

Developing and Prototyping Next-Generation
Communications Systems

MATLAB EXPO 2017

Dr. Amod Anandkumar
*Team Lead – Signal Processing and Communications
Application Engineering Group*

Proliferation of Wireless Standards

IEEE 802.15.4



A New Generation? Why?

New Use Cases

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

Requirements

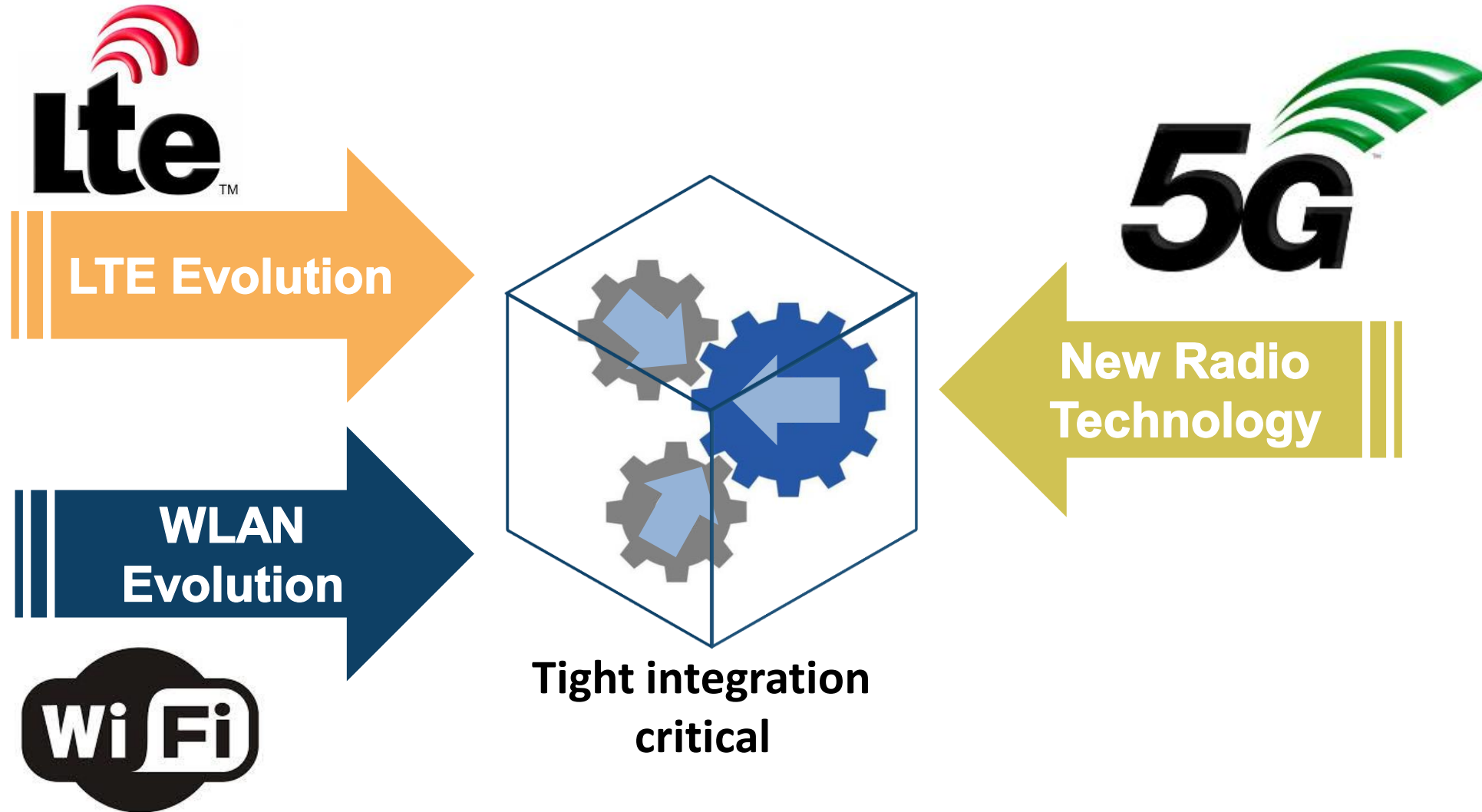
Ultra broadband
Low latency
Massive device
connectivity
Low energy and cost

Solutions

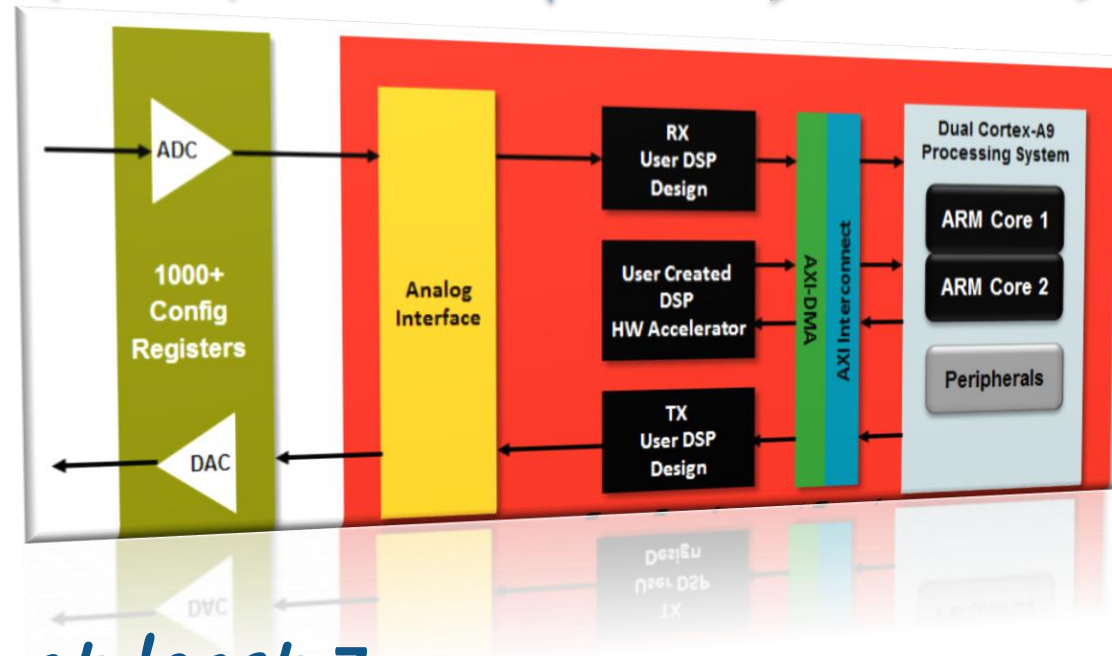
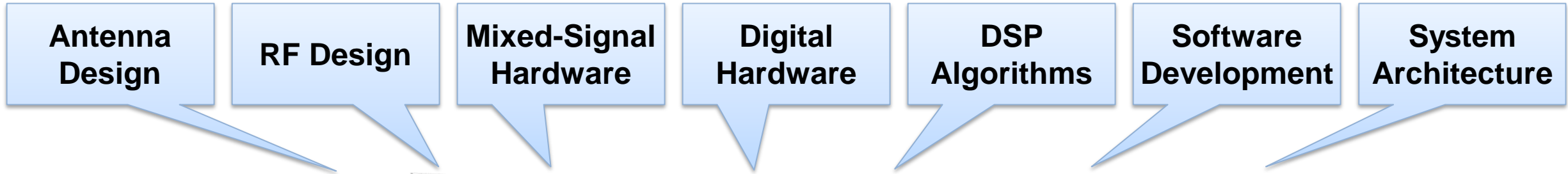
More bands
Increased bandwidth
Better spectral
efficiency
Flexible air interface
Densification

Road to 5G

Evolution of Current Standards + New Radio Technology



Developing Next Generation Wireless Technology



at least 7

Requires [∇] different design skills to be successful!

MATLAB & Simulink: Unified Wireless Design Platform

for baseband, RF, and antenna modeling and simulation

Algorithms, Waveforms, Measurements

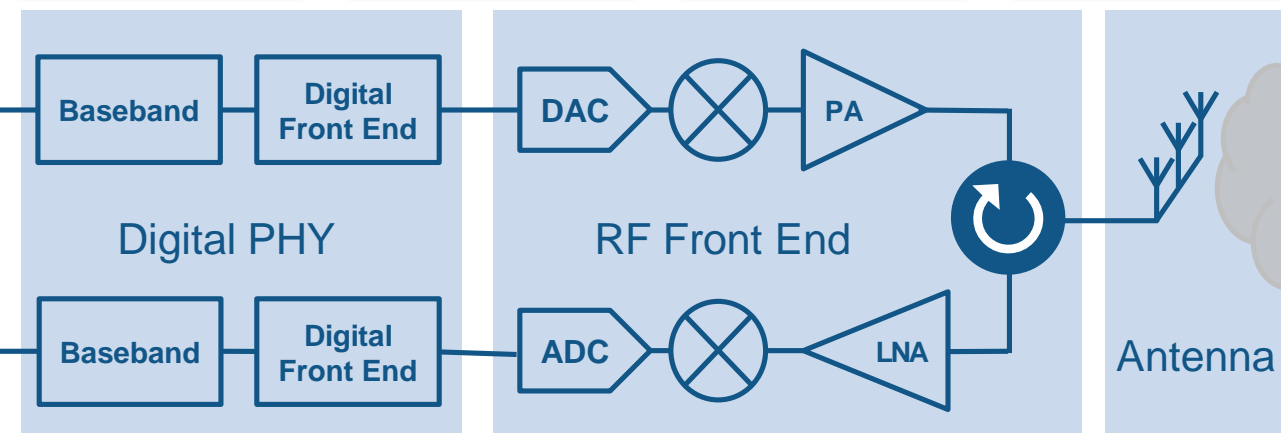
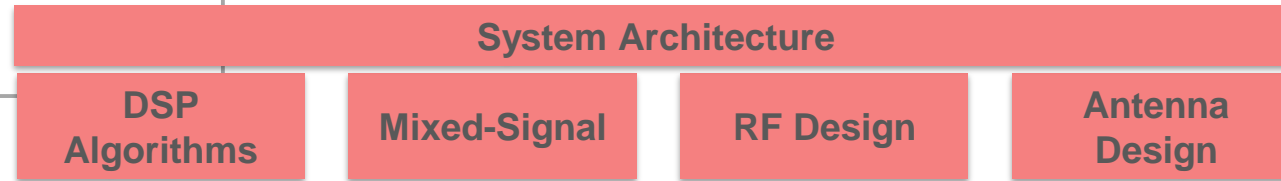
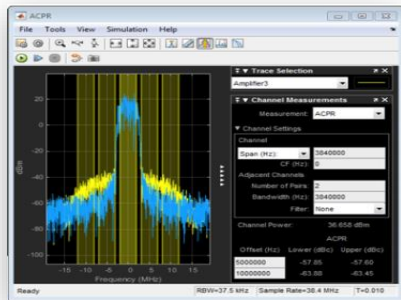
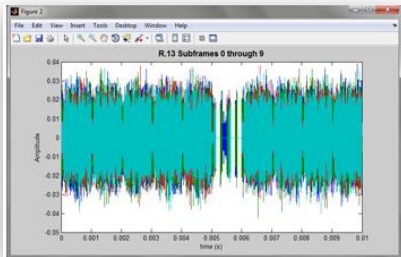
- Communications System Toolbox
- Phased Array System Toolbox
- LTE System Toolbox
- WLAN System Toolbox

RF Front End

- RF Toolbox
- RF Blockset

Antennas, Antenna Arrays

- Antenna Toolbox
- Phased Array System Toolbox



- Simulink
- DSP System Toolbox
- Control System Toolbox

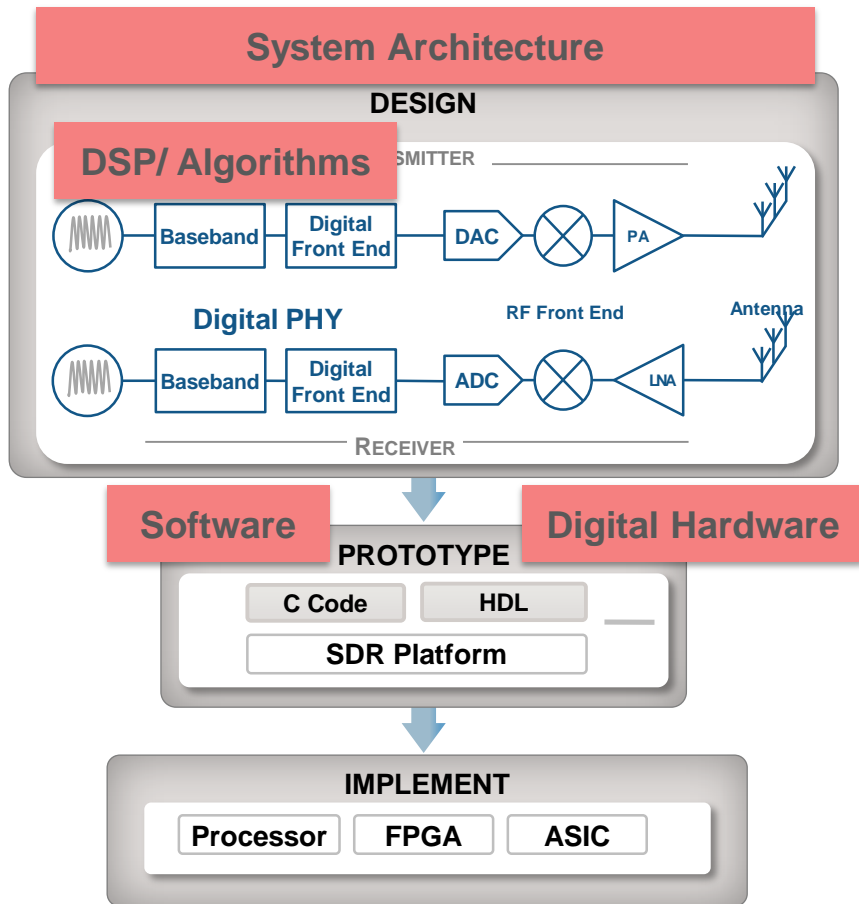
- Communications System Toolbox
- Phased Array System Toolbox
- LTE System Toolbox
- WLAN System Toolbox

Mixed-signal

Channel Modeling

MATLAB & Simulink: Unified Wireless Design Platform

for algorithm developers, system architects, HW and SW developers

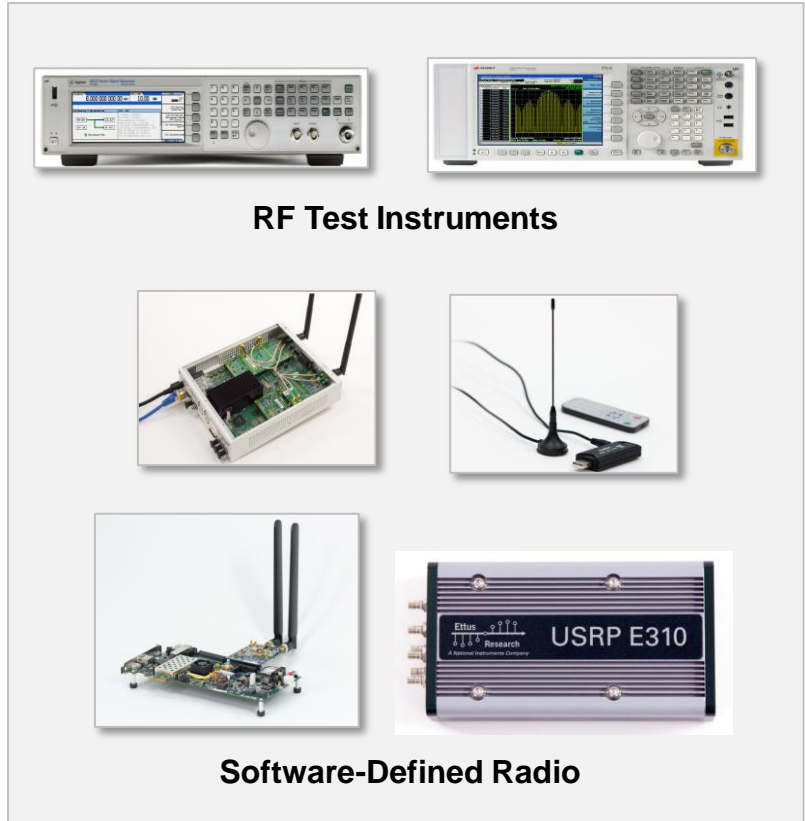


HDL and C code generation

Instrument Control Toolbox

SDR Support Packages
Communications System Toolbox

Fixed-Point Designer
HDL Coder
Embedded Coder

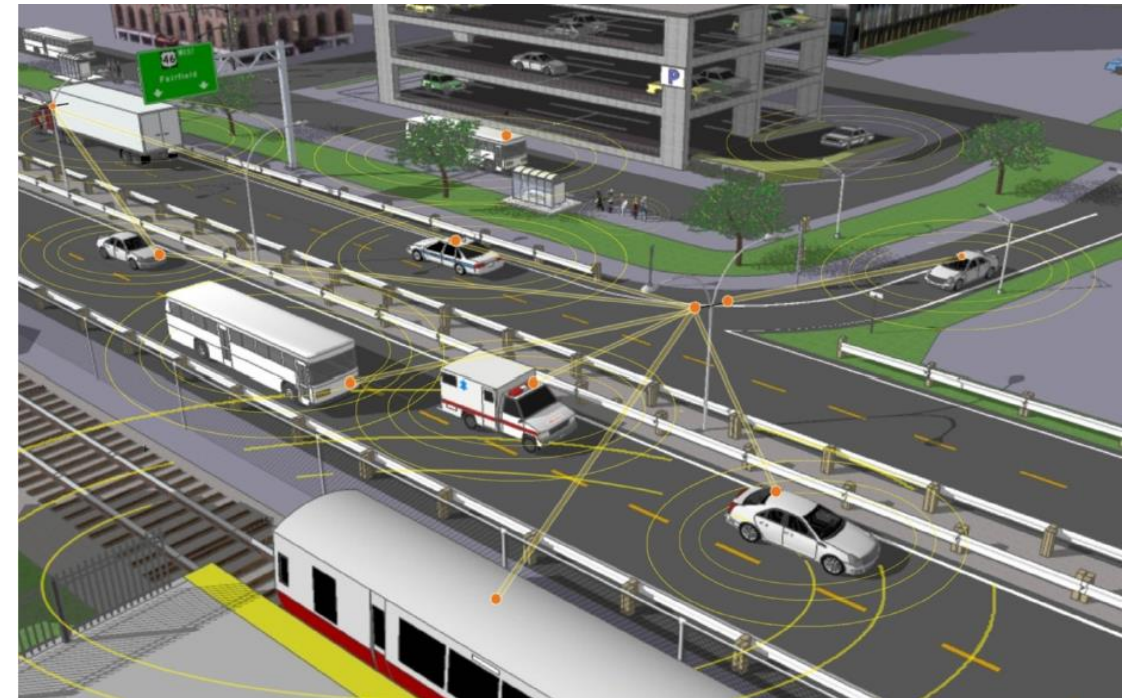


Multi-vendor hardware support

Example: Vehicular Communications

Continuous, high-speed, and authenticable safety data exchange among moving vehicles, roadway infrastructure, pedestrians, and cellular network

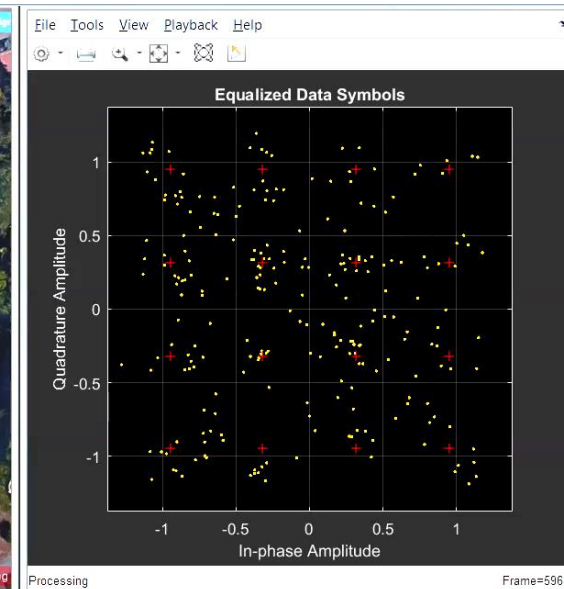
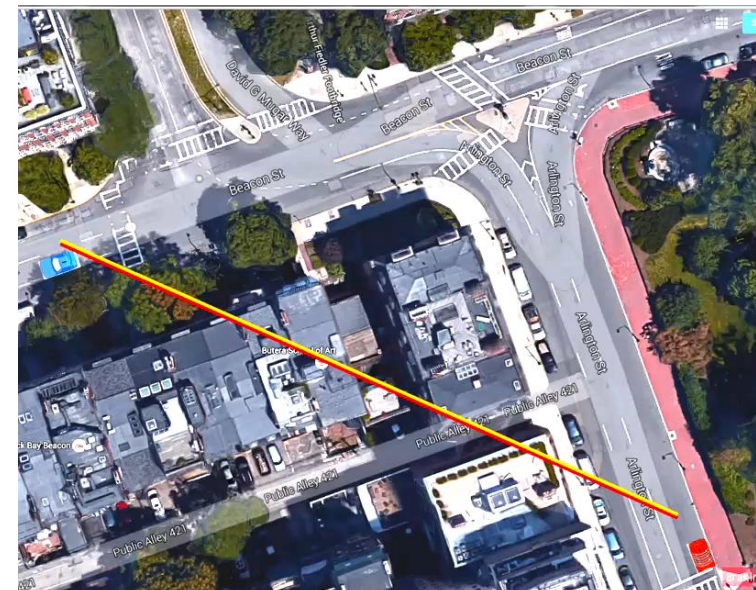
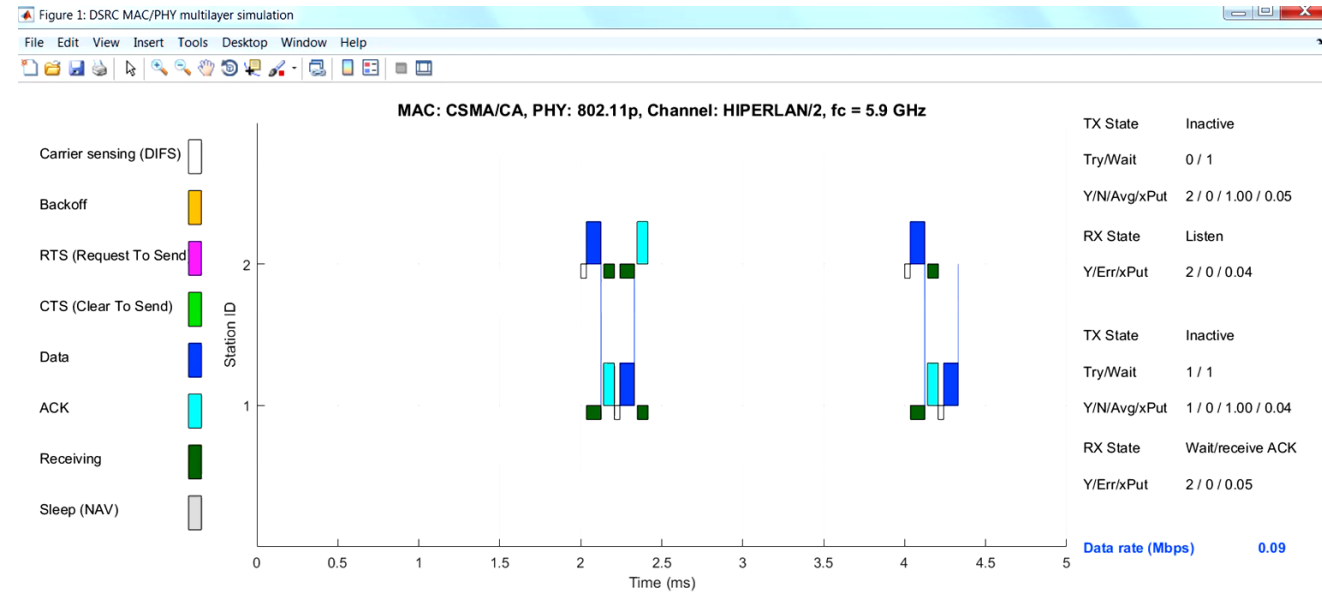
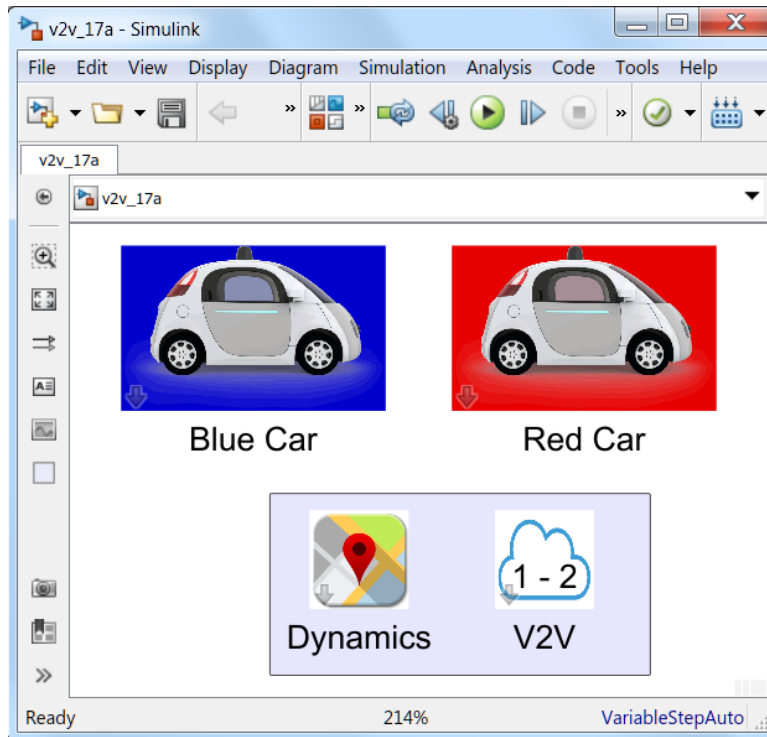
- Vehicle-to-Vehicle (V2V)
 - Vehicle-to-Infrastructure (V2I)
 - Vehicle-to-Pedestrian (V2P)
 - Vehicle-to-Network (V2N)
- } V2X



Example: DSRC V2V Safety Scenario Simulation

Dedicated Short Range Communications

- 5.9 GHz
- PHY: IEEE 802.11p
- MAC: CSMA/CA with DCF



Example Summary

1. Visualize and model traffic scene and vehicles in motion using **MATLAB**
2. Model vehicular maneuvers, collision prediction, and collision avoidance algorithms using **MATLAB**
3. Model PHY (802.11p) using **WLAN System Toolbox**
4. Model MAC (CSMA/CA with DCF) using **SimEvents**

WLAN System Toolbox

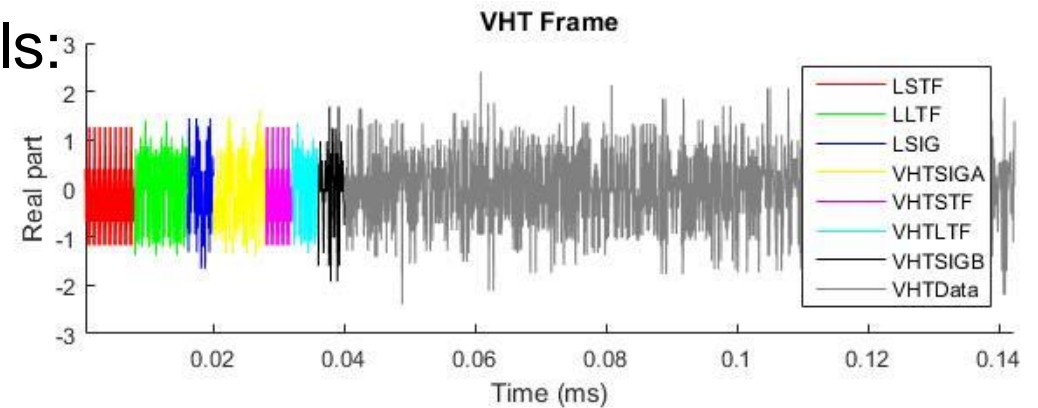
- Standards compliant **physical layer** models:

- 802.11a/b/g/n/ac
- 802.11j/p
- 802.11ah
- 802.11ad

R2016a

R2016b

R2017a



- Transmitter, receiver, and channel models

- Open, customizable MATLAB code

- C-code generation enabled with MATLAB Coder

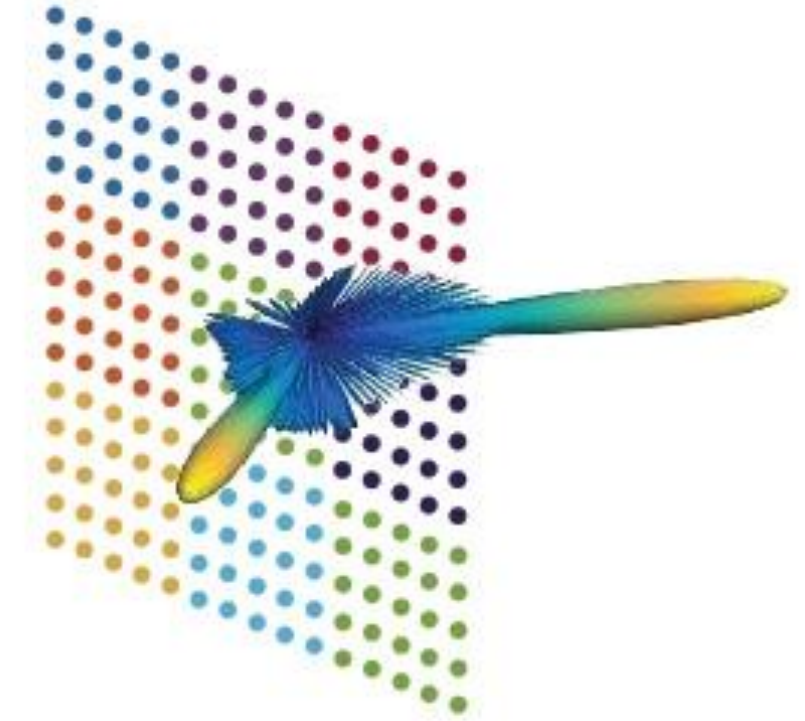
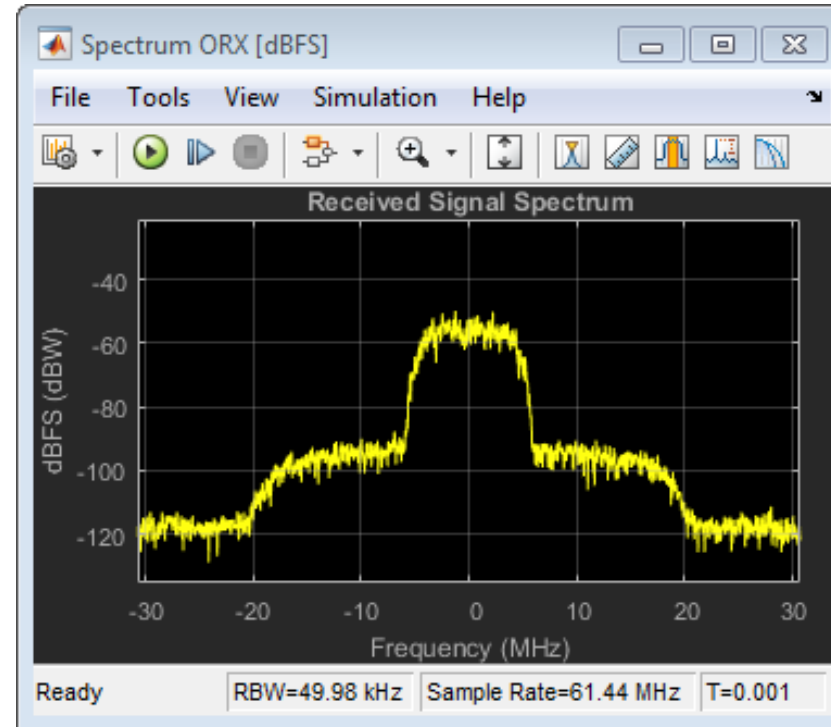
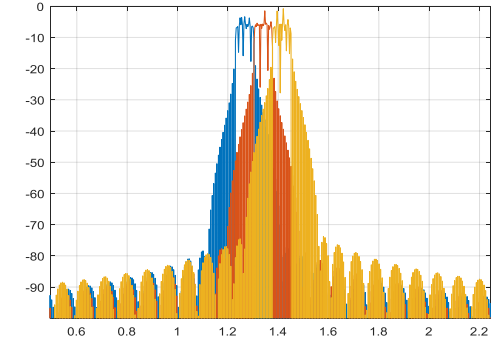
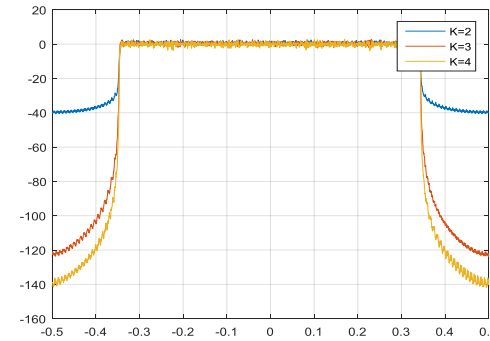
```
% OFDM demodulation
[ofdmDemodData, ofdmDemodPilots] = wlanOFDMDemodulate( ...
    rxVHTData(1:minInputLen, :), cfgOFDM, symOffset);

% Pilot phase tracking
if calculateCPE==true || strcmp(pilotPhaseTracking, 'PreEQ')
    % Get reference pilots, from Eqn 22-95, IEEE Std 802.11ac-2013
    % Offset by 4 to allow for L-SIG, VHT-SIG-A, VHT-SIG-B pilot symbols
    z = 4;
    refPilots = vhtPilots(numOFDMSym, z, chanBW, numSTS);
```

MATLAB Coder
Generate C and C++ code

Key 5G Technologies

- New Waveforms / Modulation Schemes
- Massive MIMO
- mmWave Bands



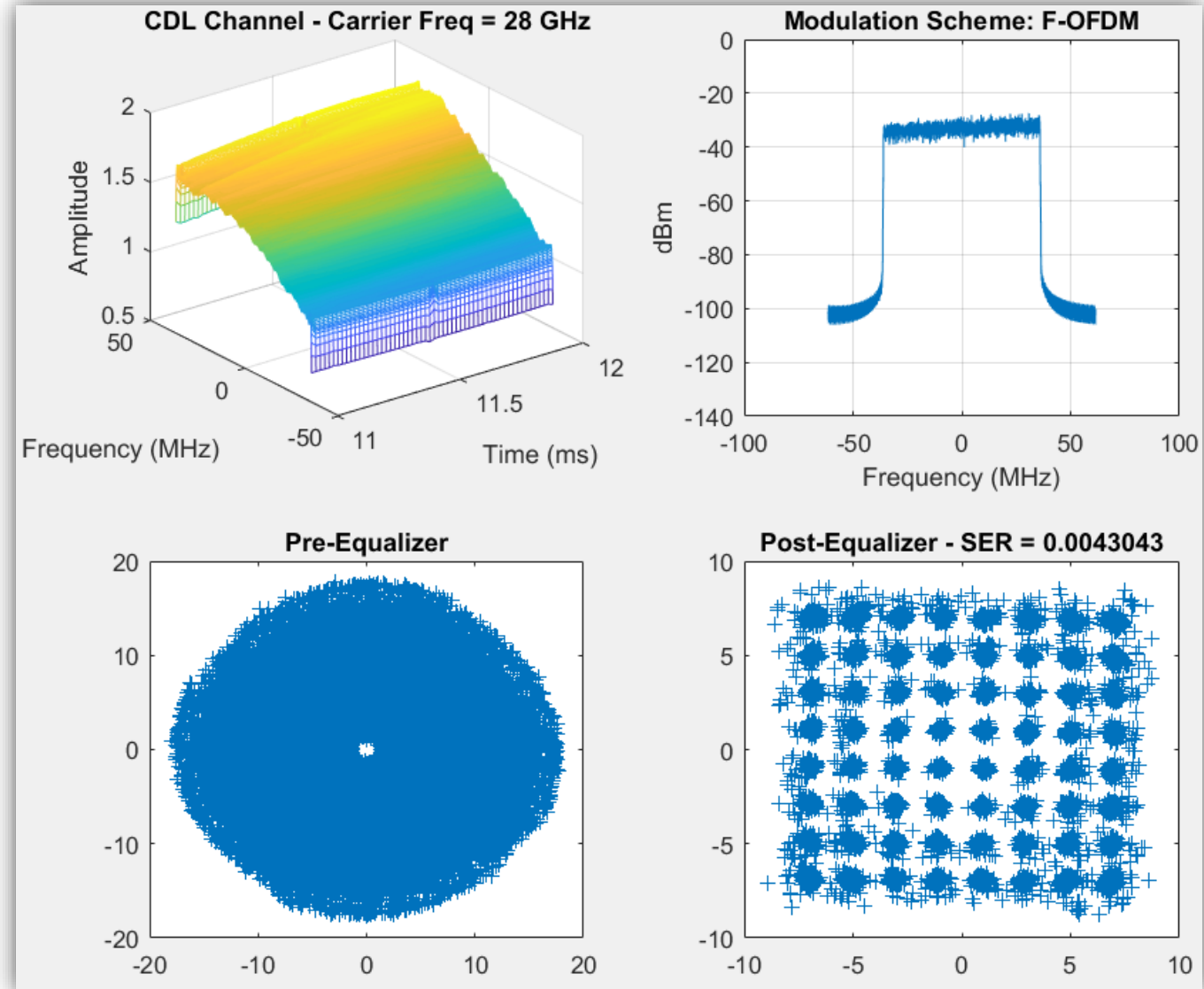
New Waveforms, Massive MIMO and mmWave Communications

Some Challenges

- New modulation schemes
 - Requirements: reduced out of band emissions and relaxed synchronization requirements
 - Non-orthogonal waveforms → complex receiver design
- High frequency – above 30GHz
 - Large communication bandwidth → digital signal processing is challenging
 - High-throughput DSP → linearity requirements imposed over large bandwidth
 - Wavelength ~ 1mm → small devices, many antennas packed in small areas
- Large antenna arrays
 - Antennas need to be close together to avoid grating lobes
 - Digital beamforming can be complex and power hungry ($BW \times N_T$, many ADCs)
 - Analog beamforming has limited capabilities

Example: 5G Waveforms over 3GPP mmWave Channel

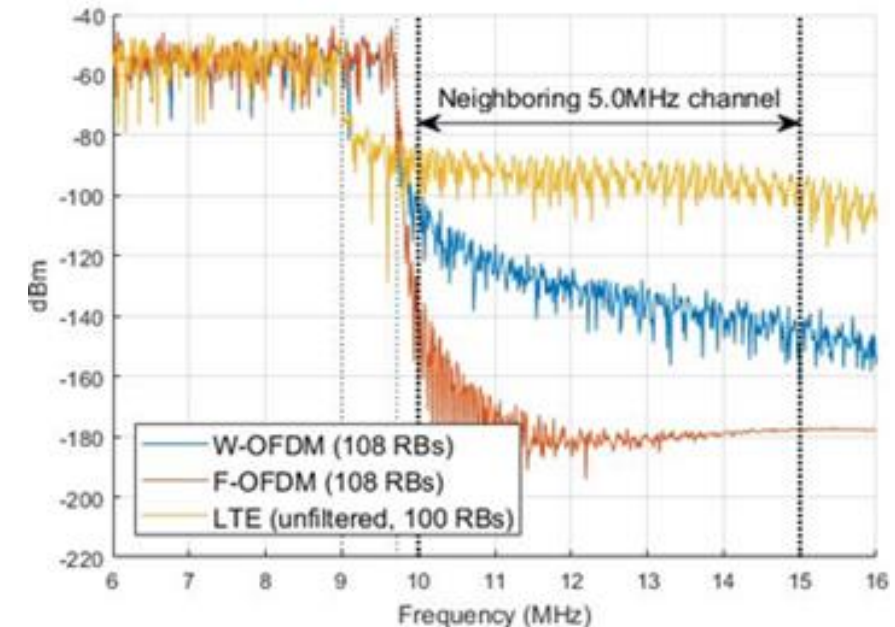
- Modulation schemes
 - CP-OFDM, F-OFDM, W-OFDM
- Variable subcarrier spacing
 - 60 kHz
- Variable no. of RBs
 - 100
- mmWave channel model
 - 28 GHz



Introducing the 5G Library

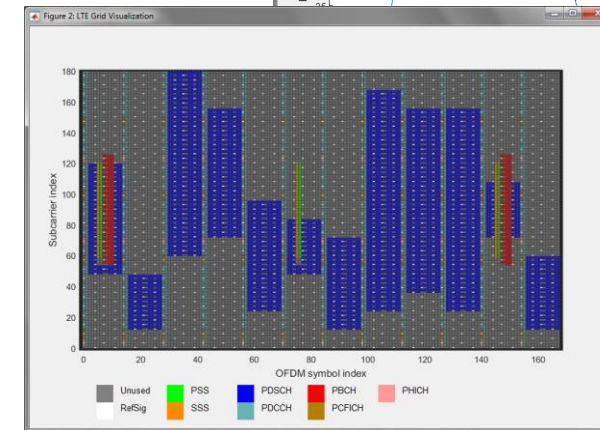
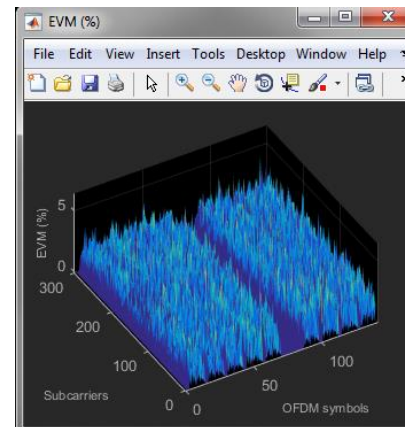
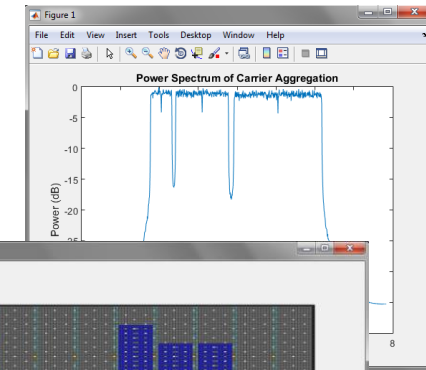
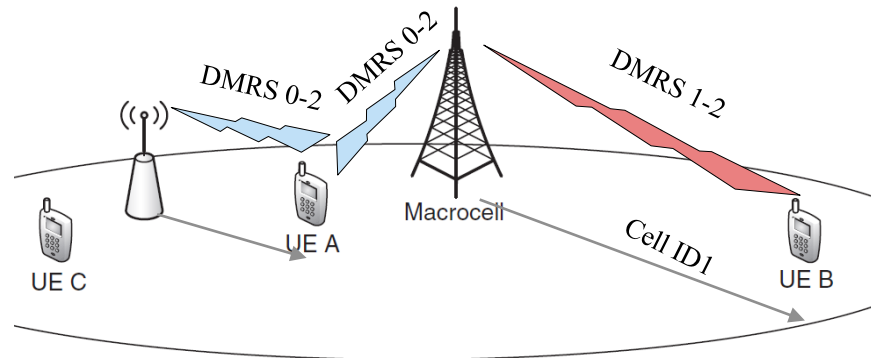
Free Add-on for LTE System Toolbox

- 5G channel models (3GPP TR 38.900)
 - 6 GHz – 100 GHz
- New Radio (NR) Waveforms
 - (F-OFDM, W-OFDM)
- Link level simulation reference design



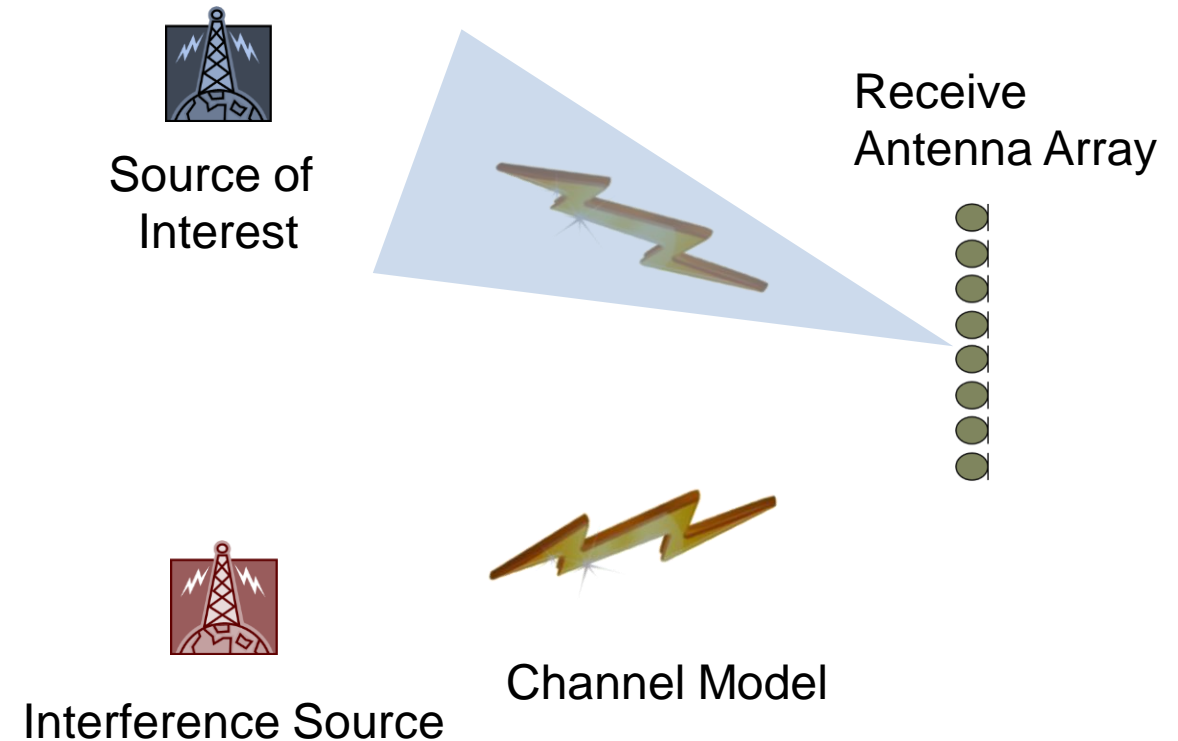
LTE System Toolbox

- LTE and LTE-Advanced (Rel-8 through Rel-12)
- Scope
 - FDD/TDD
 - Uplink/Downlink/Sidelink
 - Transmitter/Receiver
 - Channel models
- >200 functions for physical layer (PHY) modeling
- LTE Signal generation
- ACLR/EVM measurement
- Conformance Tests



Example: Interference Mitigation using Massive MIMO

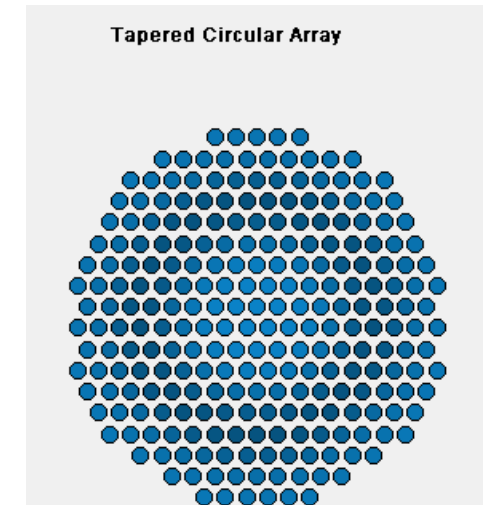
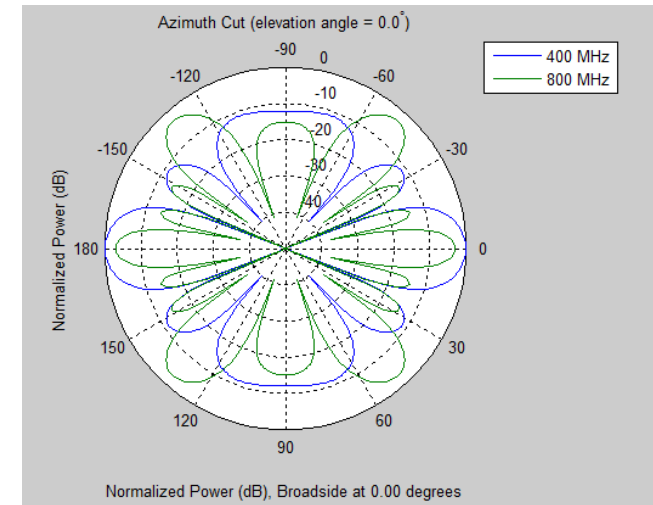
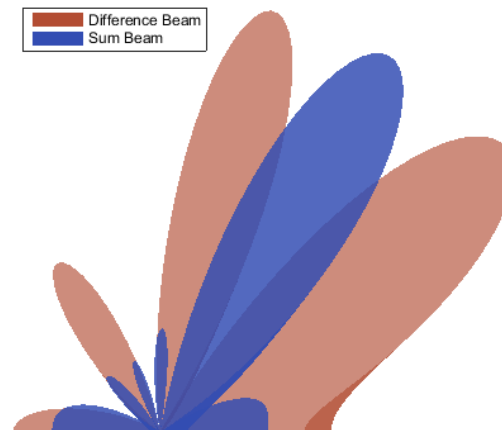
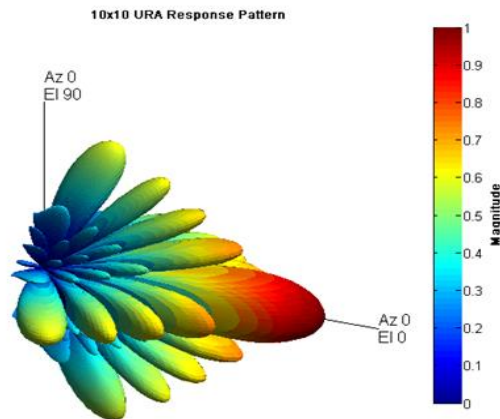
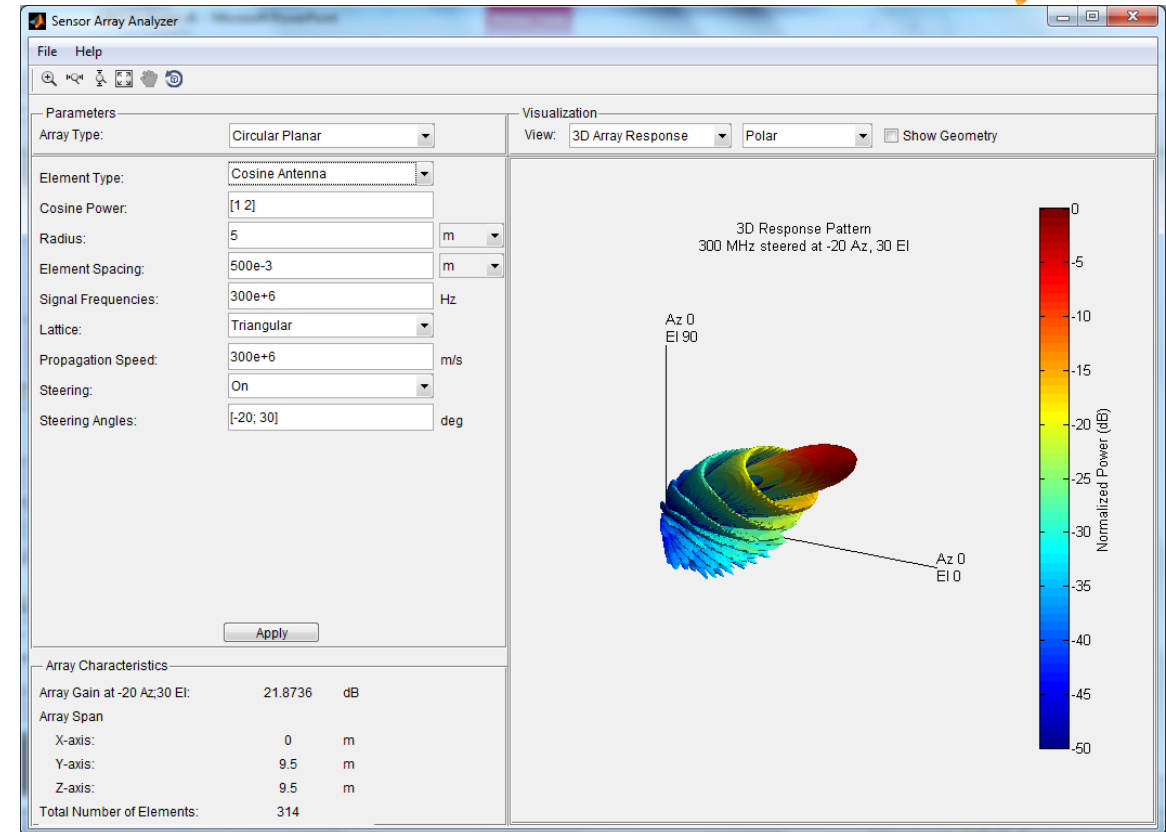
- System model
 - Receiver
 - Antenna array, Beamformer, Signal Processing
 - Source of interest
 - LTE node with specific cell ID
 - Propagation channel
 - Path loss, environment
 - Interference source
 - LTE node with neighboring cell ID



Model and simulate to determine expected performance, operational limits and mitigation effectiveness

Phased Array System Toolbox

- Array design and analysis
- Advanced array processing algorithms
 - Temporal processing
 - Spatial processing
 - Space-time adaptive processing
- End-to-end system modeling



Tools for Mathematical Analysis and Modelling

- MATLAB

- Linear algebra, sparse matrices, graphs, computational geometry, ...

- Symbolic Math Toolbox

- Simplification and manipulation, calculus, transforms, linear algebra, ...

```
transform::fourier heaviside(t - t0), t, s)
```

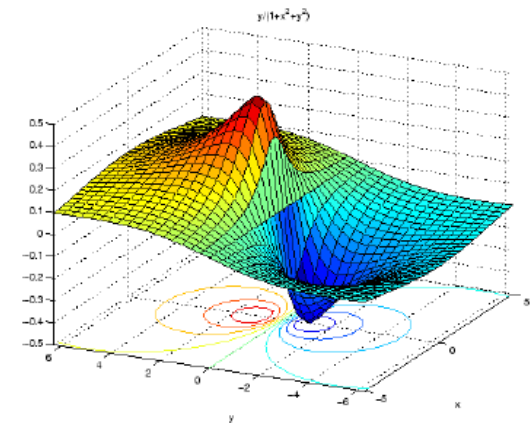
$$e^{s t_0 i} \left(\pi \delta(s) + \frac{i}{s} \right)$$

- Optimization Toolbox

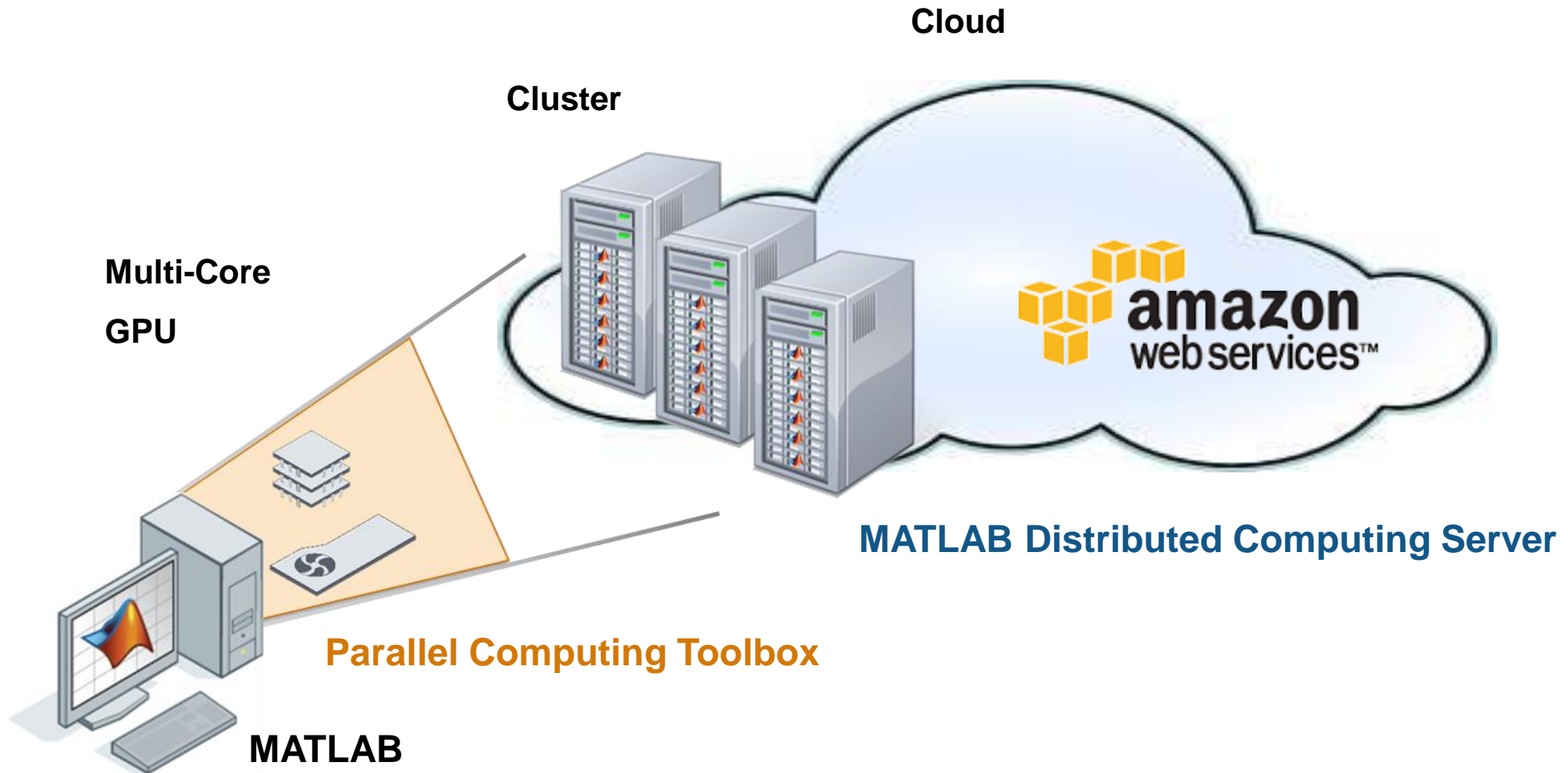
- linear programming, mixed-integer linear programming, quadratic programming, ...

- Global Optimization Toolbox

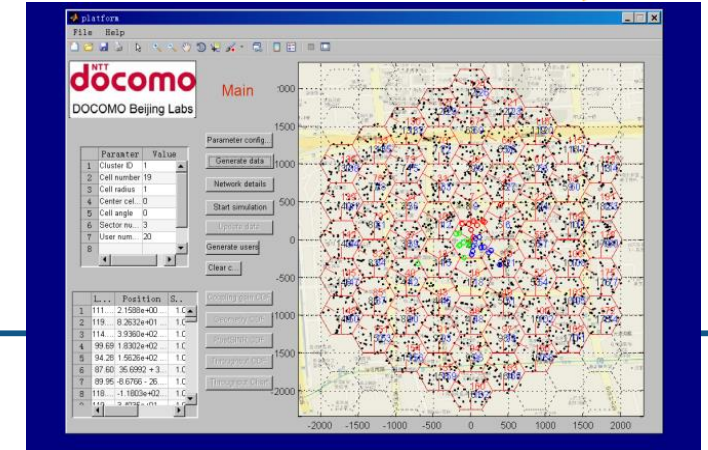
- pattern search, genetic algorithm, simulated annealing, ...



Accelerate Simulations with Scalable Computing



DOCOMO Beijing Labs Accelerates the Development of Mobile Communications Technology



User interface for DCOMO Beijing Labs' system-level simulator.

Challenge

Research, develop, and verify next-generation mobile communications technologies

Solution

Use MATLAB and Parallel Computing Toolbox to accelerate the development and simulation of innovative algorithms at the link level and the system level

Results

- Development time halved
- Simulation time reduced from weeks to hours
- Five times more scenarios verified

“With MATLAB we spend less time coding and more time developing innovative mobile communications algorithms. More importantly, with only minor modifications we can accelerate the simulation of algorithms on our computing cluster to thoroughly evaluate and verify them under a wide range of operating conditions and scenarios.”

**Lead Research Engineer
DOCOMO Beijing Labs**

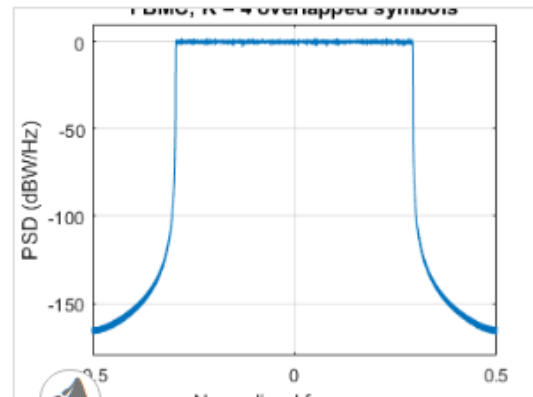
More Examples – 5G Waveform Exploration in Communications System Toolbox

5G Exploration

5G Waveforms with LTE

Highlights LTE PDSCH processing with two 5G candidate waveforms, namely, Filtered-OFDM (F-OFDM) and Universal Filtered Multi-Carrier

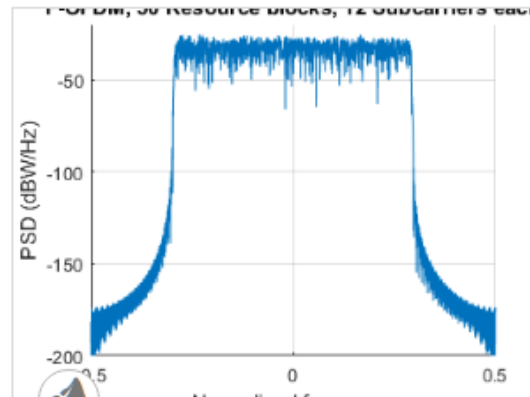
[Open Script](#)



FBMC vs. OFDM Modulation

Compares Filter Bank Multi-Carrier (FBMC) with Orthogonal Frequency Division Multiplexing (OFDM) and highlights the merits of the new

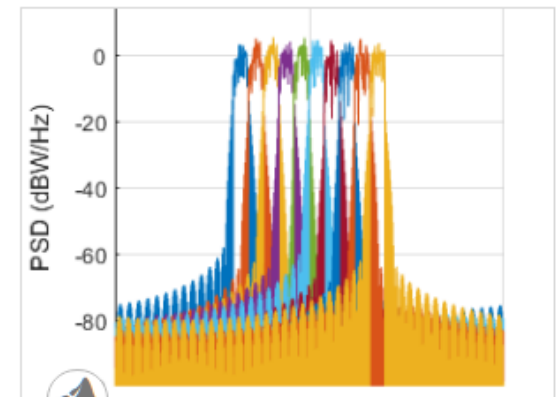
[Open Script](#)



F-OFDM vs. OFDM Modulation

Compares Orthogonal Frequency Division Multiplexing (OFDM) with Filtered-OFDM (F-OFDM) and highlights the merits of the new

[Open Script](#)

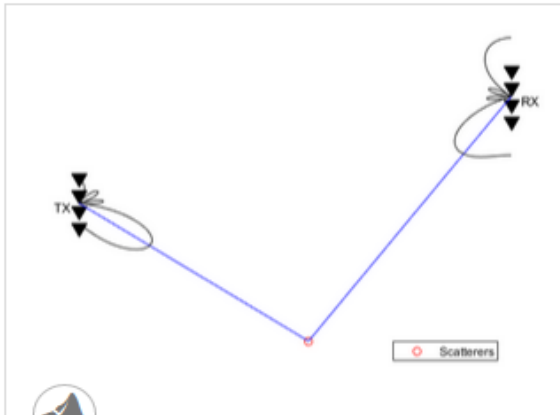


UFMC vs. OFDM Modulation

Compares Universal Filtered Multi-Carrier (UFMC) with Orthogonal Frequency Division Multiplexing (OFDM) and highlights the merits of

[Open Script](#)

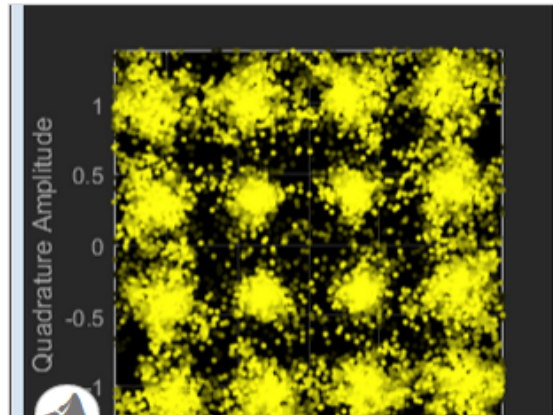
More Examples – Beamforming in Phased Array System Toolbox



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 such as

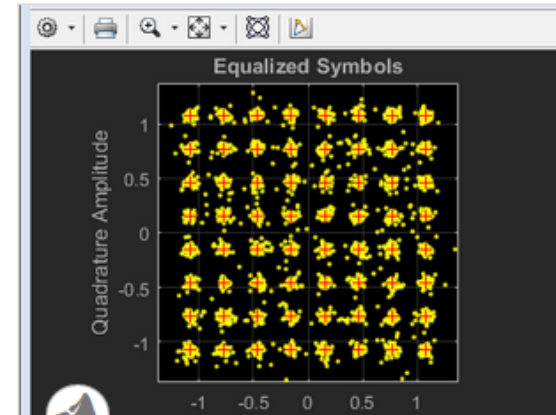
[Open Script](#)



Beamforming for MIMO-OFDM Systems

This examples shows how to model a point-to-point MIMO-OFDM system with beamforming. The combination of multiple-input-multiple-output

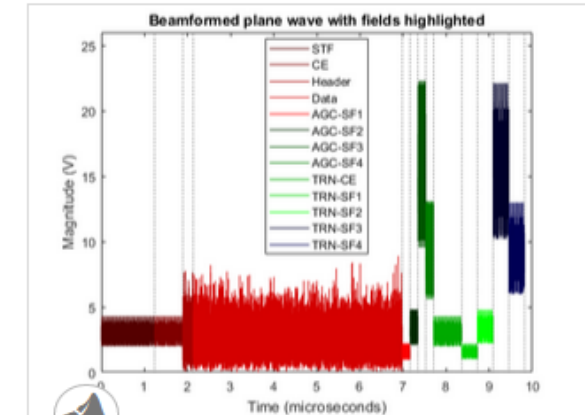
[Open Script](#)



MIMO-OFDM Precoding with Phased Arrays

How phased arrays are used in a MIMO-OFDM communication system employing beamforming. The example models the radiating

[Open Script](#)



802.11ad Waveform Generation with Beamforming

Simulate beamforming an IEEE® 802.11ad™ DMG waveform with a phased array using WLAN System Toolbox™ and Phased Array

[Open Script](#)

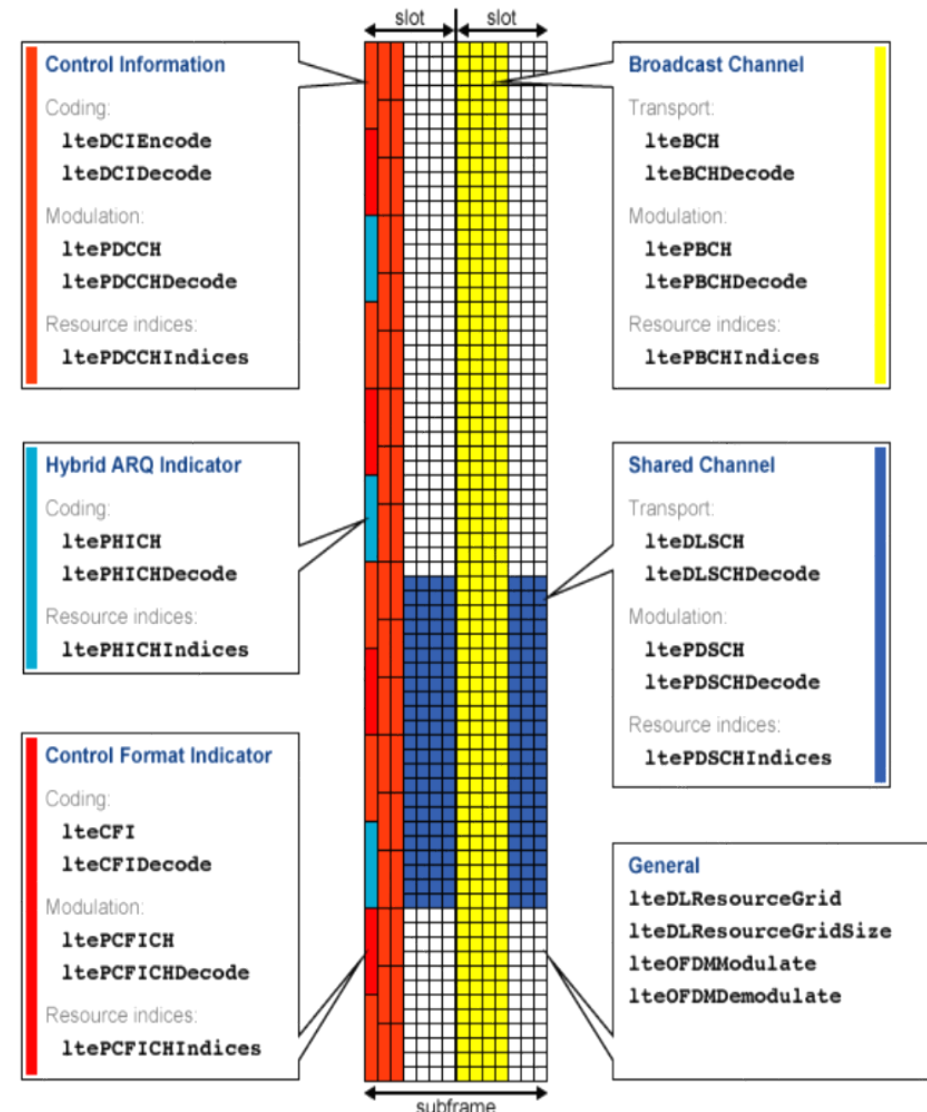


MathWorks® | Training Services

Designing LTE and LTE Advanced Physical Layer Systems with MATLAB

Topics include:

- Review of the advanced communications techniques forming the core of an LTE system: OFDMA and SC-FDMA multi-carrier techniques, and MIMO multi-antenna systems
- Descriptions of all of the signals and elements of the processing chain for the uplink and downlink LTE physical channels
- Methods for golden reference verification with the standard



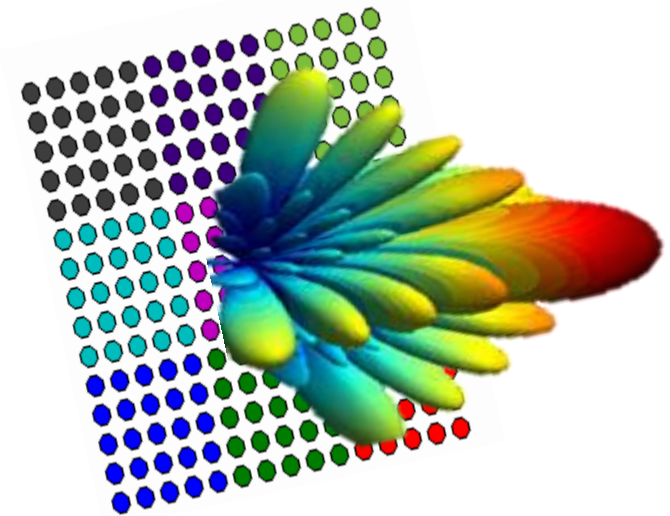


Phased Array System Toolbox Fundamentals

This one-day course provides a comprehensive introduction to the Phased Array System Toolbox™. Themes including radar characterization and analysis, radar design and modeling and radar signal processing are explored throughout the course.

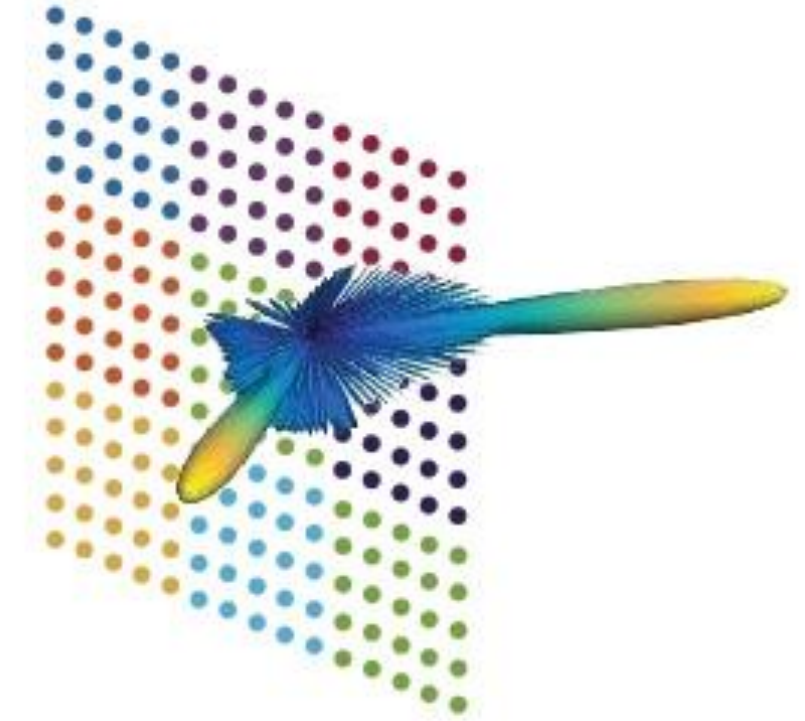
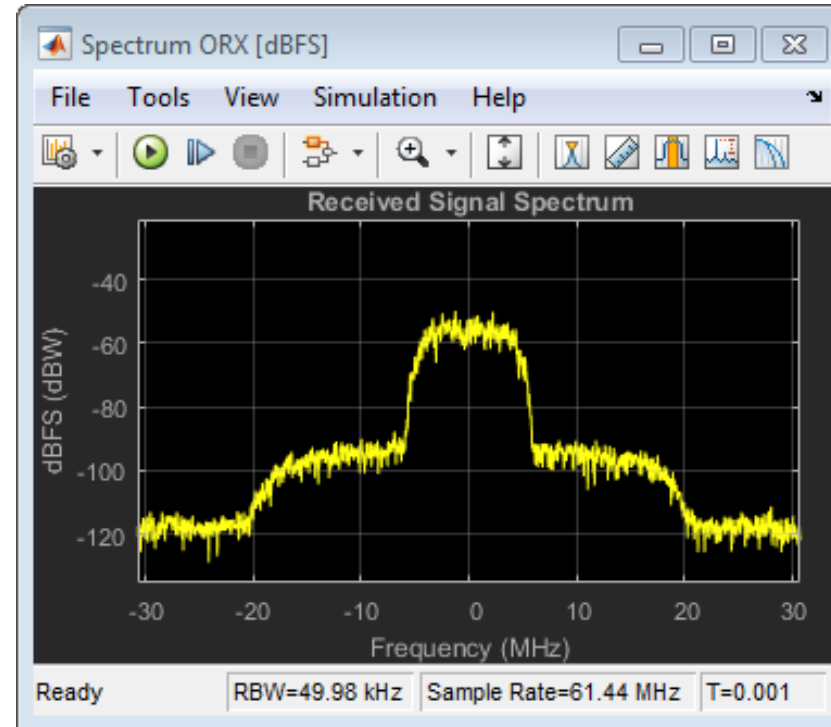
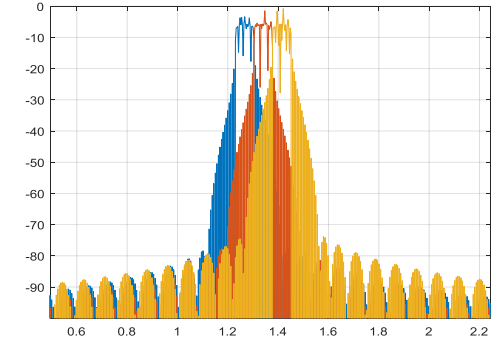
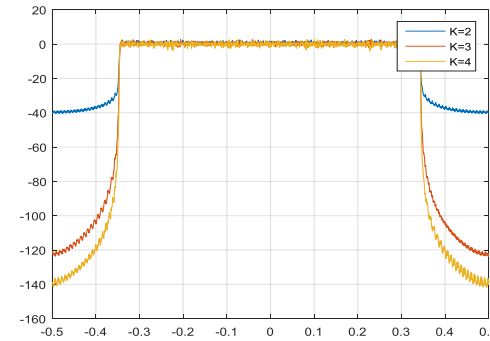
Topics include:

- Review of a Monostatic End-to-End Radar Model
- Characterize and analyze radar components and systems
- Design and model components of a radar system
- Implement a range of radar signal processing algorithms

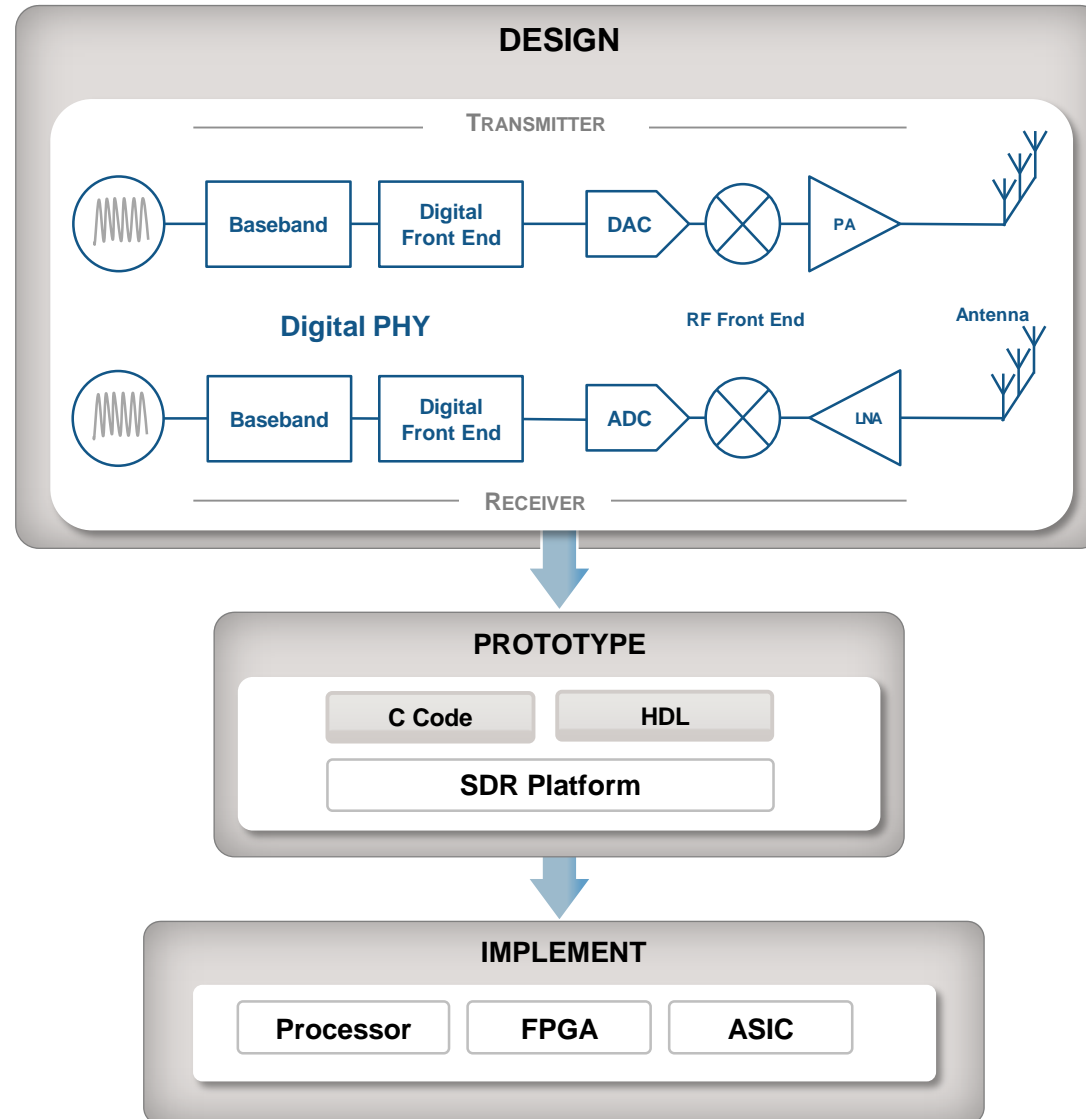


Key 5G Technologies

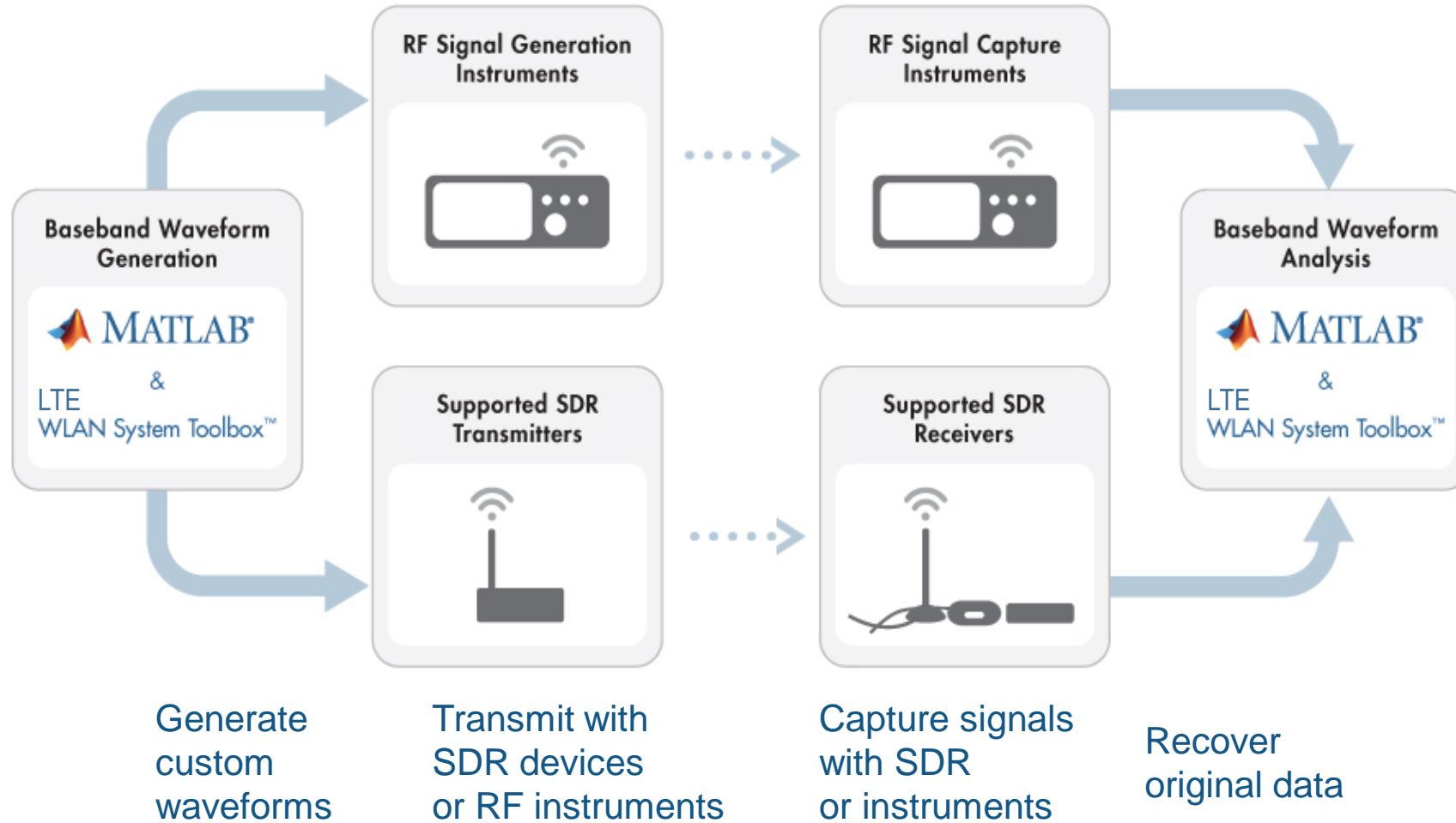
- ✓ New Waveforms / Modulation Schemes
- ✓ Massive MIMO
- ✓ mmWave Bands



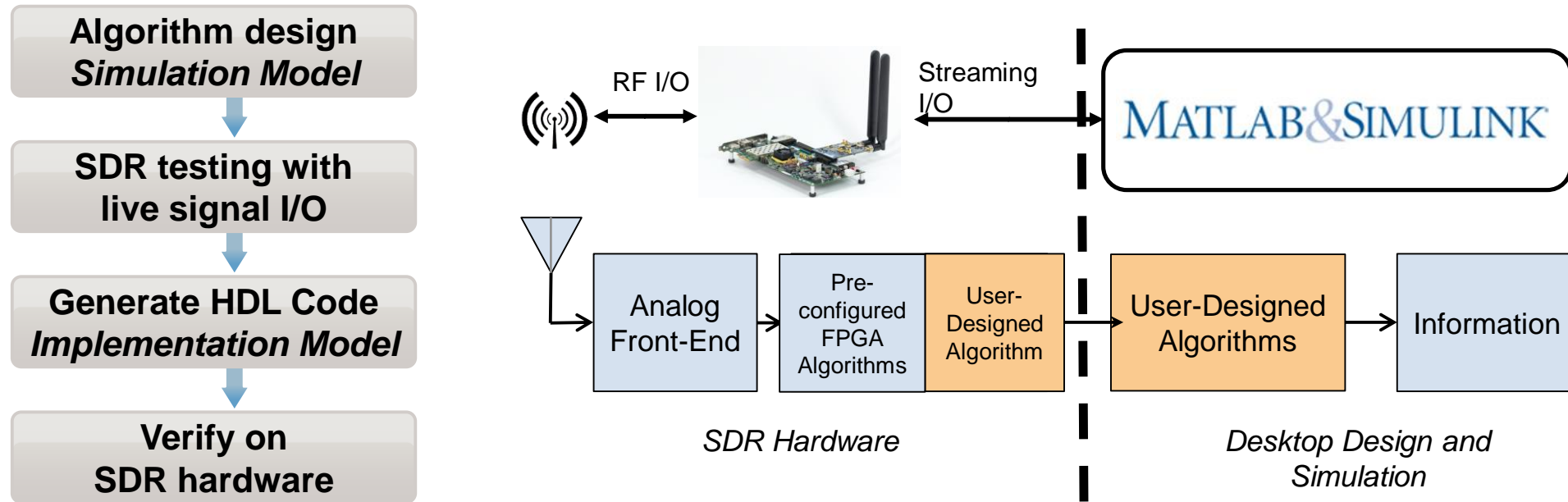
Implementation and Prototyping using Model-Based Design



Over-the-air testing with SDRs & RF instruments



Prototyping Workflow Using SDR Platforms



Supported SDR Platforms

Xilinx Zynq-Based Radio

ZC706, ZedBoard, PicoZed

ADI FMCOMMS1/2/3/4



Xilinx FPGA-Based Radio

Virtex-6 ML605, Spartan-6 SP605

ADI FMCOMMS1, Epiq FMC-1Rx



USRP Radio

USRP2, N200/210

B200/B210, X300/310

E310



Analog Devices ADALM Pluto Radio



RTL-SDR Radio



Ericsson | Tomas Andersson

Radio Test Bed Design Using HDL Coder

Challenge

Implement FPGA based radio signal processing in a small team mainly consisting of people with signal processing and programming background

Solution

Use HDL Coder to generate VHDL for signal processing

Results

- Successful implementation running on FPGA
- Generated code easy to integrate into main design
- Very short lead time for changes in design



Radio Testbed Design Using HDL Coder



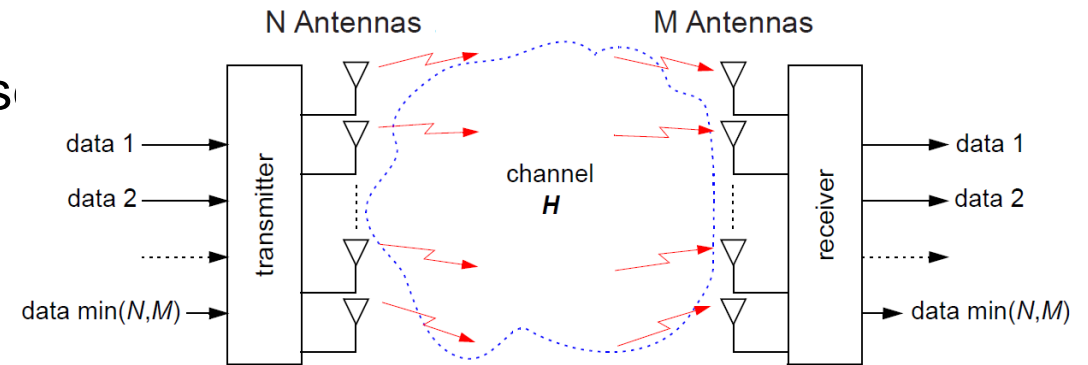
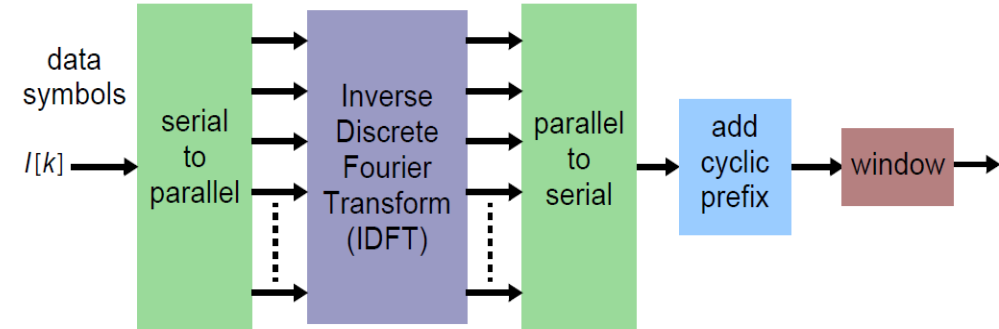
ERICSSON

<http://www.mathworks.com/videos/radio-testbed-design-using-hdl-coder-92636.html>

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Updated: Communication Systems Design with MATLAB

- Advanced communications topics
 - MIMO / OFDM
 - LDPC / Turbo Codes / OSTBCs
 - Examples using IEEE 802.11 (Wi-Fi) & LTE-based system and waveform parameters
- New hands-on content using Software Defined Radios
 - Radio-in-the-loop using RTL-SDR and USRP B210
 - Build end-to-end OFDM system using a USRP
 - Demonstrate a 2x2 OFDM-MIMO over-the-air system using USRPs



RTL-SDR (RX)



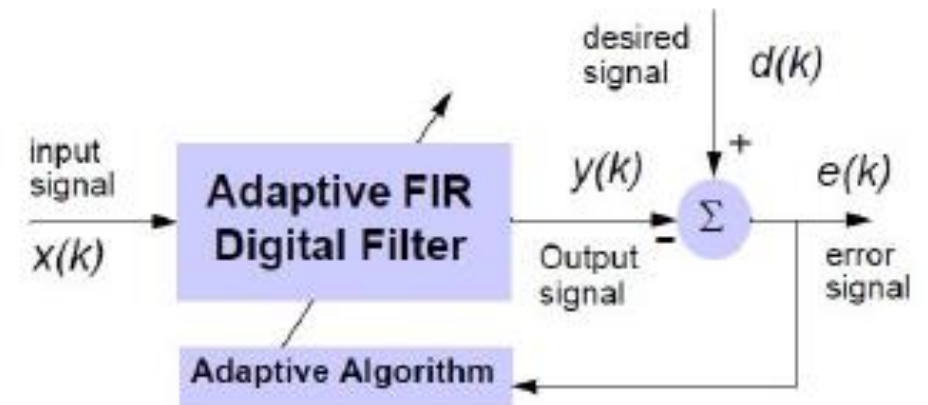
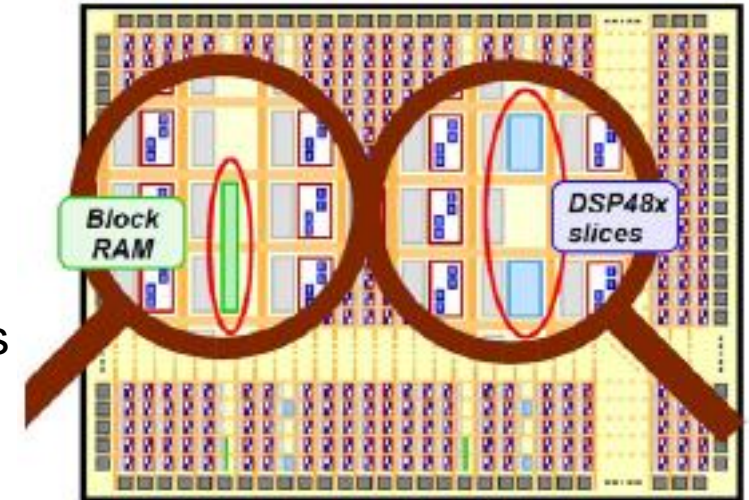
USRP (TX & RX)

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DSP for FPGAs

Topics include:

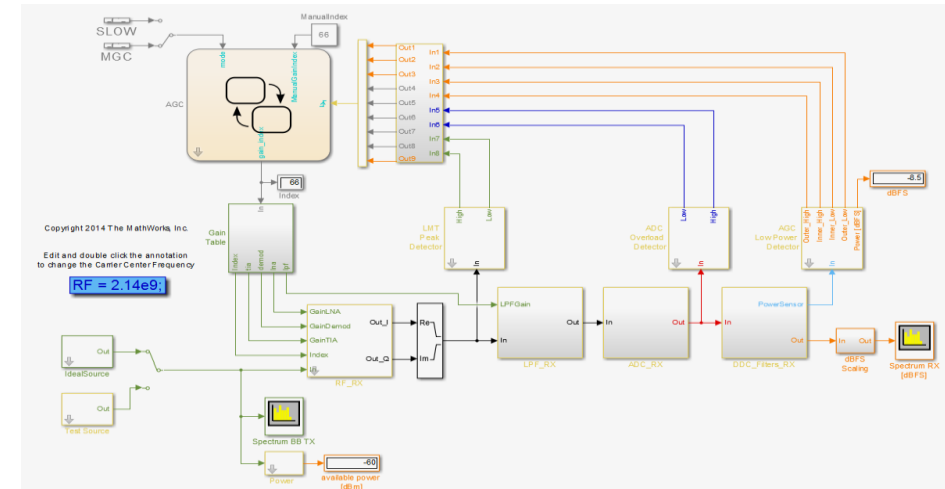
- Introduction to FPGA hardware and technology for DSP applications
- DSP fixed-point arithmetic
- Signal flow graph techniques
- HDL code generation for FPGAs
- Fast Fourier Transform (FFT) Implementation
- Design and implementation of FIR, IIR and CIC filters
- CORDIC algorithm
- Design and implementation of adaptive algorithms such as LMS and QR algorithm
- Techniques for synchronisation and digital communications timing recovery



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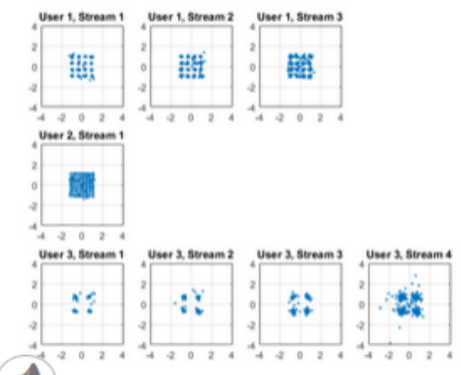
New: Software Defined Radio with Zynq using Simulink

- Learn the Model-Based Design workflow from simulation of RF chain, testing with Radio I/O to moving design to chip
- Get hands-on experience with PicoZed
 - Setting up and communicating with board
 - Capture over-the-air signal and process in MATLAB
 - AD9361 configuration
 - HW/SW co-design for SDR



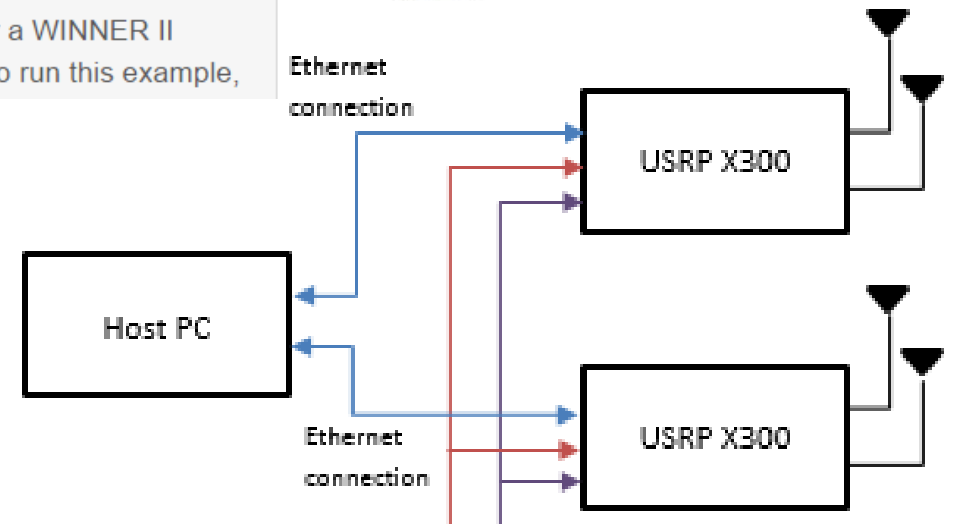
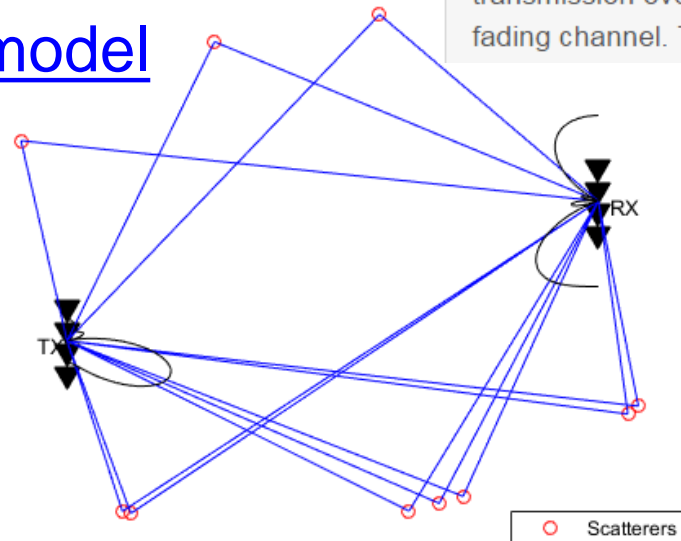
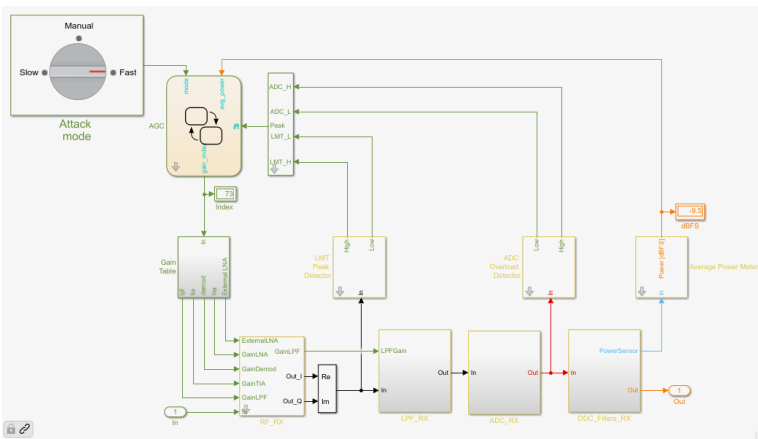
What's New for Wireless System Design

- WINNER II Channel Model
- Support for USRP® E310 SDRs
- Support for ADALM-PLUTO® SDRs
- Synchronize multiple USRP® radios
- Scattering MIMO channel model
- AD9371 Transceiver model



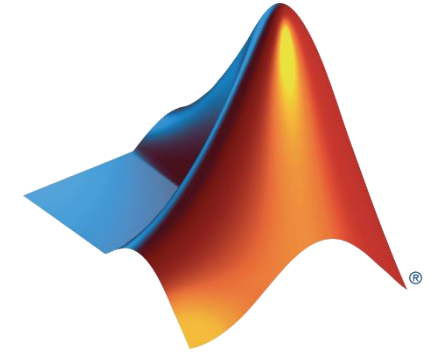
802.11ac Multi-User MIMO Precoding with WINNER II Channel Model

The transmit and receive processing for a 802.11ac™ multi-user downlink transmission over a WINNER II fading channel. To run this example,



Summary

MATLAB & Simulink: Unified Wireless Design Platform



- Trusted, diverse, open (white-boxed) libraries
- Fast simulations with scalable computing across CPU, GPU, and Clusters
- Unified modelling and simulation of digital, RF, and antenna systems
- Integrated platform for mathematical analysis, and algorithm, software, & hardware development

Enables rapid iteration between theory and implementation

Call to Action

- Learn more about accelerating simulations using parallel computing

Parallel Computing with MATLAB and Simulink

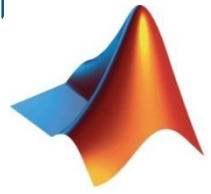
16:45–17:30

Large-scale simulations and data processing tasks take an unreasonably long time to complete or require a lot of computer memory. Users can expedite these tasks by taking advantage of high-performance computing resources, such as multicore computers, GPUs, computer clusters, and cloud computing services.



Alka Nair, Application
Engineer, MathWorks India

- Download whitepapers and technical articles
 - [Wireless Design with Today's MATLAB](#)
 - [Evaluating 5G Waveforms Over 3D Propagation Channels with the 5G Library](#)
 - [Hybrid Beamforming for Massive MIMO Phased Array Systems](#)



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Speaker Details

Email: Amod.Anandkumar@mathworks.in

LinkedIn: <https://in.linkedin.com/in/ajga2>

Twitter: [@_Dr_Amod](https://twitter.com/_Dr_Amod)

Contact MathWorks India

Products/Training Enquiry Booth

Call: 080-6632-6000

Email: info@mathworks.in

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