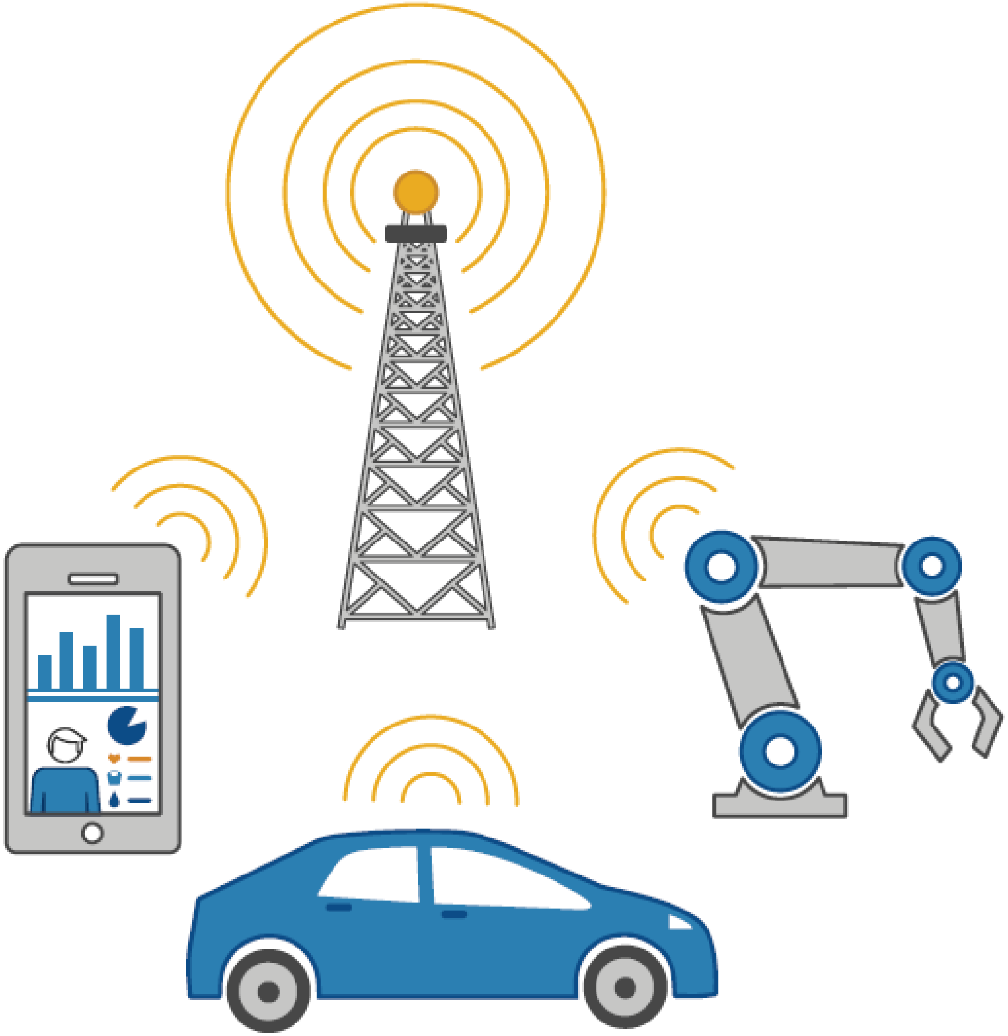
Jun-18

Release 15
- Standalone
- 5G core network

Mar-20

Release 16
- 5G Phase 2

5G Applications and Requirements



New Applications

4K, 8K, 360° Video

Virtual Reality

Connected Vehicles

Internet of Things

5G Requirements / Use Cases

Enhanced mobile broadband (>10 Gbps)

Ultra low latency (<1 ms)

Massive machine-type communication (>1e5 devices)

Achieving Higher 5G Broadband Data Rates

Technical Solutions

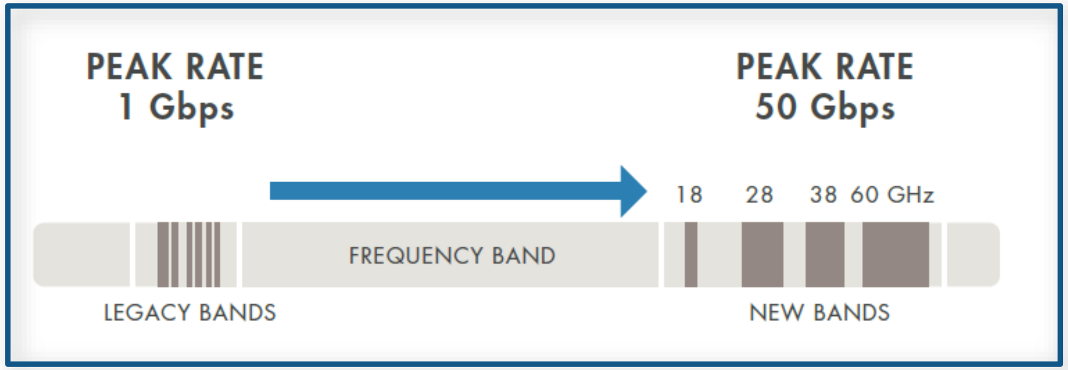
Increased bandwidth

Better spectral efficiency

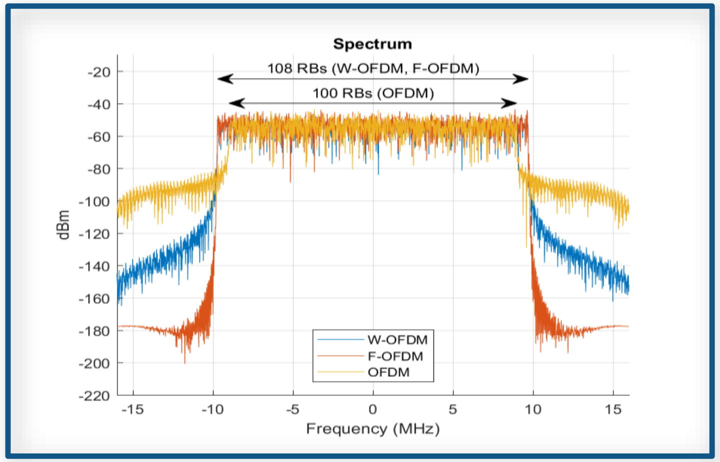
Flexible air interface

Densification

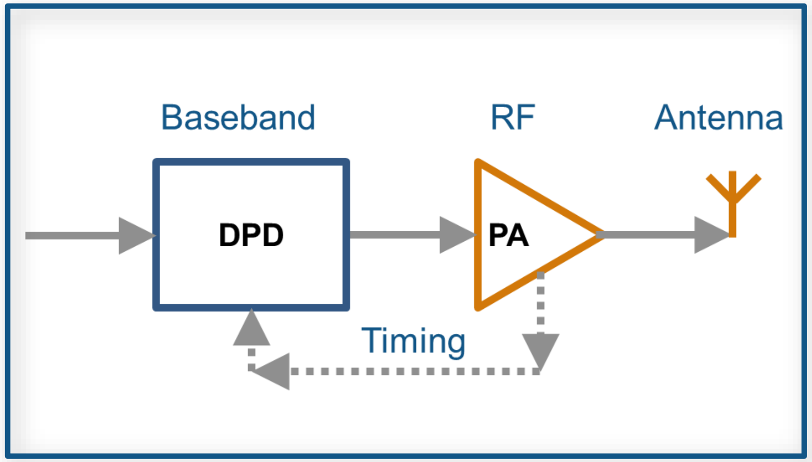
Higher Frequency Bands



New Physical Layer



New RF Architectures



Massive MIMO

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

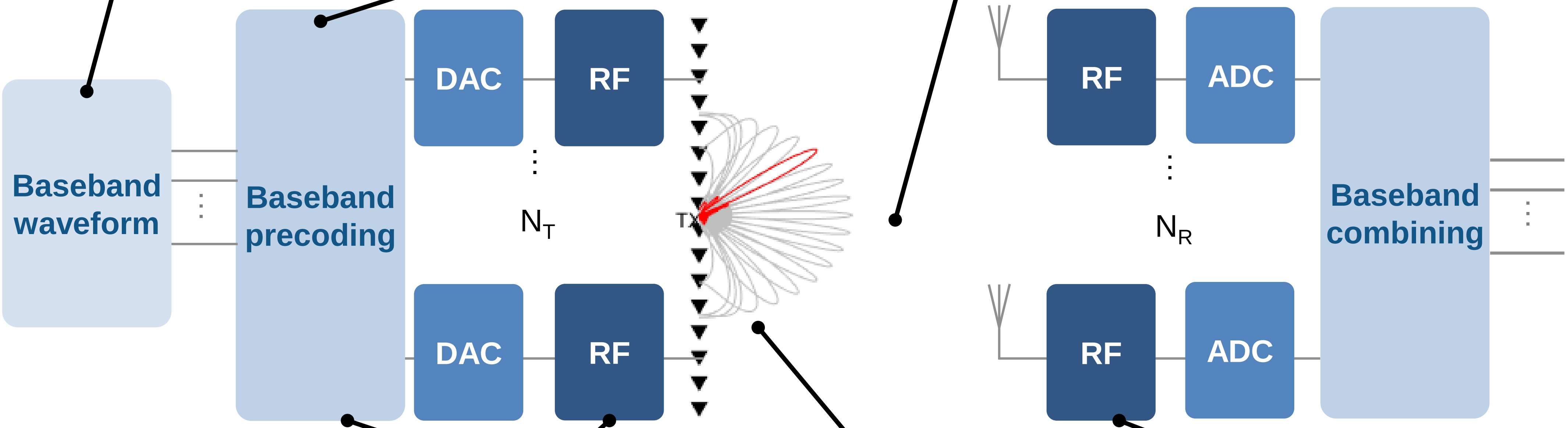
Multi-Domain Engineering for 5G

Subsystems must be designed and tested together

Standard-compliant Waveforms

Baseband DSP for Large Bandwidths

Channel and Interference



Digital or Hybrid Beamforming

MIMO Antenna Array Design

RF Transceivers and Power Amplifiers

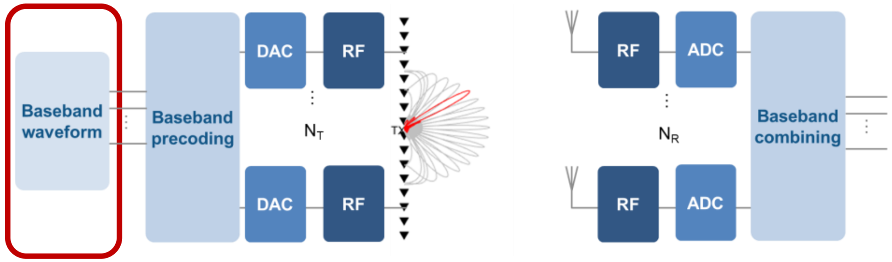
Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
  - Release 15: Enhanced Mobile Broadband
  - IoT and V2X
- 5G development workflow

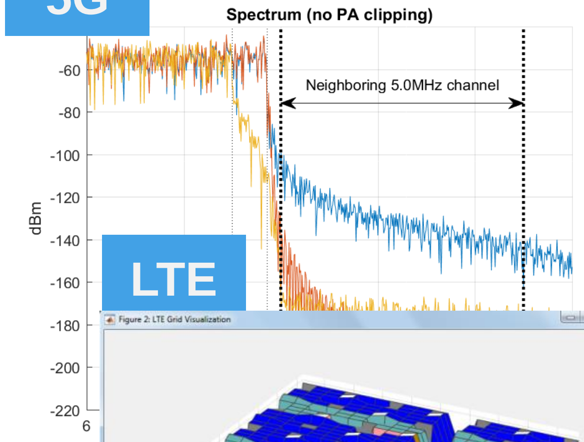
Waveform Generation

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

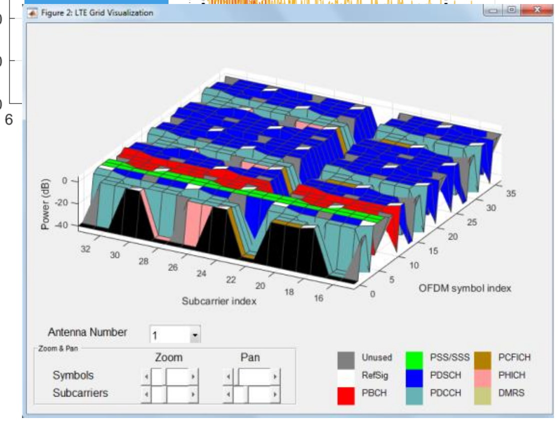
Standard compliance



5G

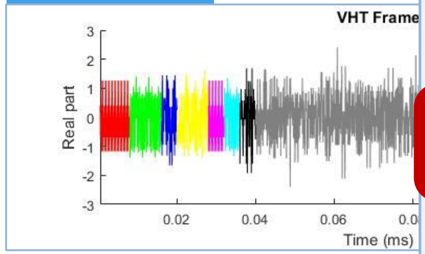


LTE



3GPP
✓ LTE & LTE-Advanced
✓ NB-IoT
✓ D2D Sidelink
✓ V2X Sidelink
✓ *5G New Radio* R2018a

WLAN



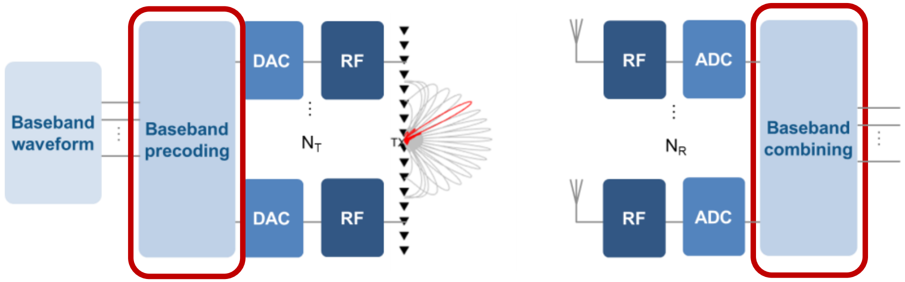
IEEE 802.11
✓ *802.11ax (draft)* R2018a
✓ 802.11ad
✓ 802.11ah
✓ 802.11ac
✓ 802.11a/b/g/n
✓ 802.11p/j

New Physical Layer in Release 15

- Enhanced Mobile Broadband (eMBB):
  - Larger bandwidth
  - Greater spectral efficiency
- PHY techniques used to achieve goals
  - Flexible frame structure and carrier spacing
    - Shorter latency
    - Variable bandwidth
  - Higher capacity coding schemes
  - Channel models: sub-6GHz to mmWave

5G Baseband Processing

- Increased bandwidth
- Greater spectral efficiency

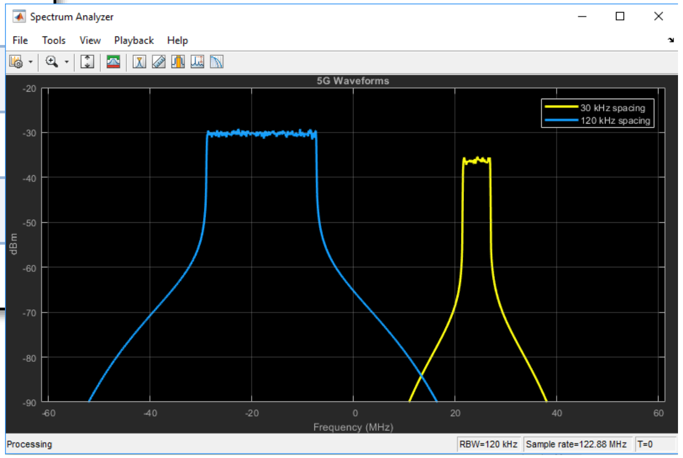


Baseband DSP for Large Bandwidths

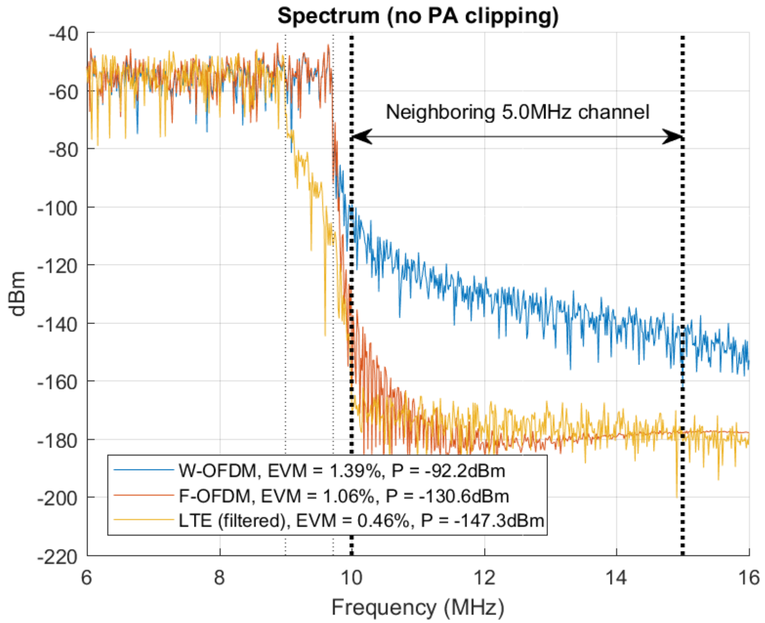
- 5G waveform same as LTE: Cyclic-Prefix OFDM (CP-OFDM)
- New baseband techniques for higher capacity

μ	Subcarrier Spacing $\Delta f = 2^{\mu} * 15\text{kHz}$	Bandwidth (MHz)
0	15	49.50
1	30	99
2	60	198
3	120	396
4	240	397.44
5	480	397.44

R2018a



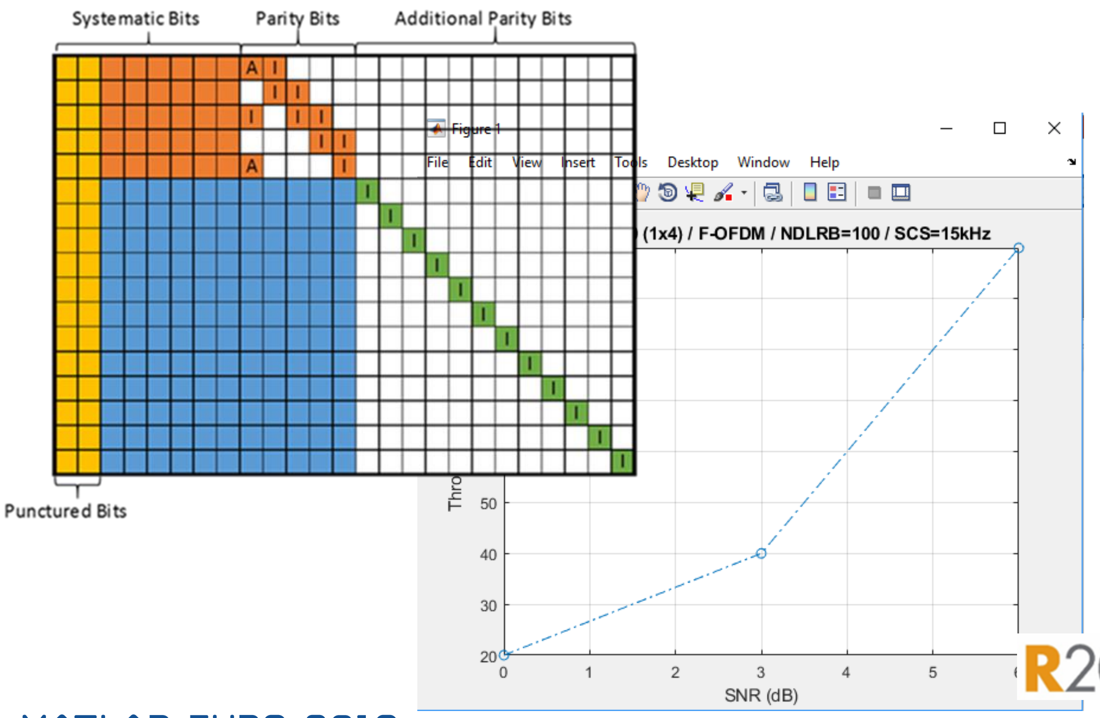
Increase bandwidth and reduce latency with flexible subcarrier spacing



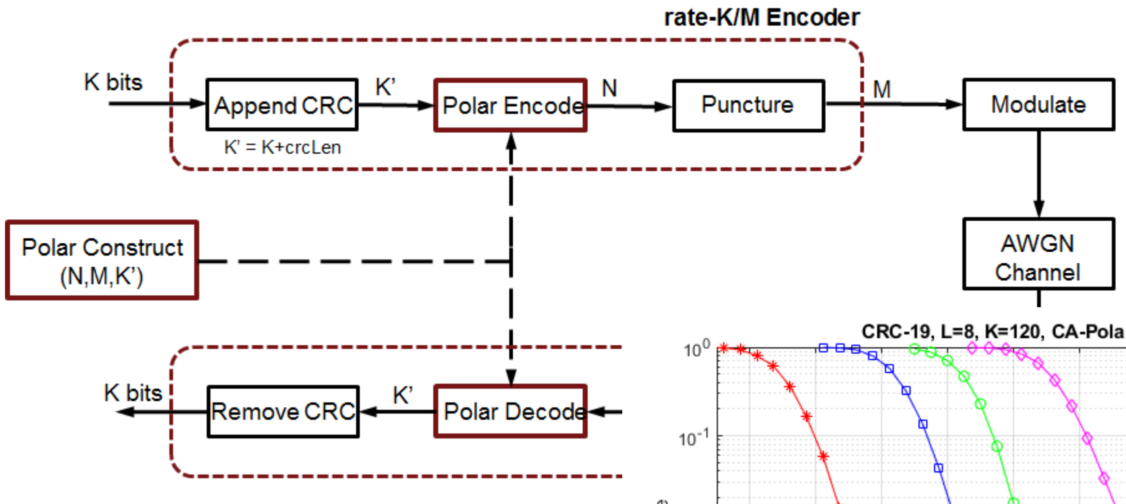
Reduce spectral leakage with filtering or windowing

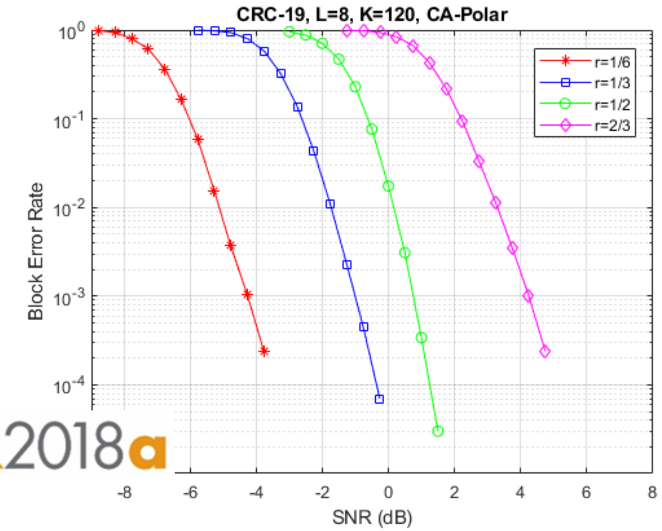
Efficient Channel Coding Methods

- Low-Density Parity Check (LDPC) for data channel: memoryless block coding



- Polar Codes for control channel: achieve channel capacity

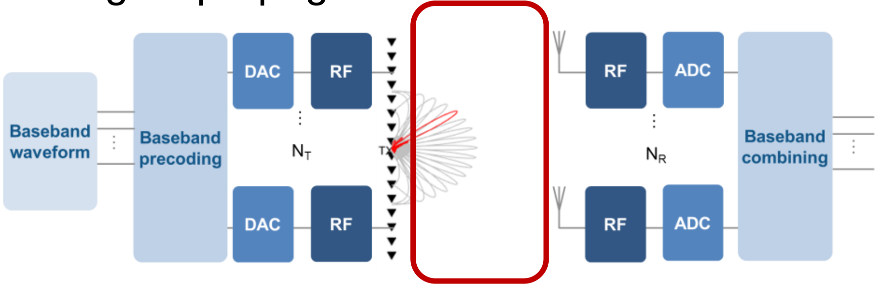


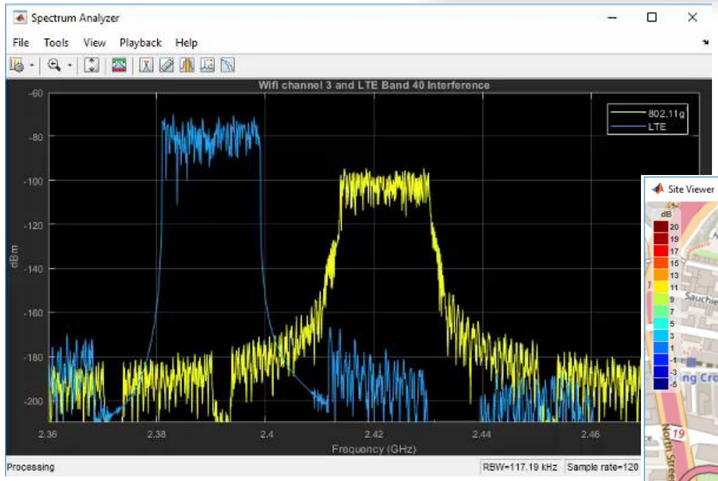


Model Channel and Interference

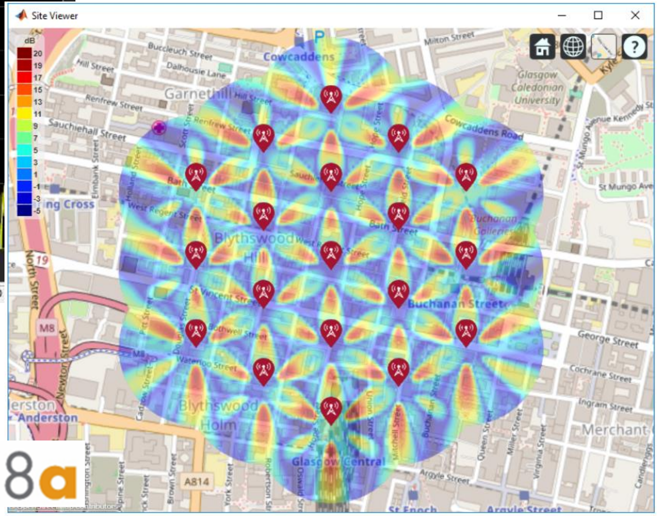
- Interference
  - Multiple standards: 5G/LTE/WLAN
- 3D propagation channels
  - 5G, LTE, 802.11, Custom
- Visualize propagation on maps
  - Rx/Tx location
  - Signal strength and coverage
  - Signal-to-interference-plus-noise (SINR)

Channel and Interference
- Multiple UEs/Base Stations
- Signal propagation





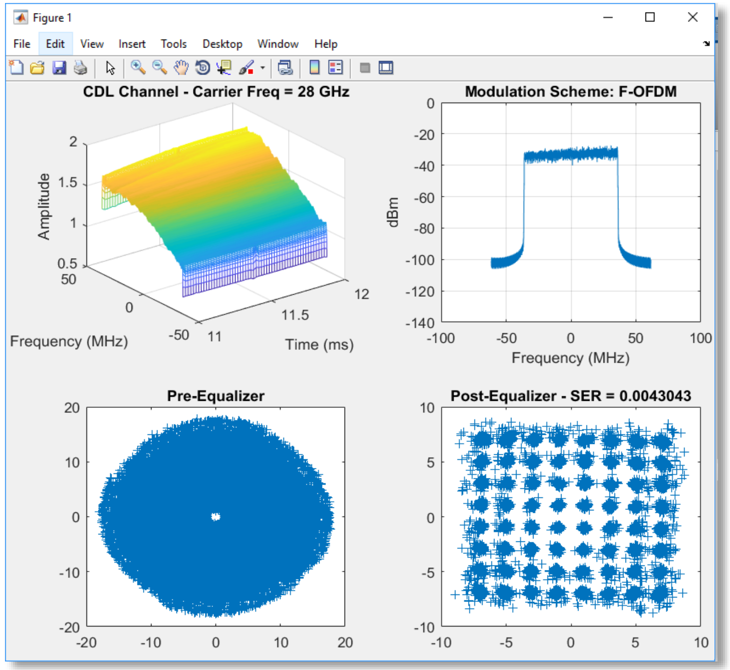
LTE-WLAN interference



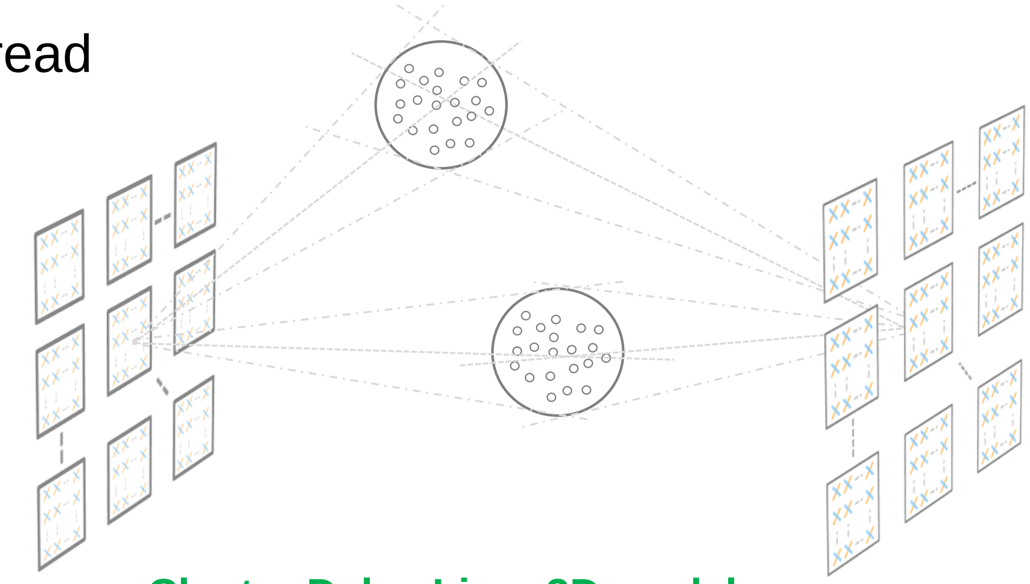
R2018a

SINR for 5G urban macro-cell

5G Channel Model



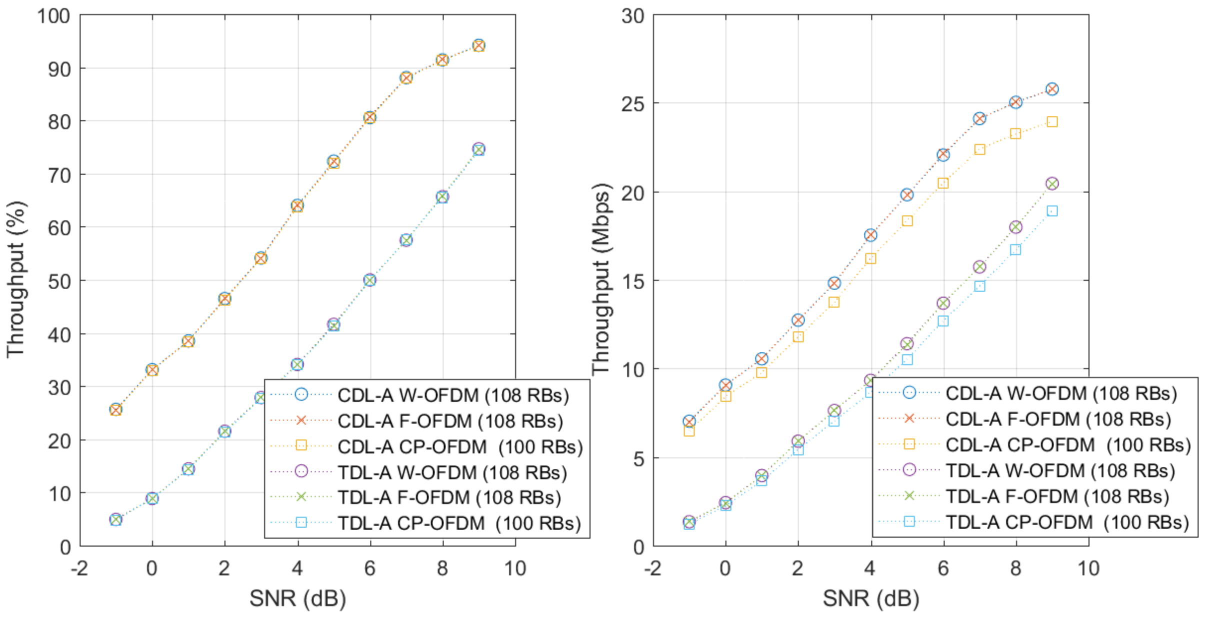
- 3GPP TR 38.901: 500 MHz - 100 GHz (mmWave)
- For massive MIMO arrays (>1024 elements)
- Delay profiles:
  - Clustered delay line (CDL): Full 3D model
  - Tapped delay line (TDL): Simplified for faster simulation
- Control key parameters
  - Channel delay spread
  - Doppler shift
  - MIMO correlation

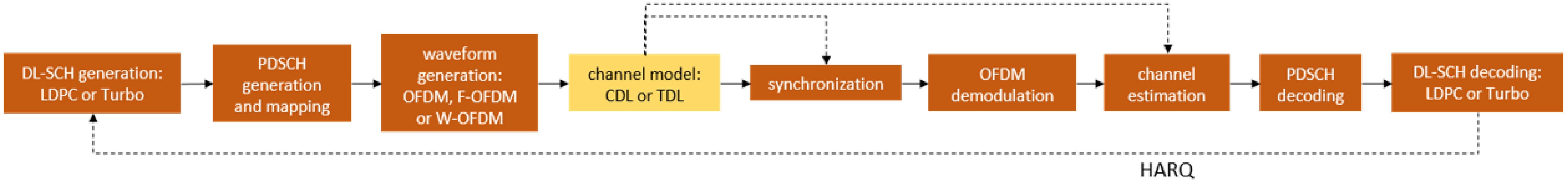


Cluster Delay Line: 3D model

5G Link Level Simulation

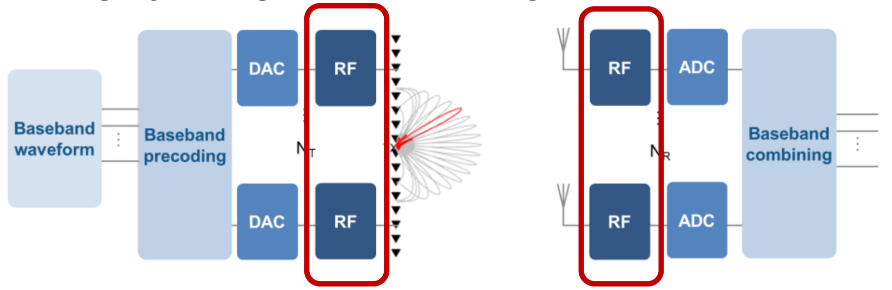
- End-to-end physical layer reference model
- Verify implementation
- Evaluate impact of algorithm designs on link performance





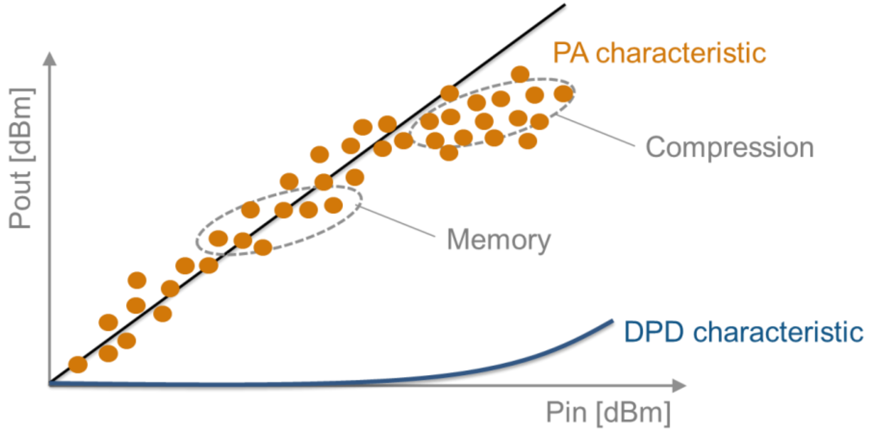
RF Power Amplifier (PA) Linearization

RF challenges in 5G
- Frequency dependent behavior
- Highly integrated RF + digital devices

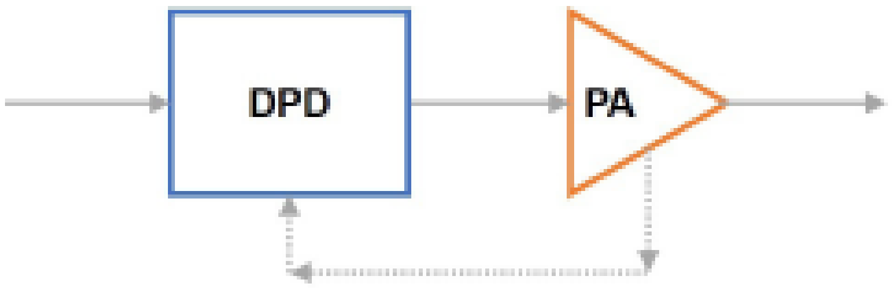


- 5G frequencies and bandwidth put greater requirements on RF transmitter efficiency

- 5G PA's are difficult to model
  - Non-linearity
  - Memory effects

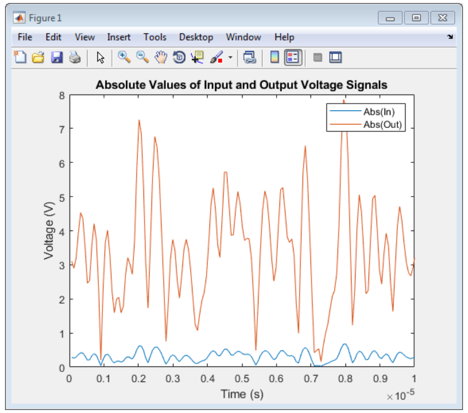


- Solution: Linearization using adaptive digital pre-distortion (DPD)



Characterize PA Model Using Measured Data

PA Data

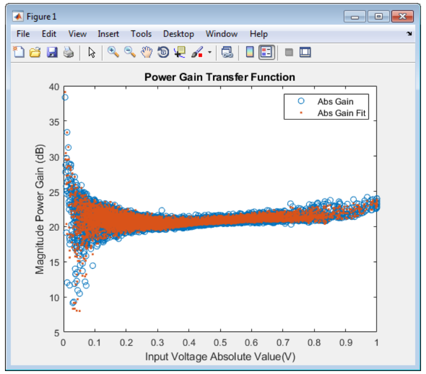


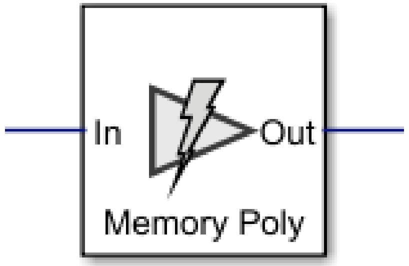
MATLAB fitting procedure (White box)

```
function a_coef = fit_memory_poly_model(x,y,memLen,degLen,modType)
% FIT_MEMORY_POLY_MODEL
%   Procedure to compute a coefficient matrix given input and output
%   signals, memory length, nonlinearity degree, and model type.
%
%   Copyright 2017 MathWorks, Inc.

x = x(:);
y = y(:);
xLen = length(x);

switch modType
  case 'memPoly'  % Memory polynomial
    xrow = reshape((memLen:-1:1)' + (0:xLen:xLen*(degLen-1)),1,[]);
    xVec = (0:xLen-memLen)' + xrow;
    xPow = x.*(abs(x).^(0:degLen-1));
    xVec = xPow(xVec);
  case 'ctMemPoly'  % Cross-term memory polynomial
    absPow = (abs(x).^(1:degLen-1));
    partTop1 = reshape((memLen:-1:1)'+(0:xLen:xLen*(degLen-2)),1,[]);
    topPlane = reshape(                                                  ...
        [ones(xLen-memLen+1,1),absPow((0:xLen-memLen)' + partTop1)].',   ...
        1,memLen*(degLen-1)+1,xLen-memLen+1);
    sidePlane = reshape(x((0:xLen-memLen)' + (memLen:-1:1)).',          ...
        memLen,1,xLen-memLen+1);
    cube = sidePlane.*topPlane;
    xVec = reshape(cube,memLen*(degLen-1)+1),xLen-memLen+1).';
end

coef = xVec\y(memLen:xLen);
a_coef = reshape(coef,memLen,numel(coef)/memLen);
```

R2018a

MATLAB PA model

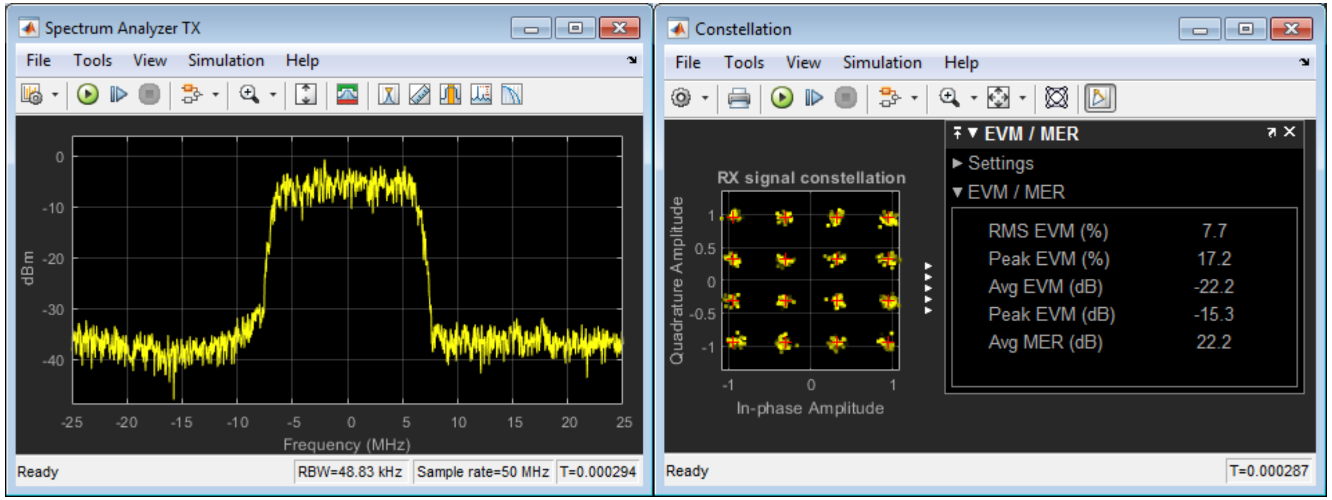


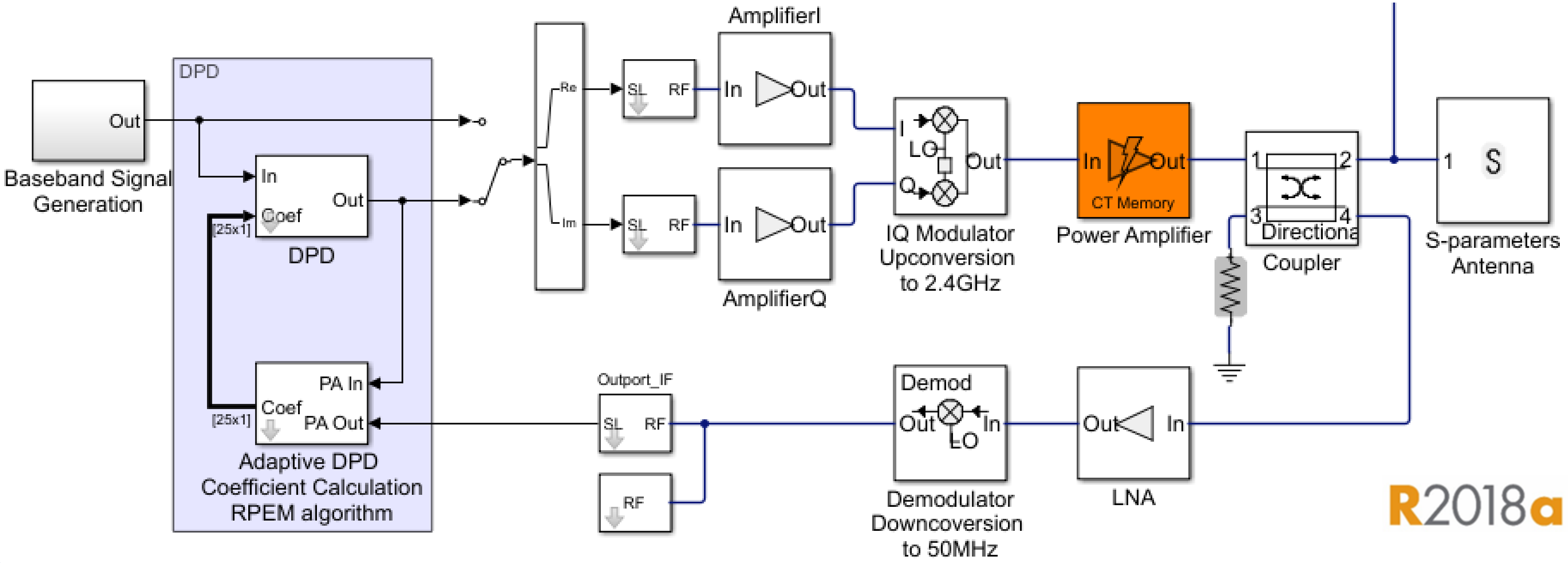


PA model for circuit envelope simulation

PA + DPD Simulation

- Closed loop multi-domain simulation
  - Circuit Envelope for fast RF simulation
  - Low-power RF and analog components
  - DPD signal processing algorithm (behavioral or hardware-accurate)



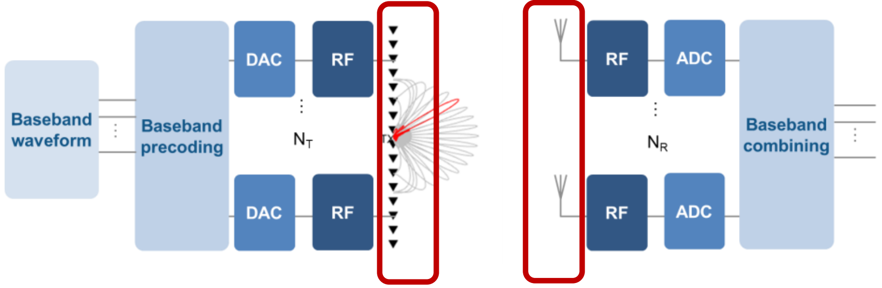


R2018a

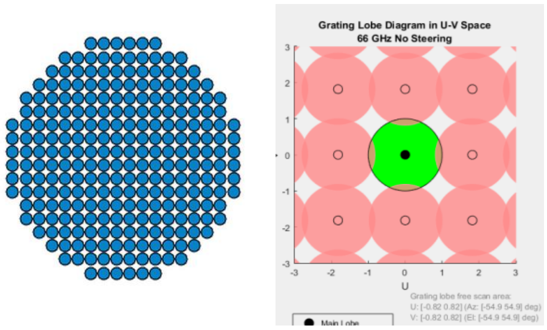
Massive MIMO Antenna Arrays

- Model antenna and array beam patterns
- Model antenna element failures
- Optimize tradeoffs between antenna gain and channel capacity
- Simulate with 3D channel model

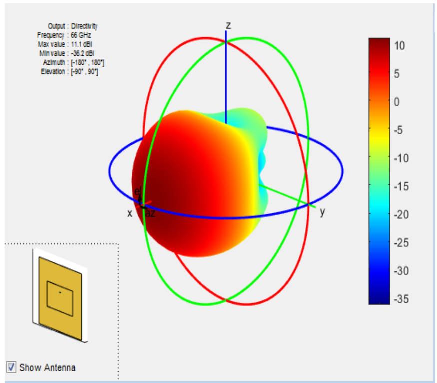
Antenna array design considerations
- Element coupling
- Imperfections



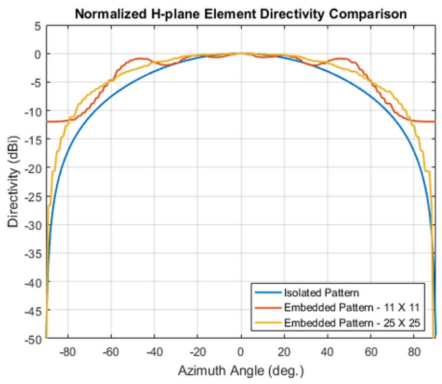
Design an array



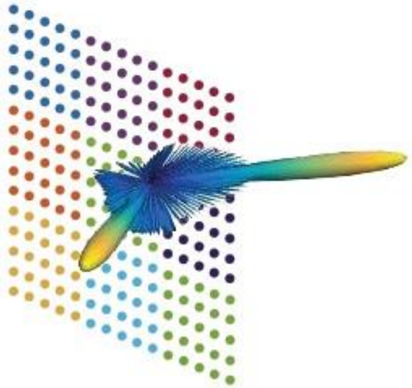
Import antenna patterns



Model mutual coupling



Array beam pattern

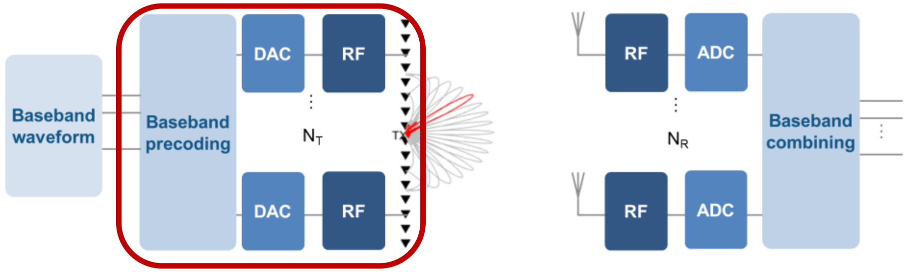


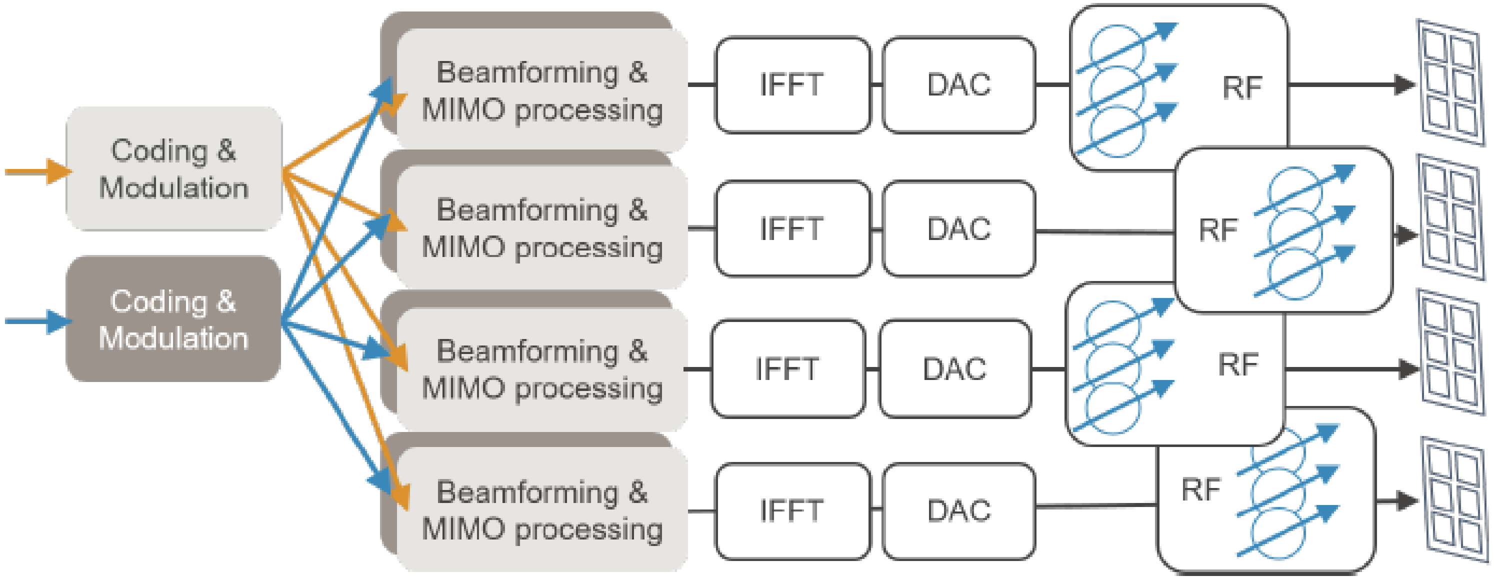
Hybrid Beamforming for Massive MIMO

- 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

Why Hybrid Beamforming?

- Massive MIMO reduces mmWave propagation loss
- Hybrid beamforming reduces implementation cost



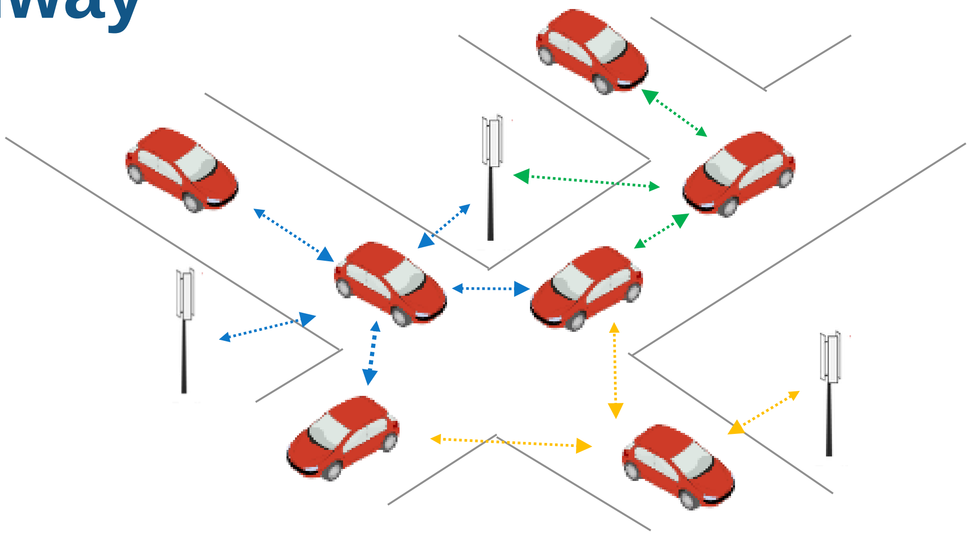


Different realizations have different complexity tradeoffs

Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
  - Release 15: Enhanced Mobile Broadband
  - Connecting Vehicles and IoT Devices
- 5G development workflow

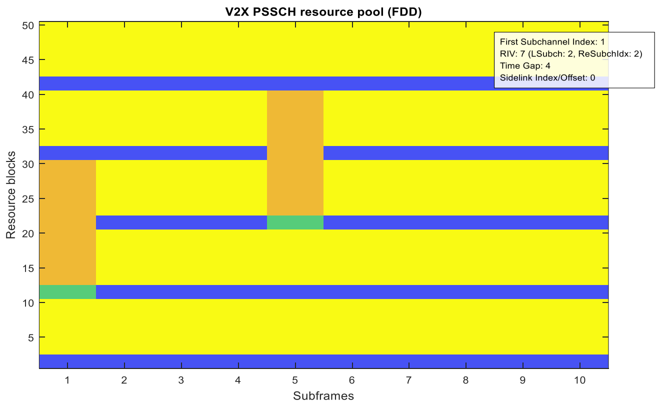
V2X: Building the Connected Car Highway



Standards for V2X

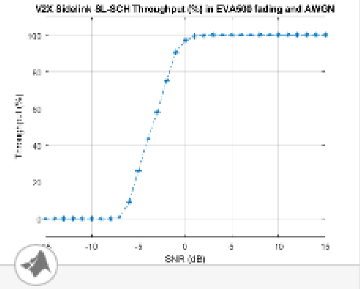
- 5G: Reserved for future release
- Cellular V2X (C-V2X)
  - Release 14 LTE Sidelink
  - **LTE System Toolbox**
- DSRC
  - IEEE 802.11p
  - **WLAN System Toolbox**

PHY Waveform Generation



Throughput Simulation

R2017b

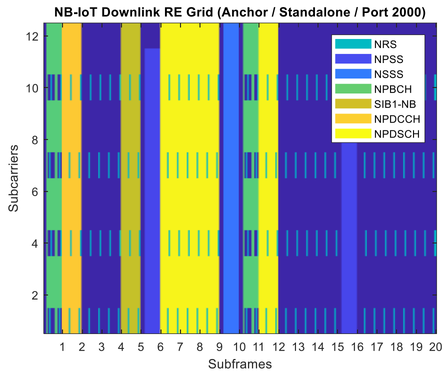


Release 14 V2X Sidelink PSCCH and PSSCH Throughput

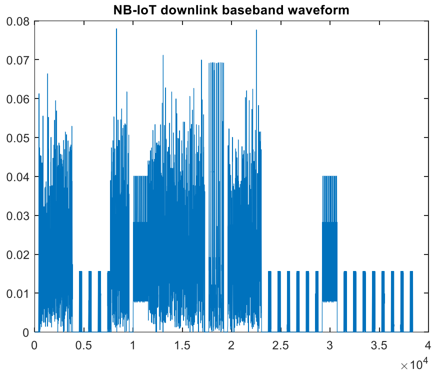
Demonstrates how to measure the Physical Sidelink Shared Channel (PSSCH) and Physical Sidelink Control Channel (PSCCH)

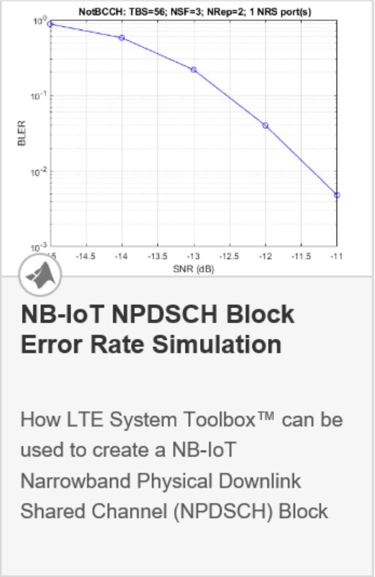
Future 5G Use Case: IoT Connectivity

- IoT use case reserved for future 5G release
- Cellular long-range standard: LTE NB-IoT
  - Compatible with LTE networks
  - Lower cost and power, extended range
- NB-IoT cost and power reduction techniques
  - Reduced peak rate and bandwidth (180 kHz)
  - Reduced maximum transmit power
  - Single antenna
  - No higher-order modulation (BPSK and QPSK)



Waveform Generation



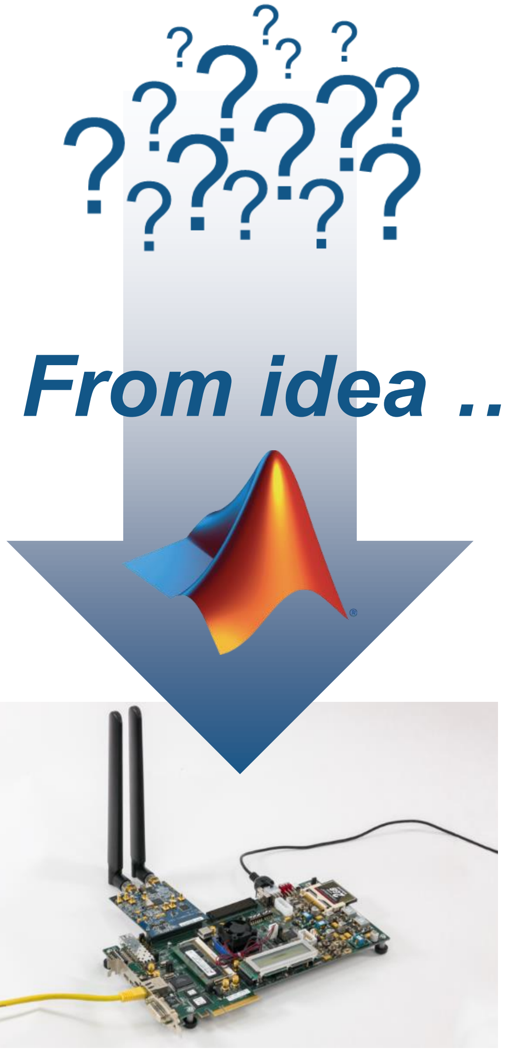


R2018a

BLER Simulation

Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
  - Release 15: Enhanced Mobile Broadband
  - Connecting Vehicles and IoT Devices
- 5G development workflow



… to implementation

Customer Perspective

“We need a multidomain platform for simulation, rapid prototyping, and iterative verification from the behavior model to testbed prototyping to the industrial product. MATLAB and Simulink are helping us to achieve these goals.”

- Kevin Law, director of algorithm architecture and design, Huawei

> **Can you tell us more about how MATLAB and Simulink are helping you?**
>
> These two platforms play an important role in our innovation areas like 5G, optical communication, and wireless terminals. The tools give us top-down Model-Based Design, a product ecosystem that covers multiple domains, and code generation and iterative verification.

https://www.mathworks.com/content/dam/mathworks/tag-team/Objects/h/80861v00_Huawei_QA.pdf

MATLAB & Simulink Wireless Design Environment

for baseband, RF, and antenna modeling and simulation

Algorithms, Waveforms, Measurements

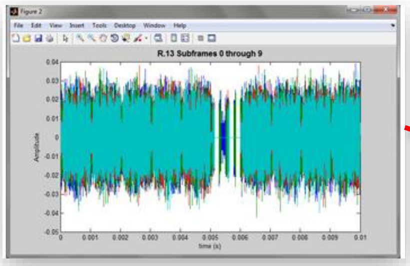
- Communications System Toolbox
- LTE System Toolbox (5G Library)
- WLAN System Toolbox

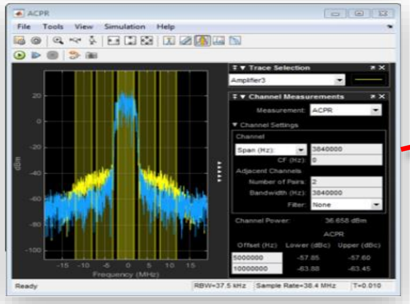
RF Front End

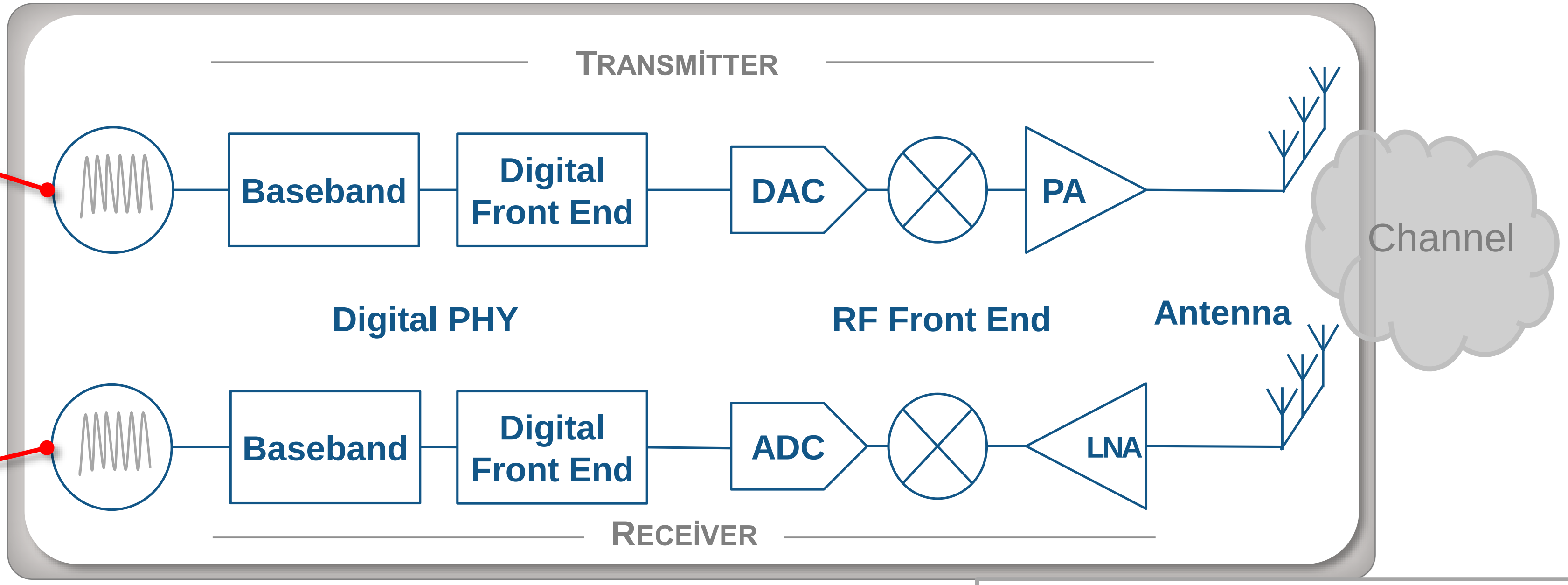
- RF Toolbox
- RF Blockset

Antennas, Beamforming

- Antenna Toolbox
- Phased Array System Toolbox







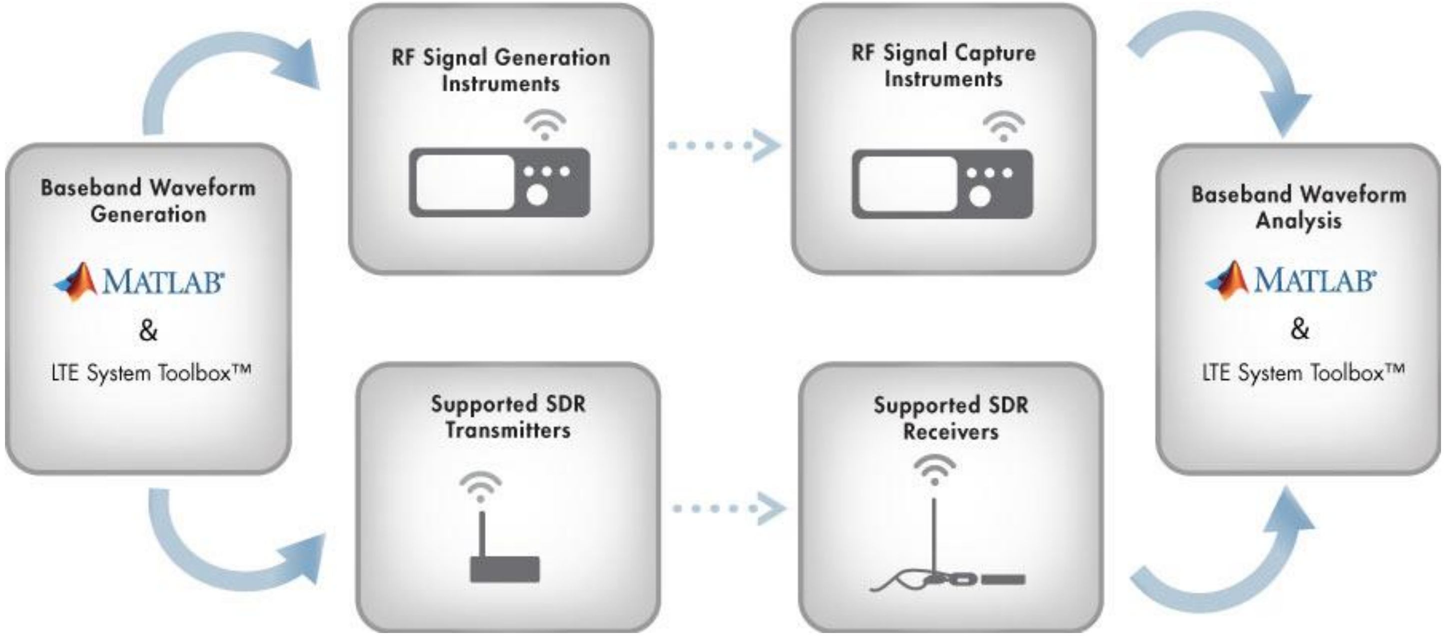
- Simulink
- DSP System Toolbox
- Control System Toolbox

Mixed-signal

- Communications System Toolbox
- Antenna Toolbox
- LTE System Toolbox
- WLAN System Toolbox

Channel and Propagation

Over-the-Air Testing with SDR and RF Instruments



Ettus USRP SDR

RTL-SDR

Pluto SDR

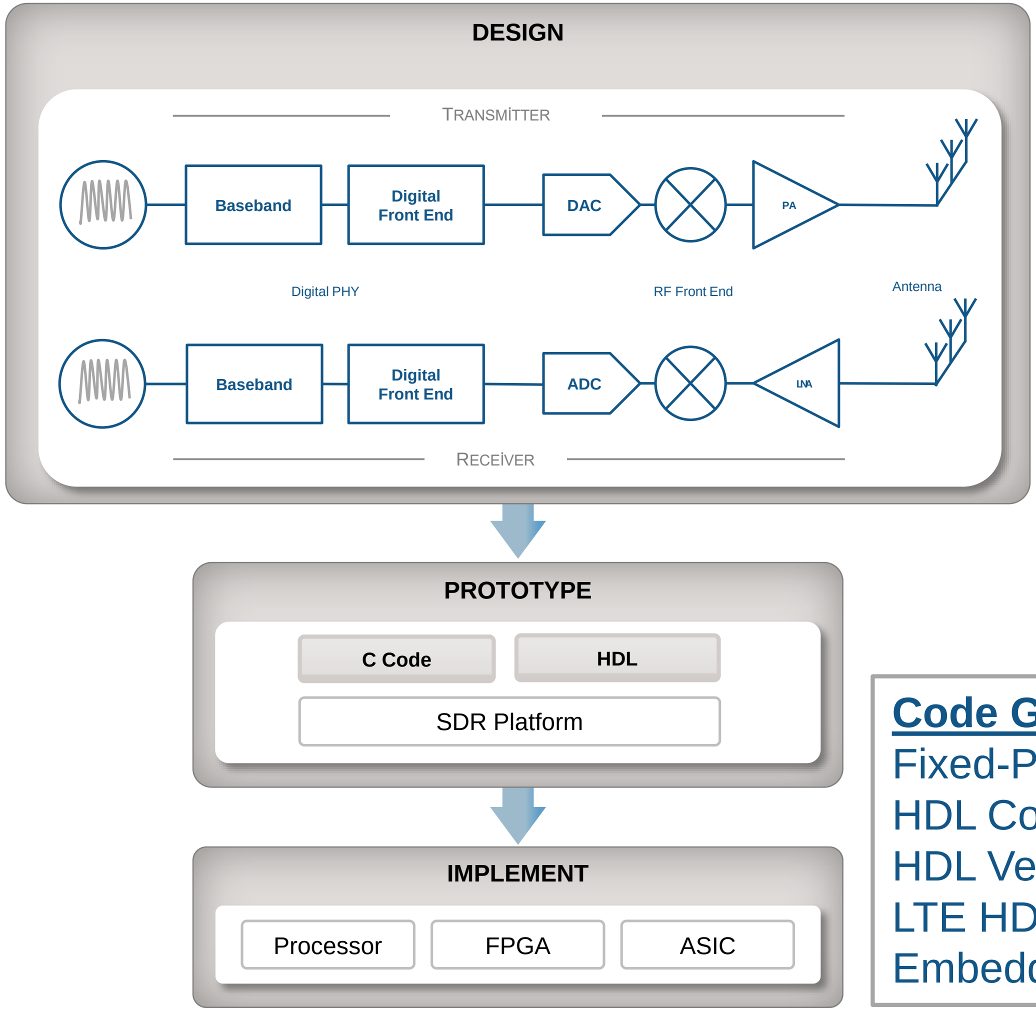
Zynq SDR

RF Signal Generator

Spectrum Analyzer

[Over-the-air Testing]()
Instrument Control Toolbox
SDR Support Packages
Communications System Toolbox

Common Platform for Wireless Development



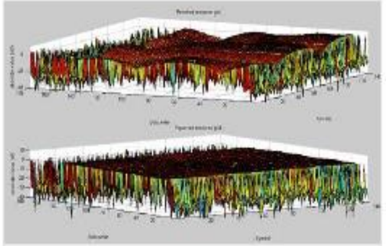
- Algorithm Design and Verification
- RF, Digital and Antenna Co-Design
- System Verification and Testing
- Rapid Prototyping and Production

Code Generation and Verification
Fixed-Point Designer
HDL Coder
HDL Verifier
LTE HDL Toolbox R2017b
Embedded Coder

Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
  - Release 15: Enhanced Mobile Broadband
  - Connecting Vehicles and IoT Devices
- 5G development workflow
- Learn more…

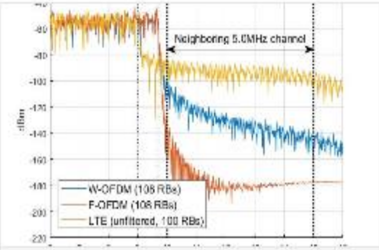
Resources to Help You Get Started – Links in PDF Document



Conformance Testing

Ensure your designs comply with the supported 3GPP LTE standard releases.

» Learn more

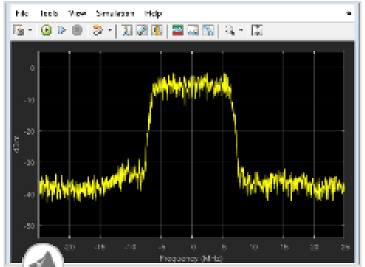


5G Library

Simulate 3GPP 5G new radio technologies.

» Learn more

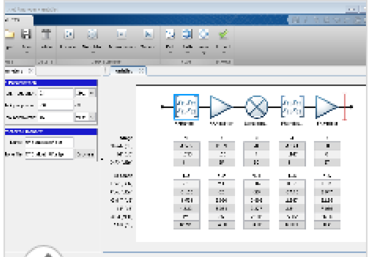
R2018a



Power Amplifier Characterization with DPD for Reduced Signal

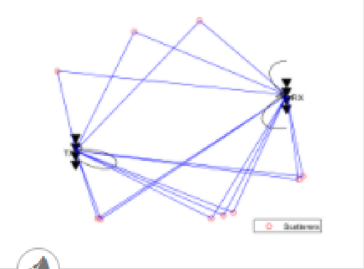
Provides a methodology for characterizing a nonlinear RF Blockset™ power amplifier (PA) with memory and an adaptive DPD

R2018a



Visualizing RF Budget Analysis Over Bandwidth

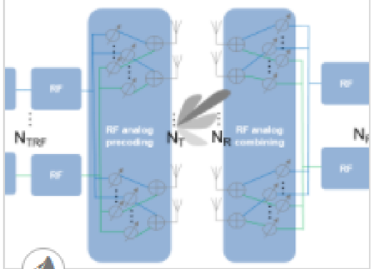
Programmatically perform an RF budget analysis of an RF receiver system and visualize computed budget results across the bandwidth



Improve SNR and Capacity of Wireless Communication Using…

The goal of a wireless communication system is to serve as many users with the highest possible data rate given constraints

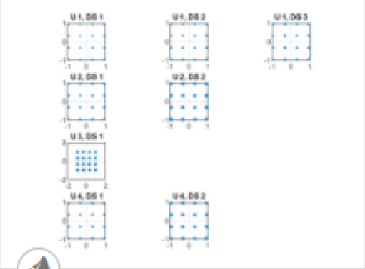
Open Script



Introduction to Hybrid Beamforming

Introduces the basic concept of hybrid beamforming and shows how to simulate such a system.

Open Script



Massive MIMO Hybrid Beamforming

How hybrid beamforming is employed at the transmit end of a massive MIMO communications system, using techniques for both

R2018a

SINR Map for a 5G Urban Macro-Cell Test Environment

This example shows how to construct a 5G urban macro-cell test environment and visualize the signal-to-interference-plus-noise

R2018a

Resources – Links in PDF Document

View web resources

[Wireless Communications Design with MATLAB]

[MATLAB and Simulink for 5G Technology Development]

Read eBook and white papers

5G Development with MATLAB (eBook)

Hybrid Beamforming for Massive MIMO Phased Array Systems (white paper)

Four Steps to Building Smarter RF Systems with MATLAB (white paper)

Evaluating 5G Waveforms Over 3D Propagation Channels with the 5G Library (white paper)

Download software

Wireless communications trial package

Download the 5G Library