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

LTE

WiMAX

LTE Advanced

DVB T TERRESTRIAL

ADSL

abg WiFi n ac

A New Generation? Why?

New Use Cases

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

Requirements

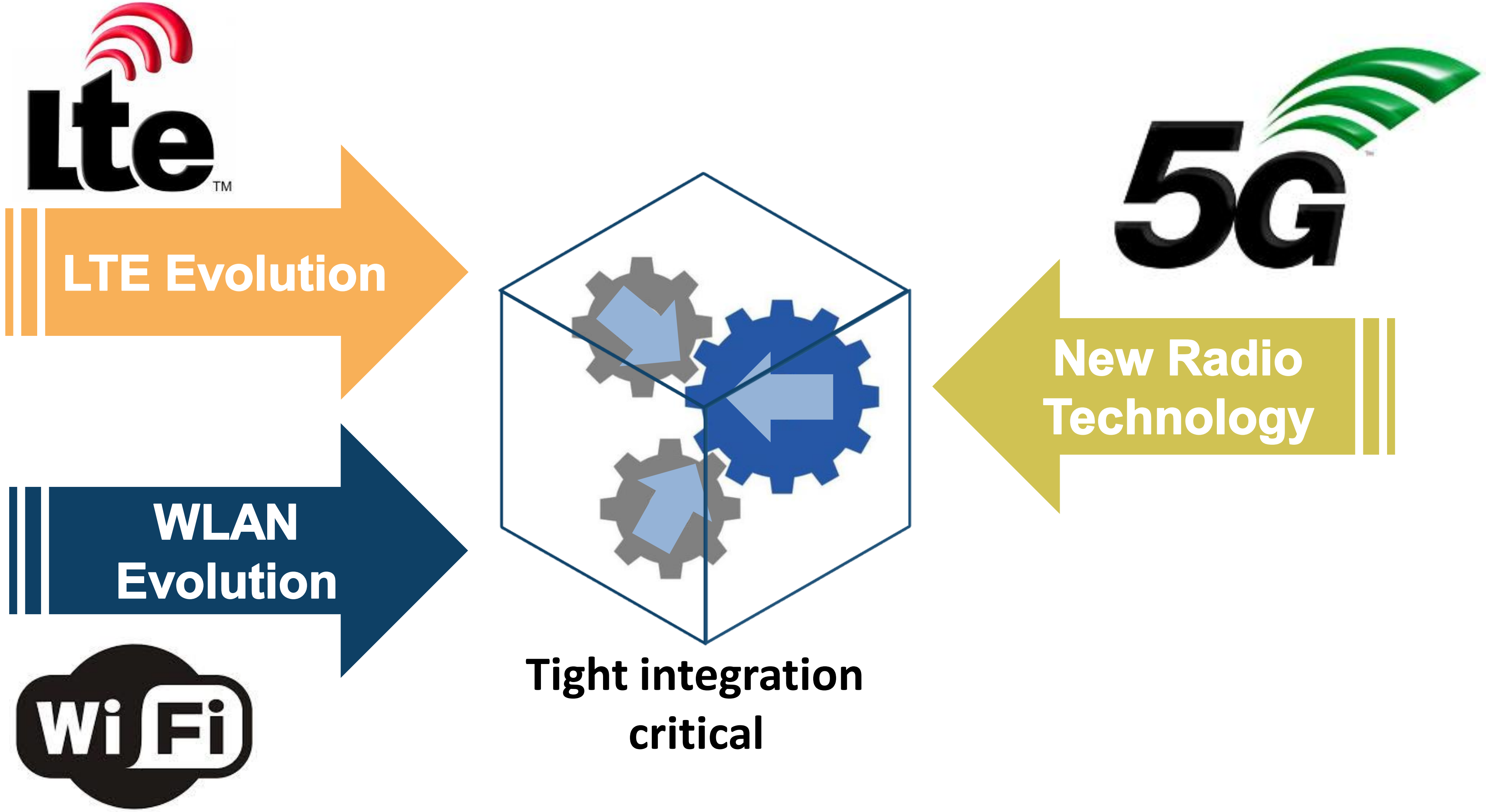
- Ultra broadband
- Low latency
- Massive device connectivity
- Low energy and cost

Solutions

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

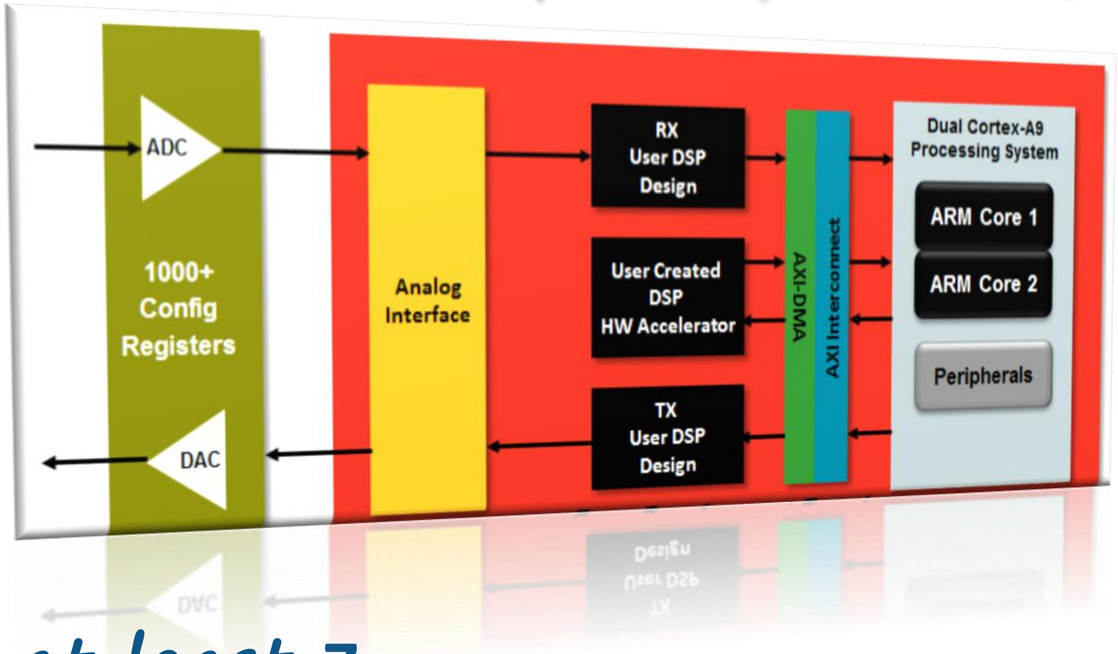
Road to 5G

Evolution of Current Standards + New Radio Technology



Developing Next Generation Wireless Technology

Antenna Design | **RF Design** | **Mixed-Signal Hardware** | **Digital Hardware** | **DSP Algorithms** | **Software Development** | **System Architecture**



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

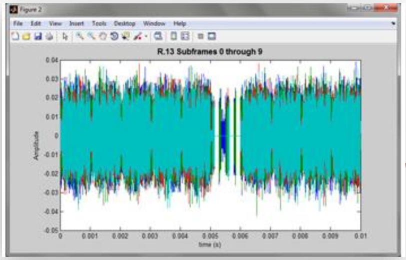
- RF Toolbox
- RF Blockset

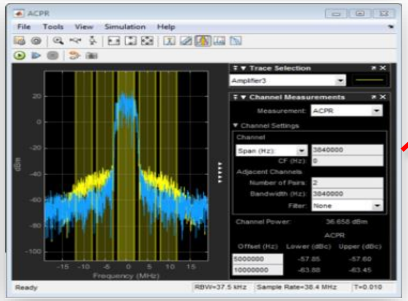
Antennas, Antenna Arrays

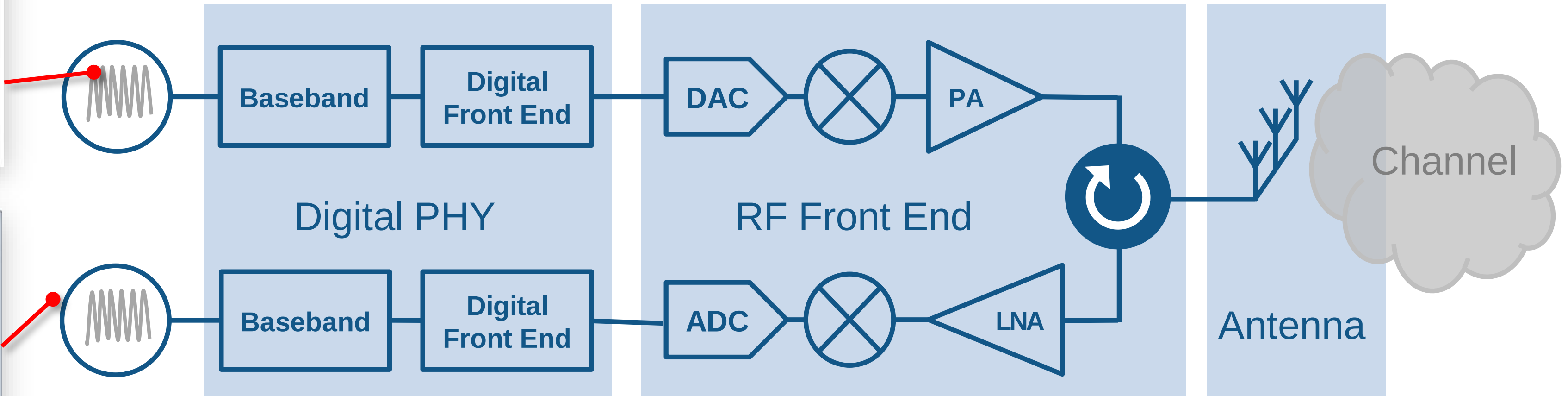
- Antenna Toolbox
- Phased Array System Toolbox

System Architecture

DSP Algorithms | Mixed-Signal | RF Design | Antenna Design







- Simulink
- DSP System Toolbox
- Control System Toolbox

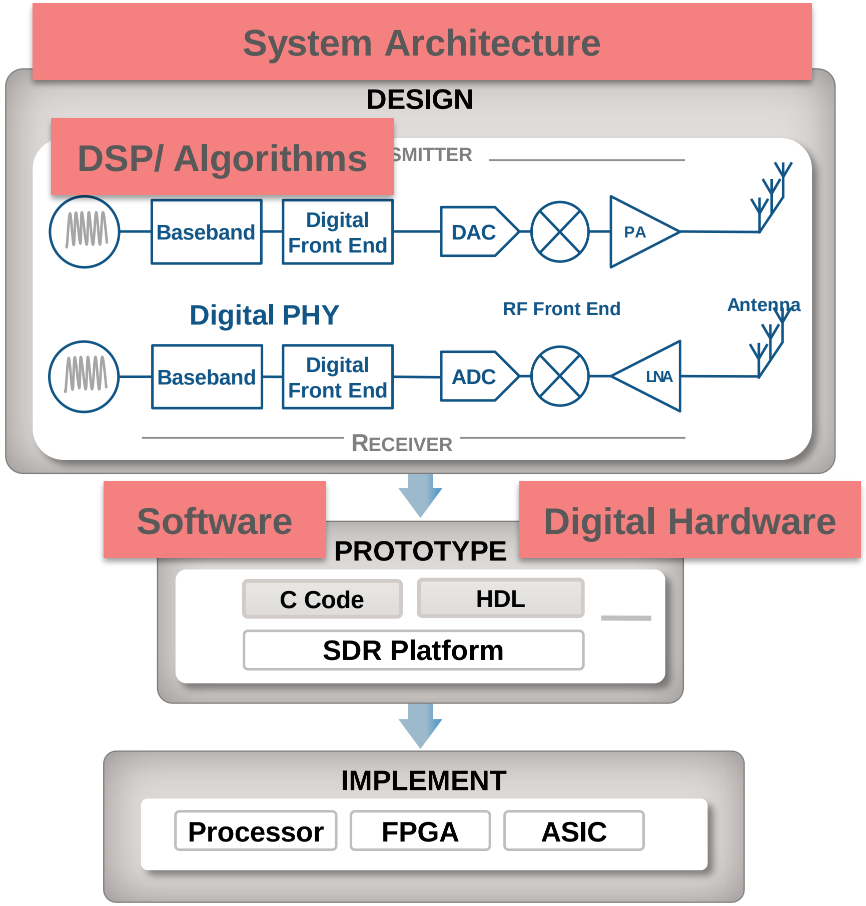
Mixed-signal

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

Channel Modeling

MATLAB & Simulink: Unified Wireless Design Platform

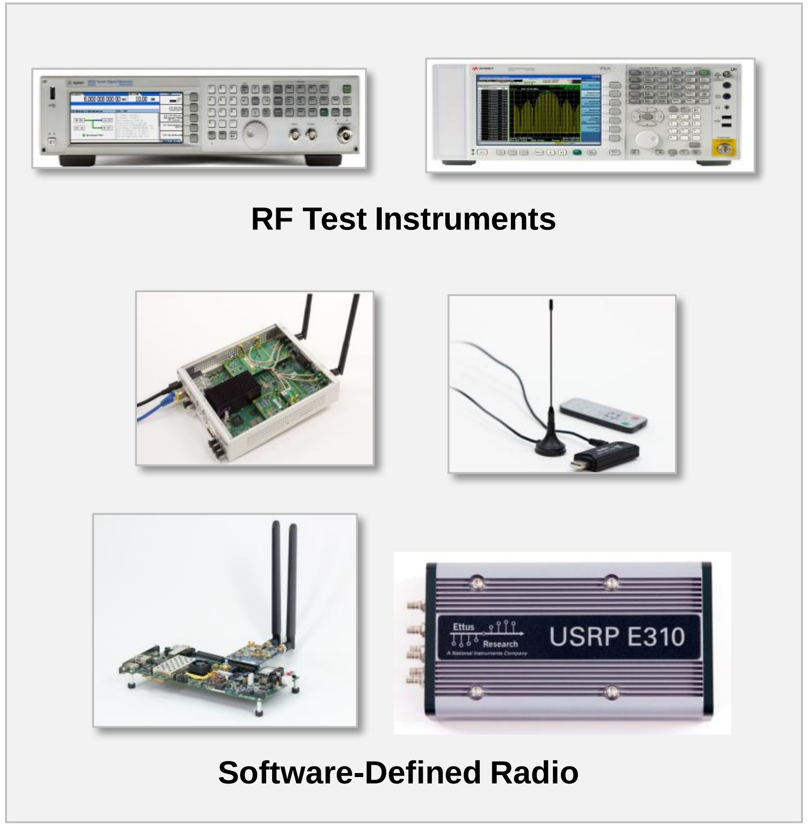
for algorithm developers, system architects, HW and SW developers



Instrument Control Toolbox

SDR Support Packages
Communications System Toolbox

Fixed-Point Designer
HDL Coder
Embedded Coder



HDL and C code generation

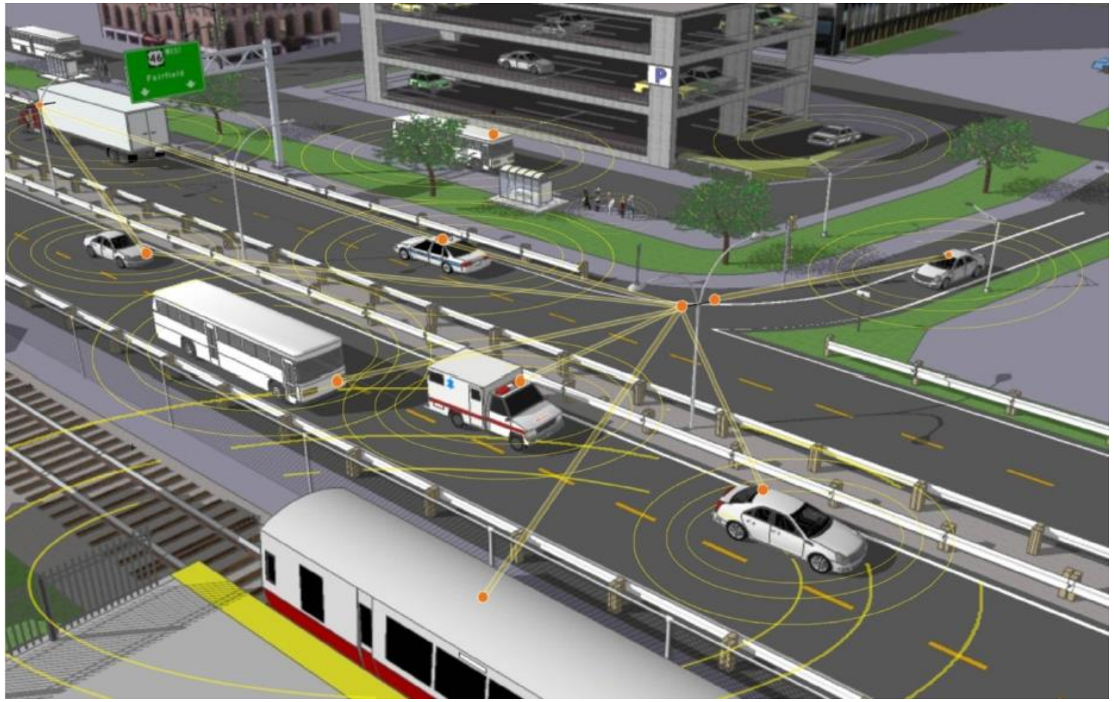
Multi-vendor hardware support

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)

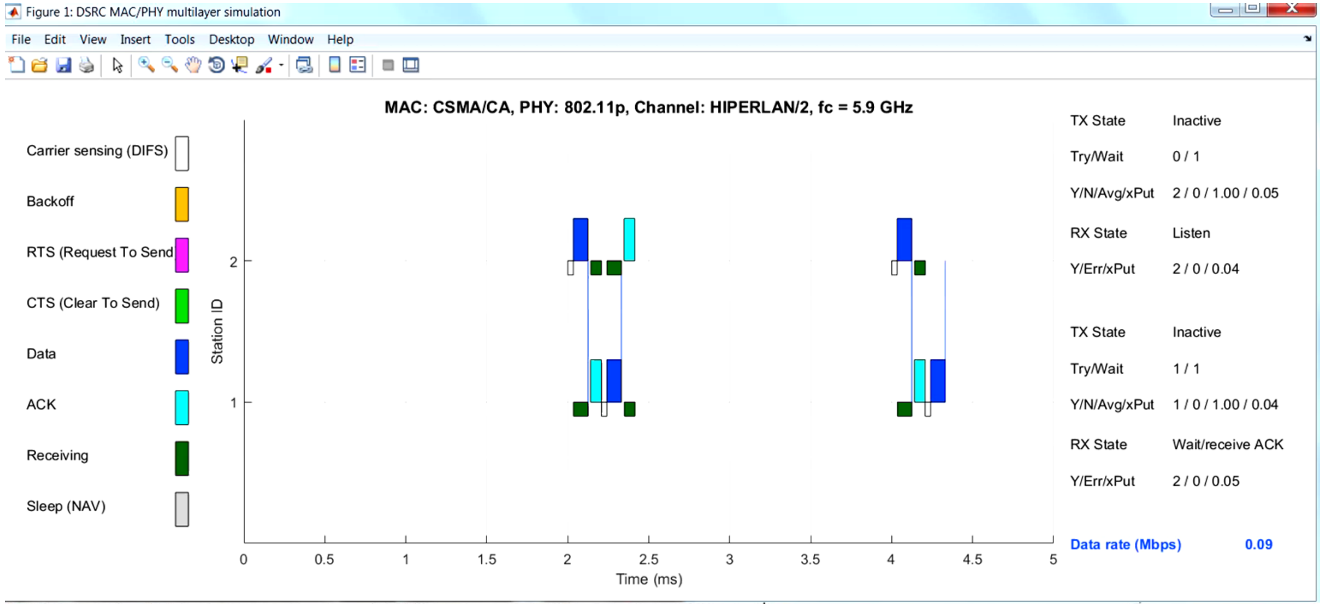
$\left.\right\}$ V2X

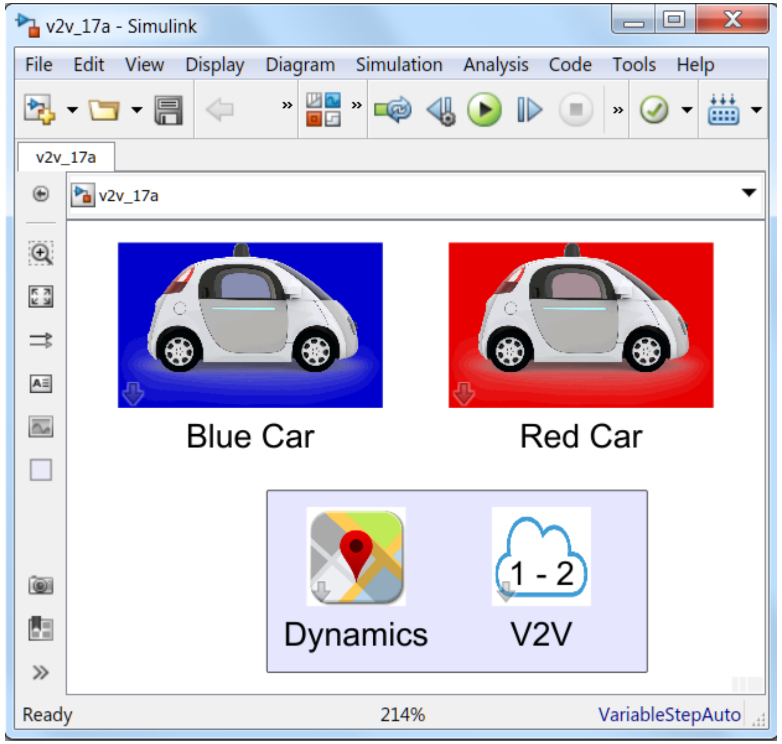


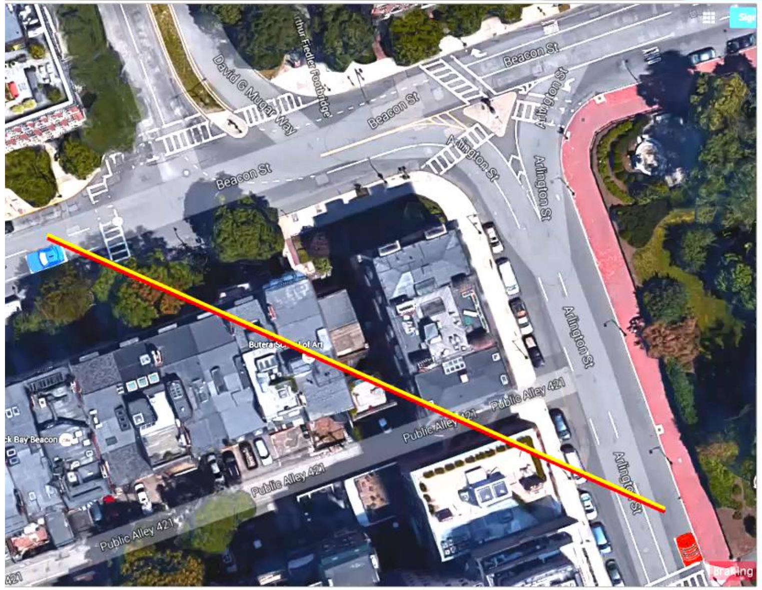
Example: DSRC V2V Safety Scenario Simulation

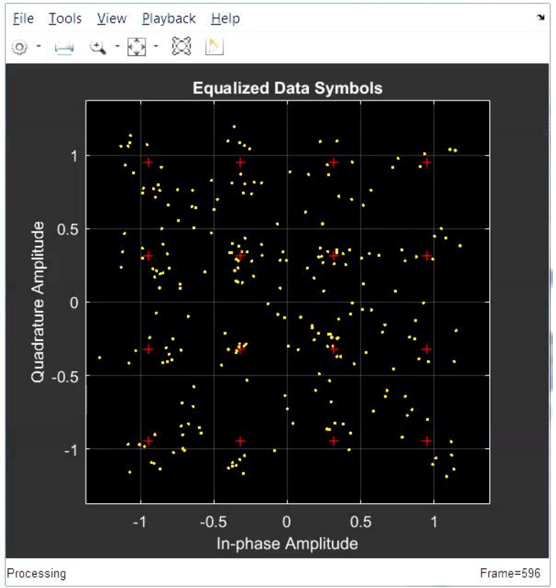
Dedicated Short Range Communications

- 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**

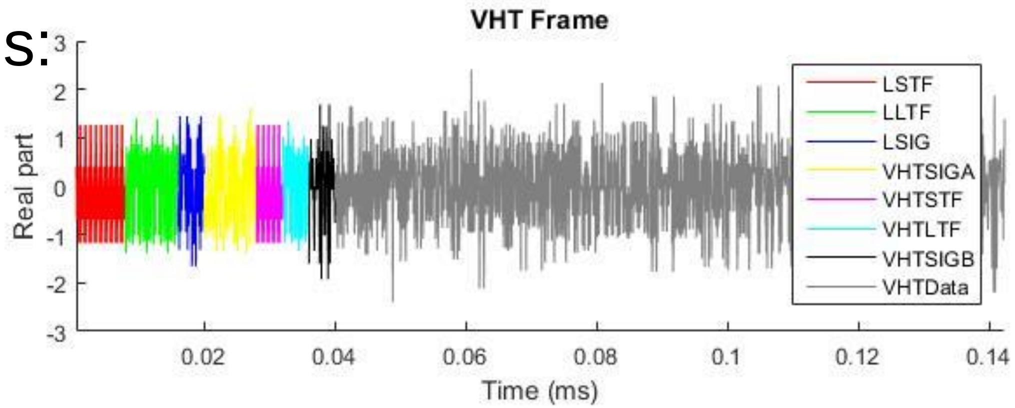
2. Model vehicular maneuvers, collision prediction, and collision avoidance algorithms using **MATLAB**

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 — R2016a
  - 802.11ah — R2016b
  - 802.11ad — R2017a



- Transmitter, receiver, and channel models

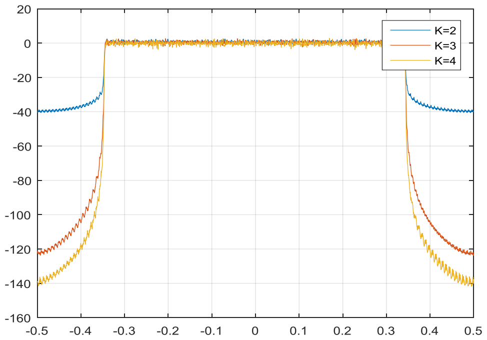
```
% OFDM demodulation
[ofdmDemodData, ofdmDemodPilots] = wlanOFDMDemodulate( ...
    rxVHTData(1:minInputLen, :), cfgOFDM, symOffset);

% 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);
```

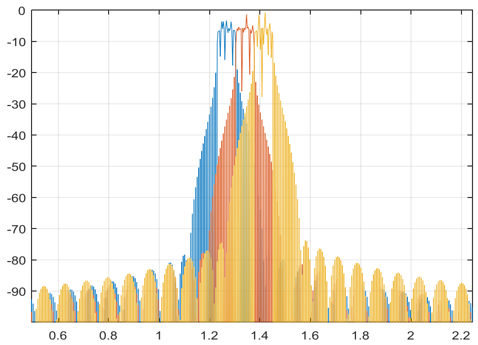
- Open, customizable MATLAB code

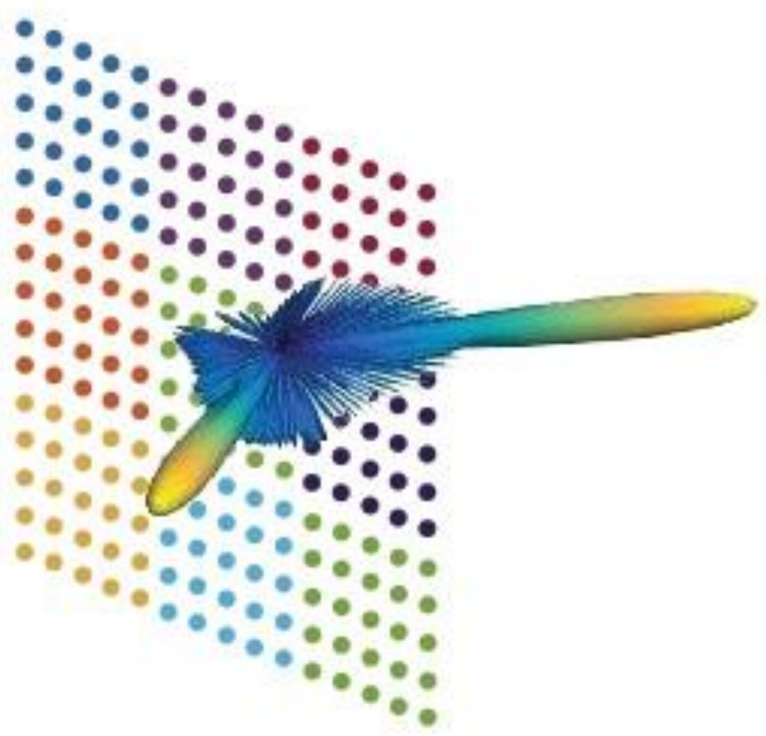
- C-code generation enabled with MATLAB Coder

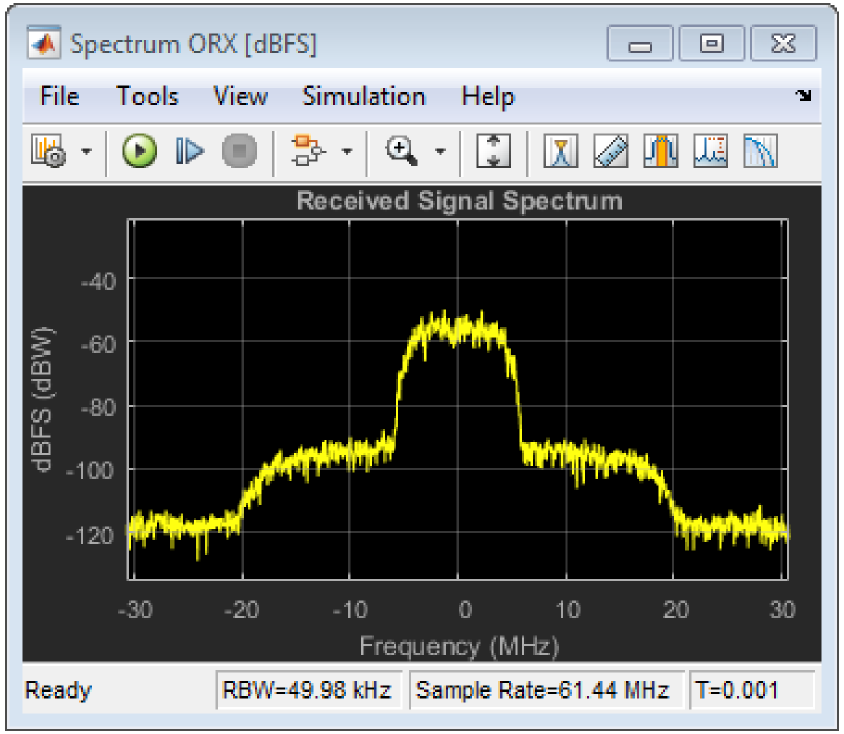
Key 5G Technologies

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







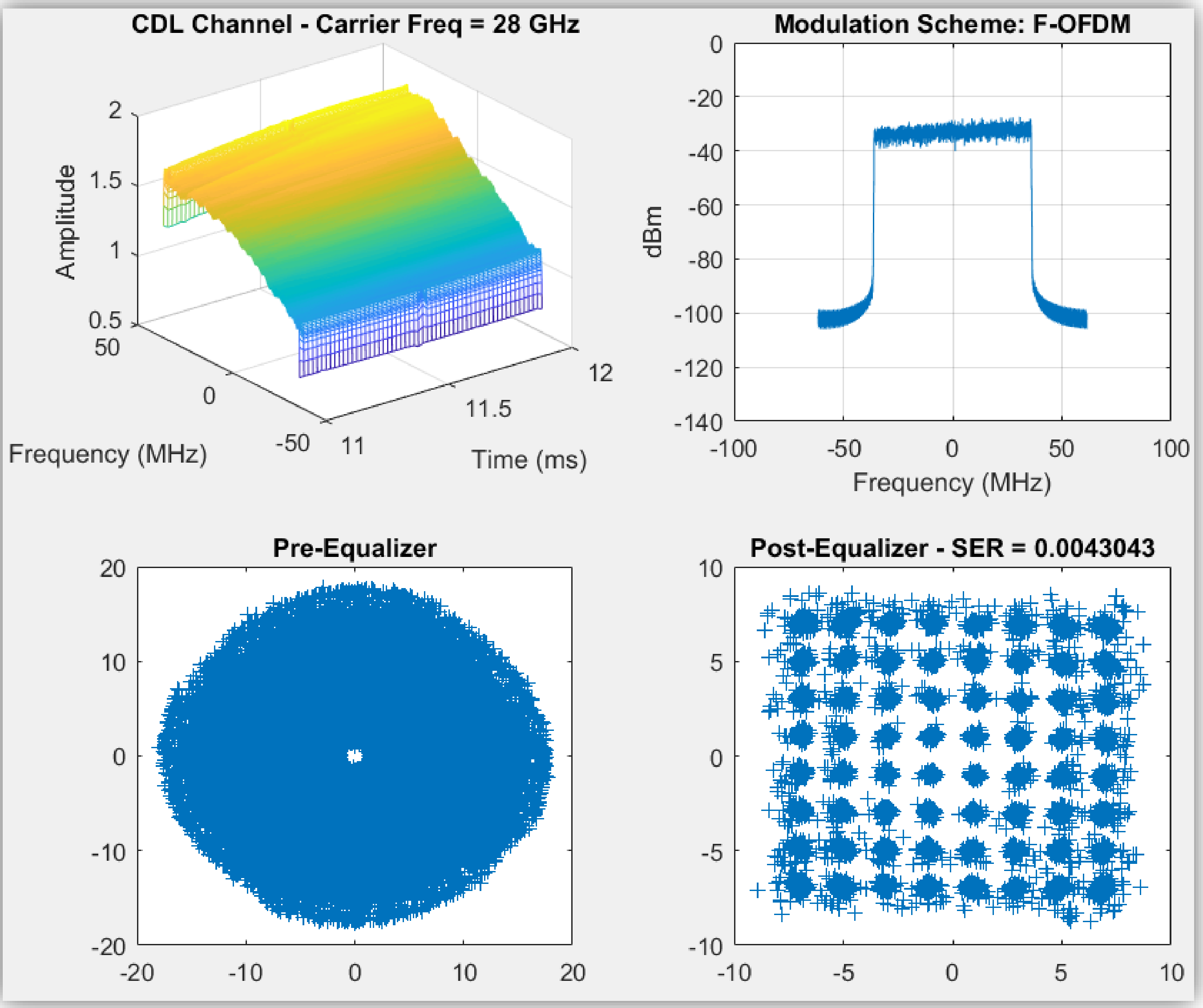


New Waveforms, Massive MIMO and mmWave Communications
Some Challenges

- 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 x N_T, many ADCs)
  - Analog beamforming has limited capabilities

Example: 5G Waveforms over 3GPP mmWave Channel

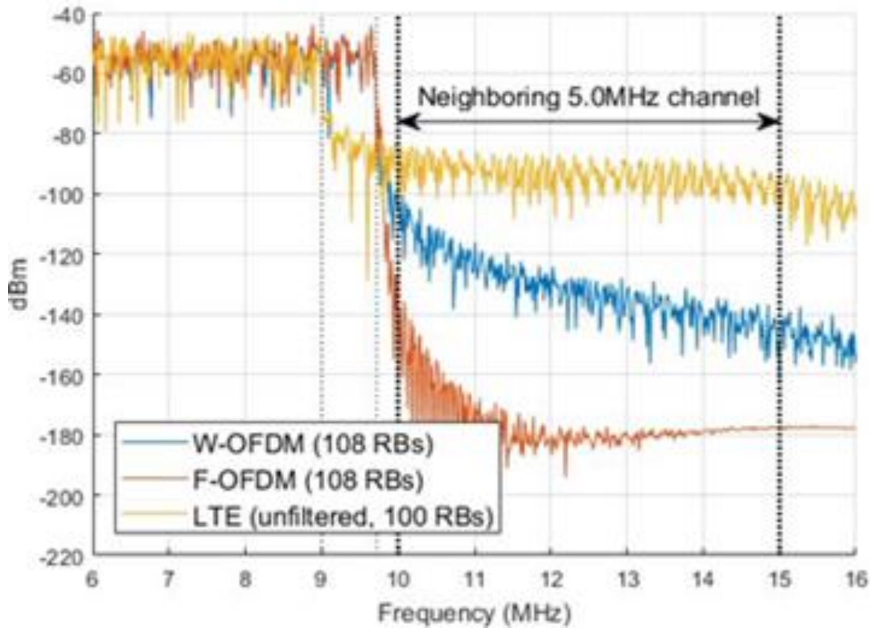
- Modulation schemes
  - CP-OFDM, F-OFDM, W-OFDM
- Variable subcarrier spacing
  - 60 kHz
- Variable no. of RBs
  - 100
- mmWave channel model
  - 28 GHz



[Get 5G Library]

Introducing the 5G Library
Free Add-on for LTE System Toolbox

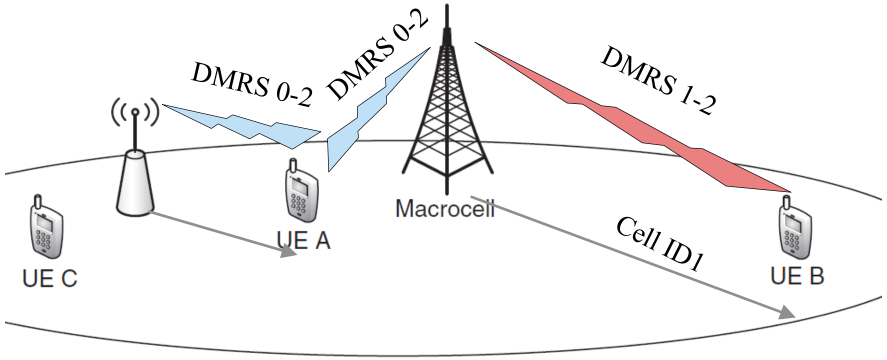
- 5G channel models (3GPP TR 38.900)
  - 6 GHz – 100 GHz
- New Radio (NR) Waveforms
  - (F-OFDM, W-OFDM)
- Link level simulation reference design



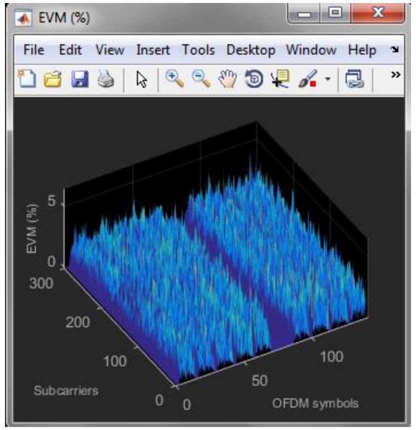
[Learn More](#)

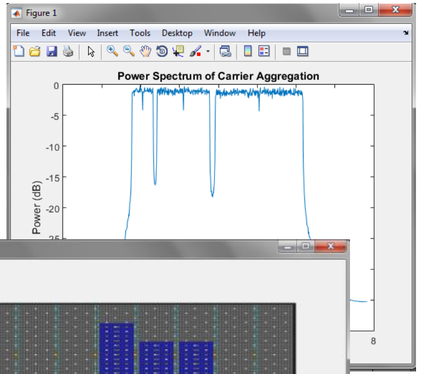
LTE System Toolbox

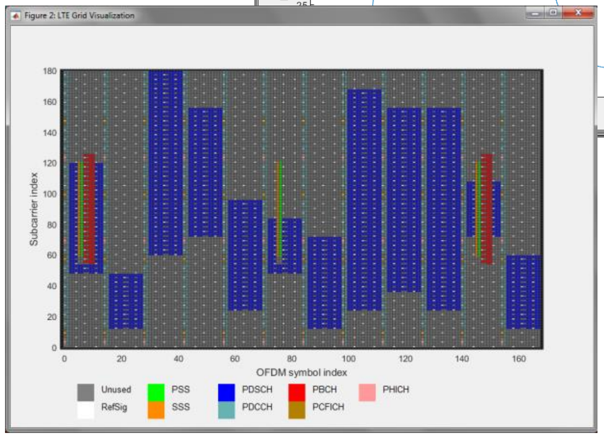
- LTE and LTE-Advanced (Rel-8 through Rel-12)
- Scope
  - FDD/TDD
  - Uplink/Downlink/Sidelink
  - Transmitter/Receiver
  - Channel models



- >200 functions for physical layer (PHY) modeling
- LTE Signal generation
- ACLR/EVM measurement
- Conformance Tests

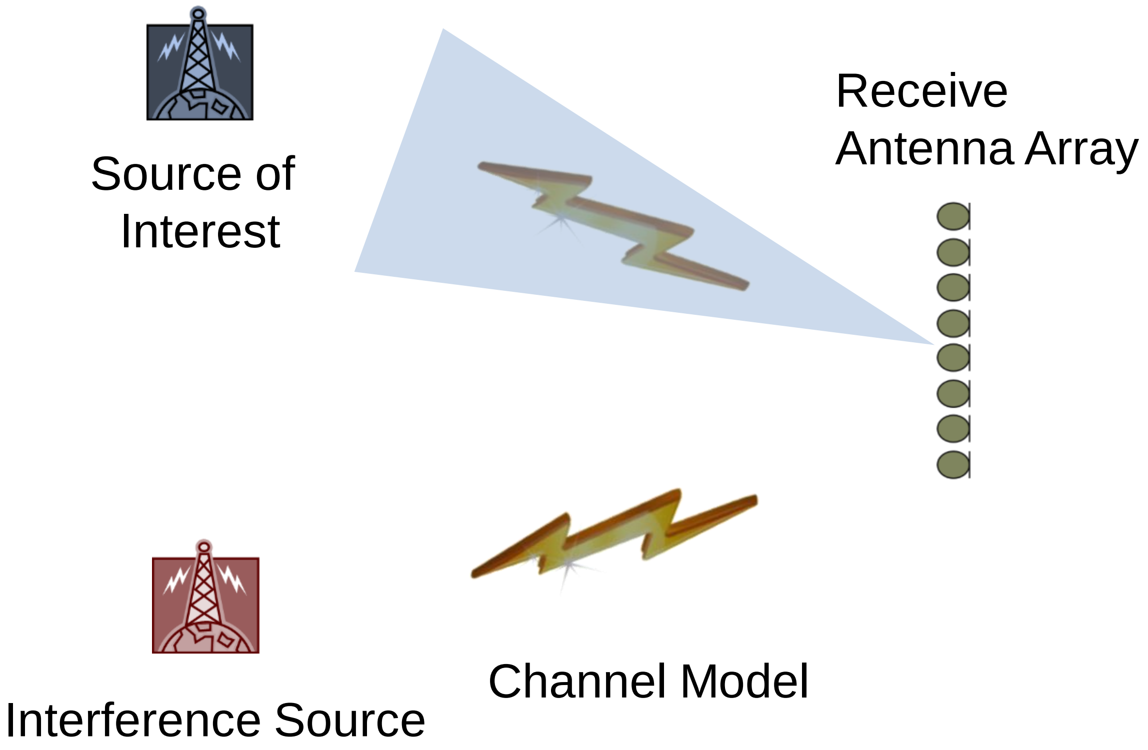






Example: Interference Mitigation using Massive MIMO

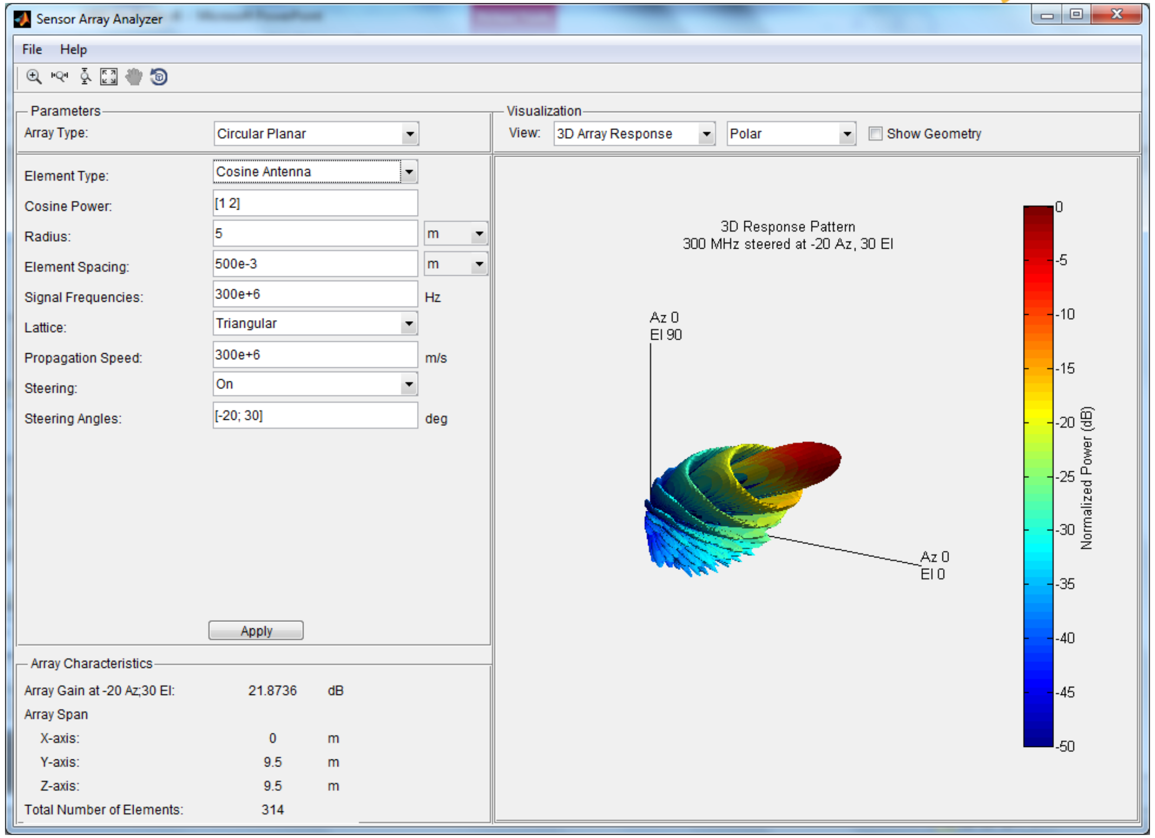
- System model
  - Receiver
    - Antenna array, Beamformer, Signal Processing
  - Source of interest
    - LTE node with specific cell ID
  - Propagation channel
    - Path loss, environment
  - Interference source
    - LTE node with neighboring cell ID

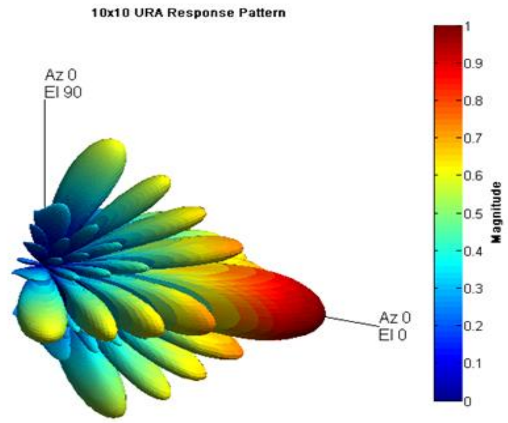


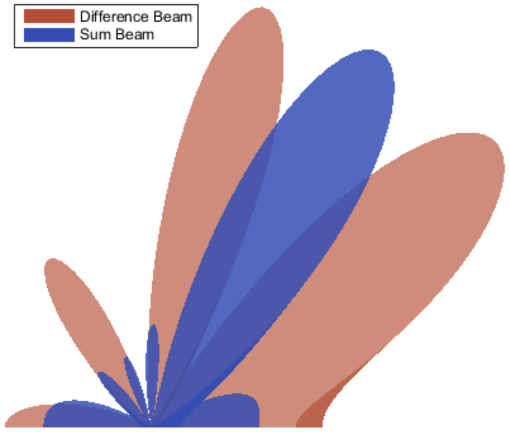
Model and simulate to determine expected performance, operational limits and mitigation effectiveness

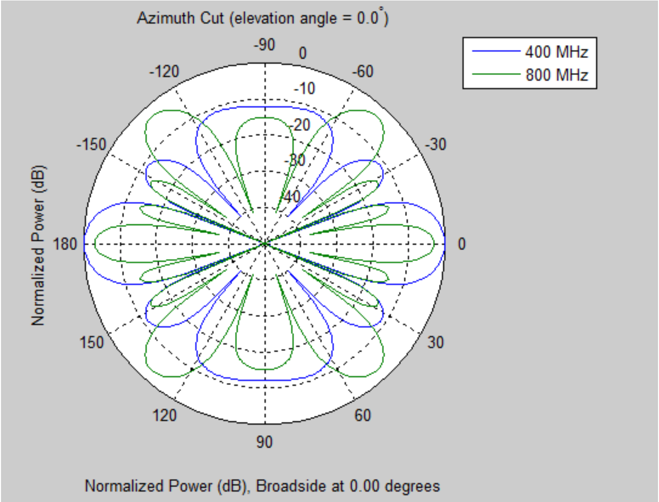
Phased Array System Toolbox

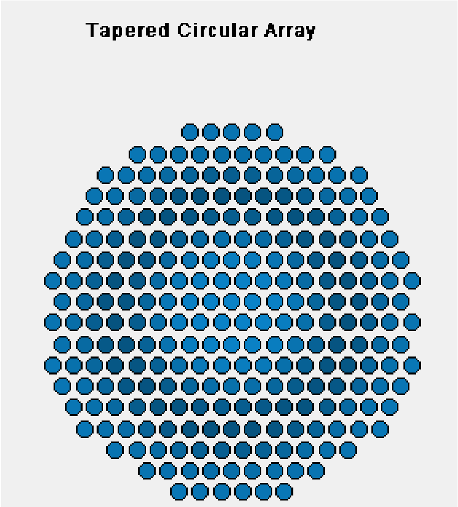
- Array design and analysis
- Advanced array processing algorithms
  - Temporal processing
  - Spatial processing
  - Space-time adaptive processing
- End-to-end system modeling











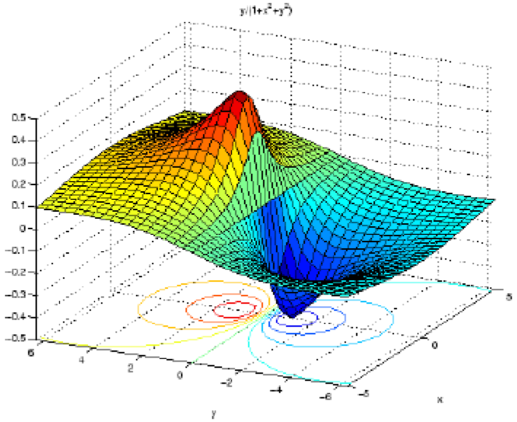
Tools for Mathematical Analysis and Modelling

- MATLAB
  - Linear algebra, sparse matrices, graphs, computational geometry, …

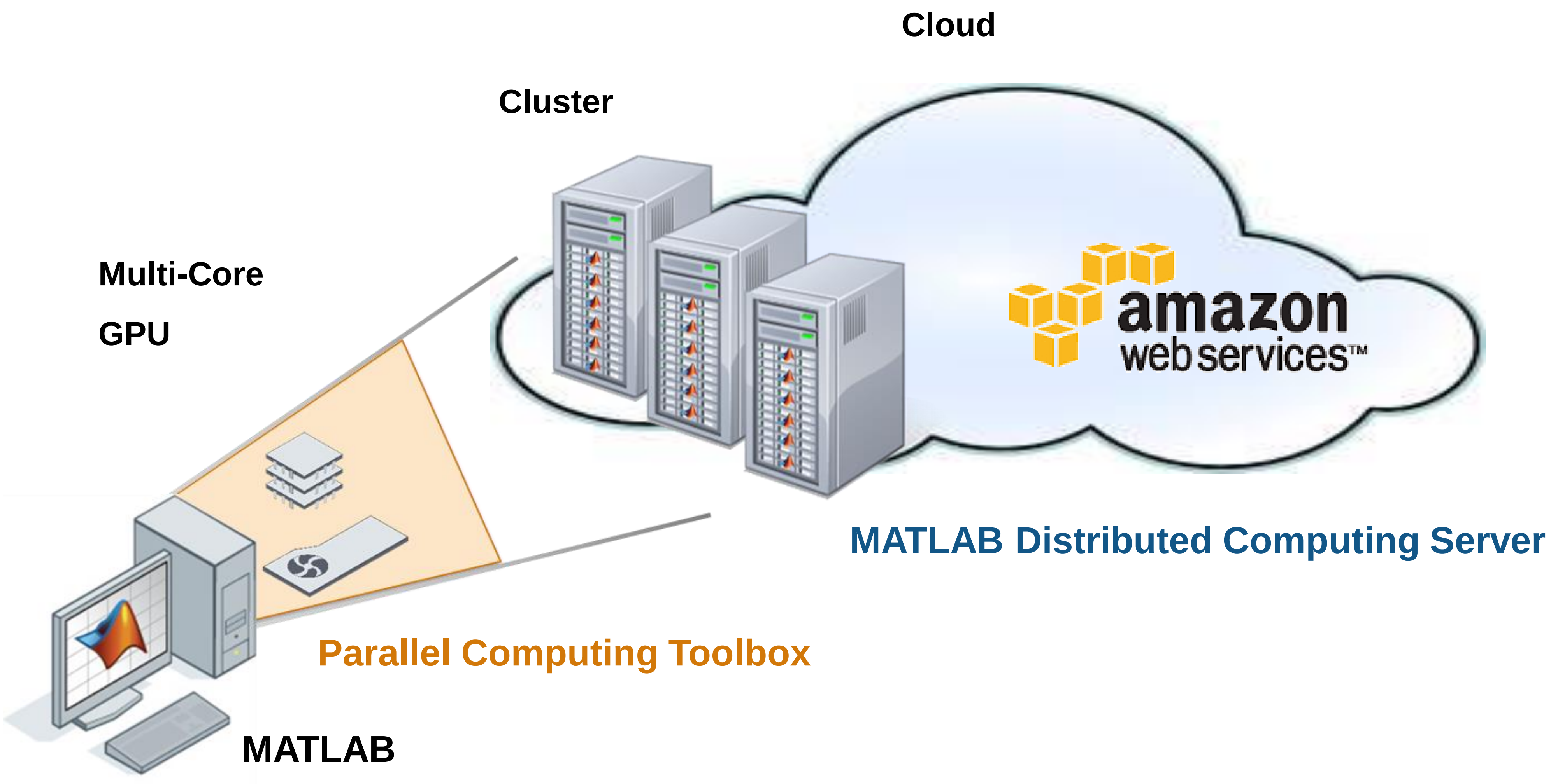
```
transform::fourier(heaviside(t - t0), t, s)
```

$$e^{s\,t0\,i}\left(\pi\,\delta(s)+\frac{i}{s}\right)$$

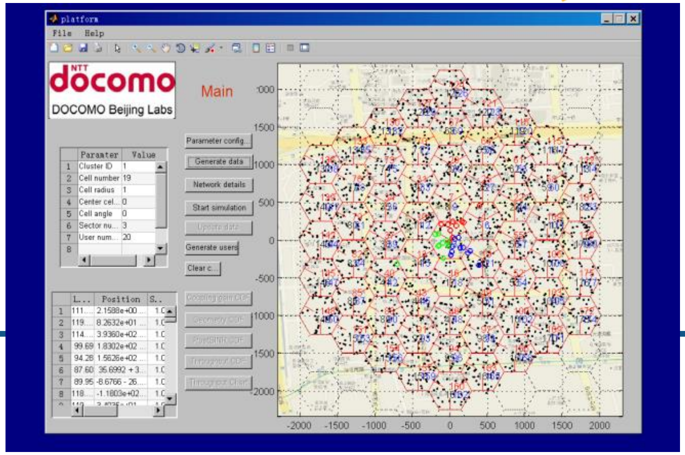
- Symbolic Math Toolbox
  - Simplification and manipulation, calculus, transforms, linear algebra, …
- Optimization Toolbox
  - linear programming, mixed-integer linear programming, quadratic programming, …
- Global Optimization Toolbox
  - pattern search, genetic algorithm, simulated annealing, …



Accelerate Simulations with Scalable Computing



DOCOMO Beijing Labs Accelerates the Development of Mobile Communications Technology



User interface for DOCOMO 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

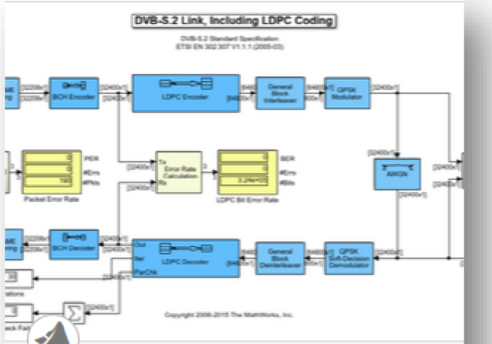
"With MATLAB we spend less time coding and more time developing innovative mobile communications algorithms. More importantly, with only minor modifications we can accelerate the simulation of algorithms on our computing cluster to thoroughly evaluate and verify them under a wide range of operating conditions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

Lead Research Engineer
DOCOMO Beijing Labs

Link to user story

Design and Prototype a Wide Range of Wireless Systems

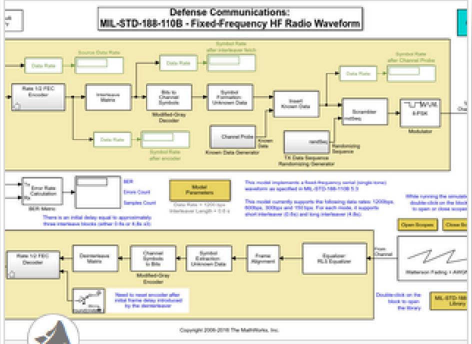
with Communications System Toolbox



DVB-S.2 Link, Including LDPC Coding

The state-of-the-art channel coding scheme used in the second generation Digital Video Broadcasting standard (DVB-S.2),

Open Model



Defense Communications: US MIL-STD-188-110B Baseband End-to-End Link

An end-to-end baseband communications system compliant with the U. S. MIL-STD-188-110B military standard. In particular, the

Open Model

EVM Measurements for a 802.15.4 (ZigBee®) System

Use the COMM.EVM System object to measure the error vector magnitude (EVM) of a simulated IEEE® 802.15.4 [1] transmitter.

Open Script

Automatic Meter Reading

Use Communications System Toolbox™ to read utility meters by processing Standard Consumption Message (SCM) signals and Interval

Open Script

Airplane Tracking Using ADS-B Signals with Raspberry Pi and RTL-SDR

Create a remote sensing station that tracks planes using a Raspberry Pi and RTL-SDR radio. You will learn how to deploy a Simulink® model

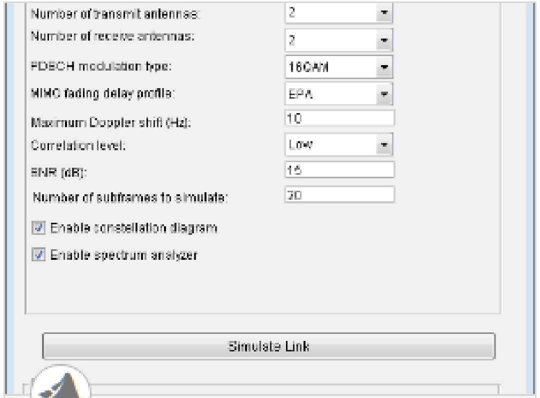
Open Model

[Available Here]

More Examples – 5G Waveform Exploration

in Communications System Toolbox

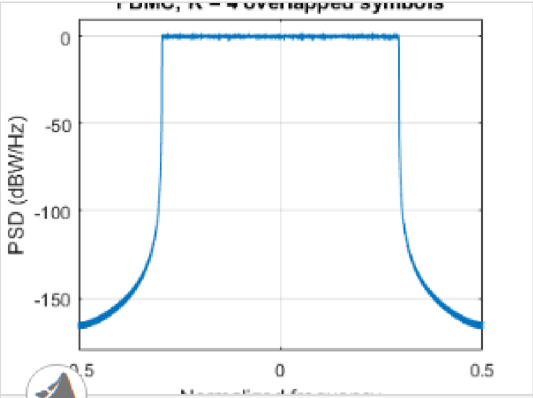
5G Exploration



5G Waveforms with LTE

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

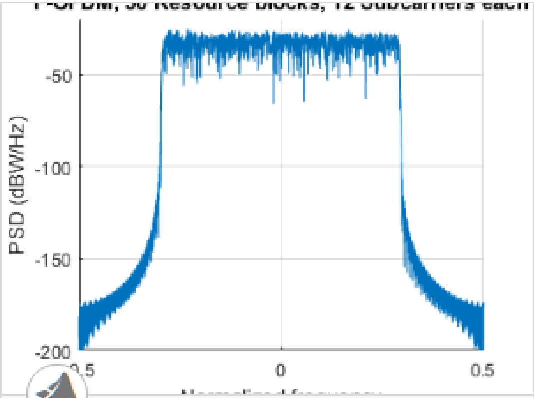
Open Script



FBMC vs. OFDM Modulation

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

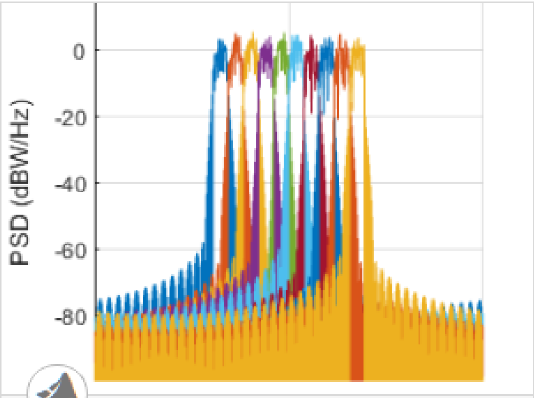
Open Script



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

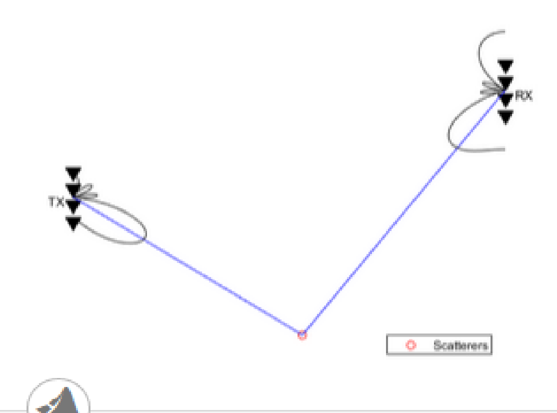
Compares Universal Filtered Multi-Carrier (UFMC) with Orthogonal Frequency Division Multiplexing (OFDM) and highlights the merits of

Open Script

[Available Here]

More Examples – Beamforming

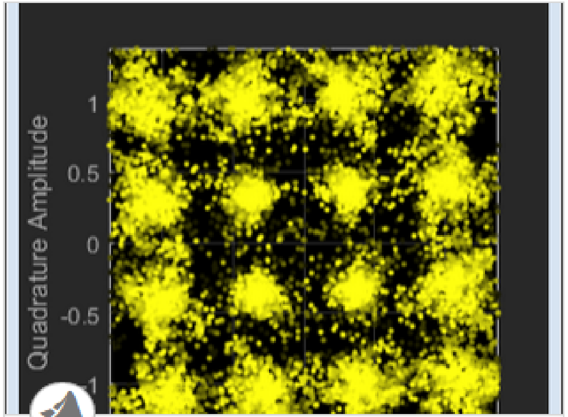
in Phased Array System Toolbox



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

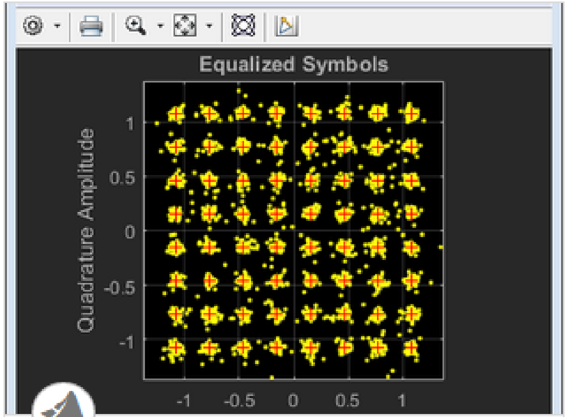
Open Script



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

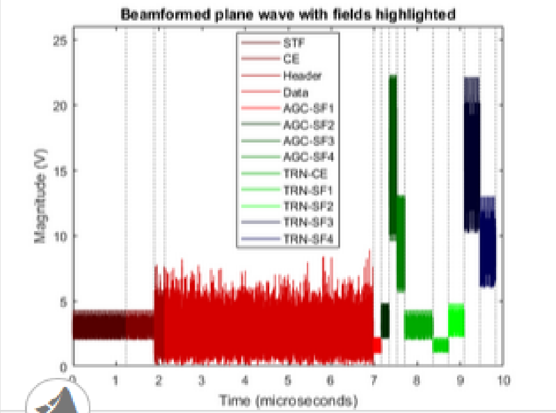
Open Script



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

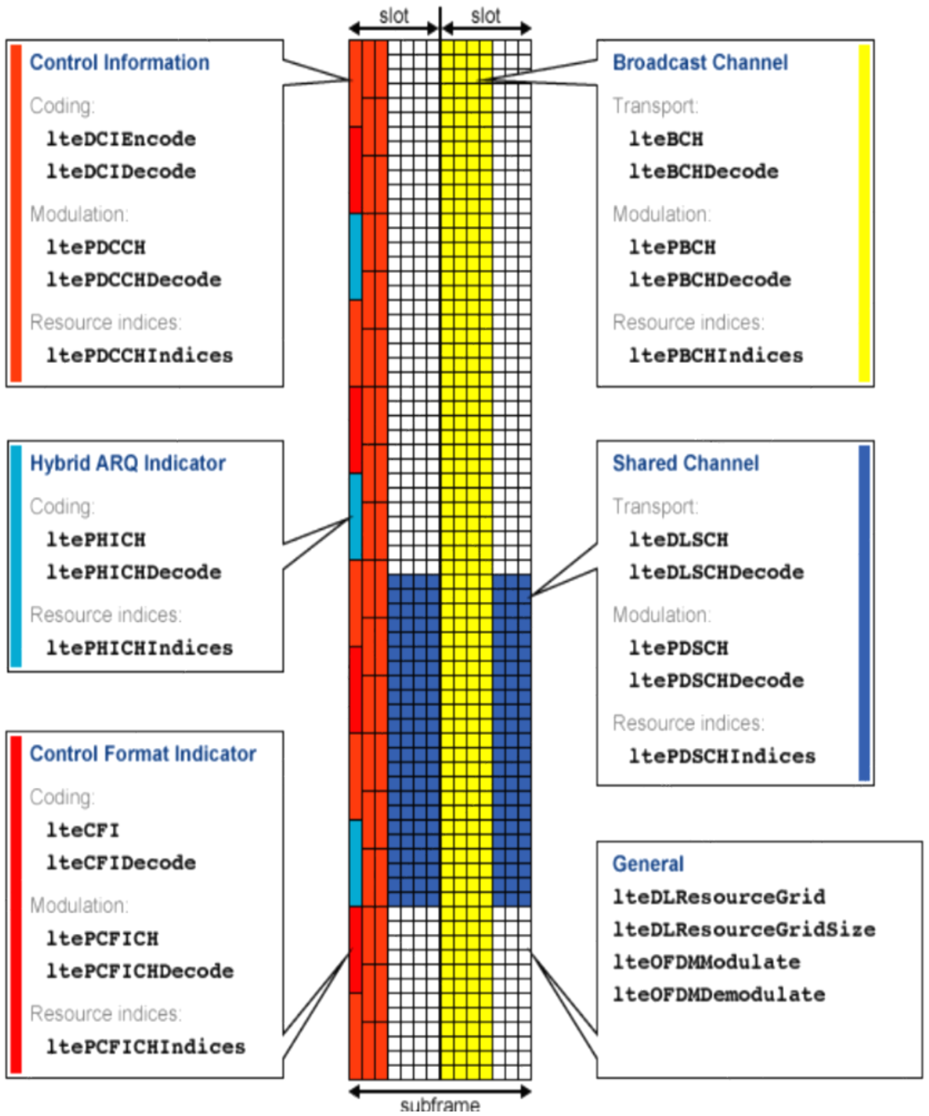
[Available Here]

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



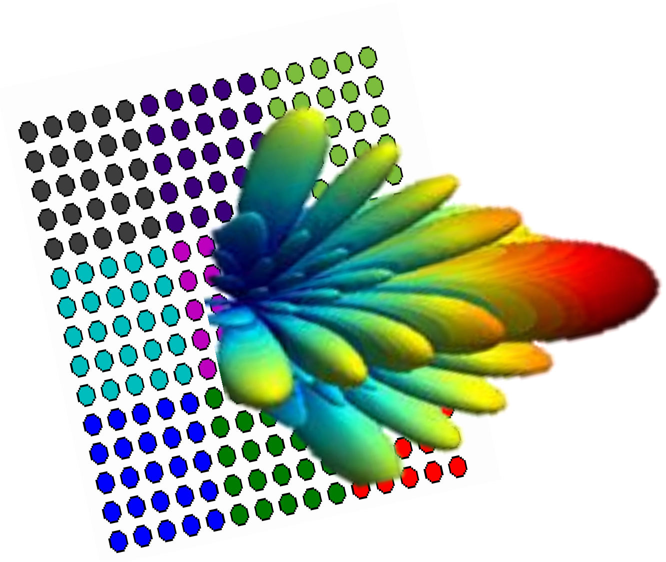
MathWorks® | *Training Services*

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.

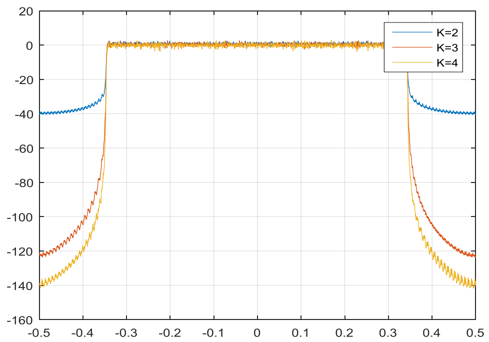
Topics include:

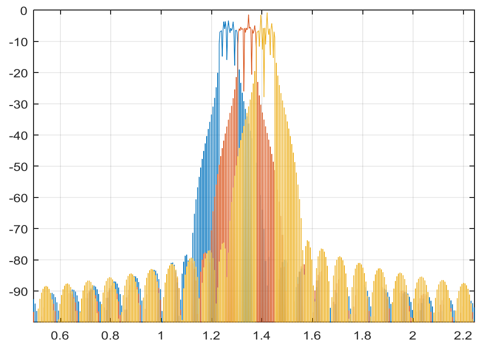
- Review of a Monostatic End-to-End Radar Model
- Characterize and analyze radar components and systems
- Design and model components of a radar system
- Implement a range of radar signal processing algorithms

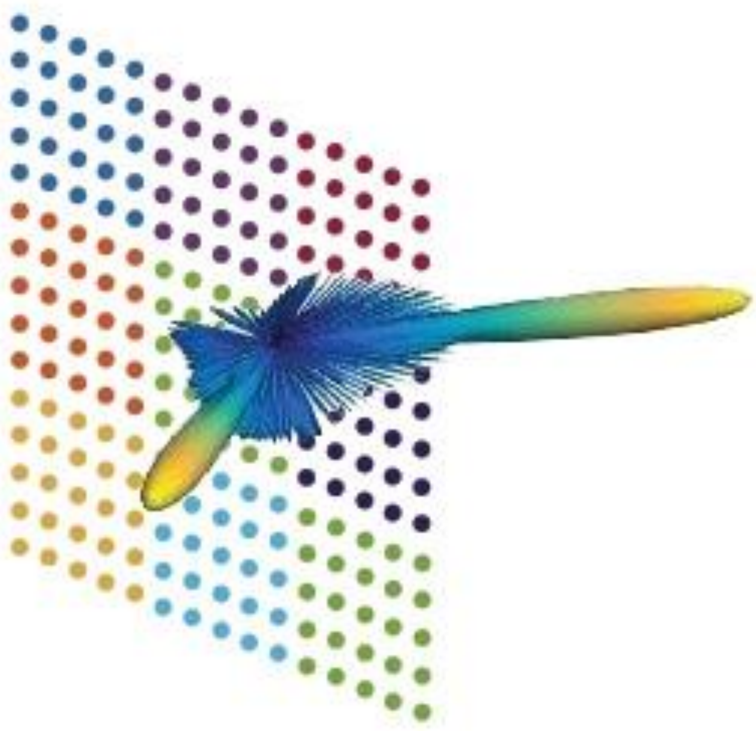


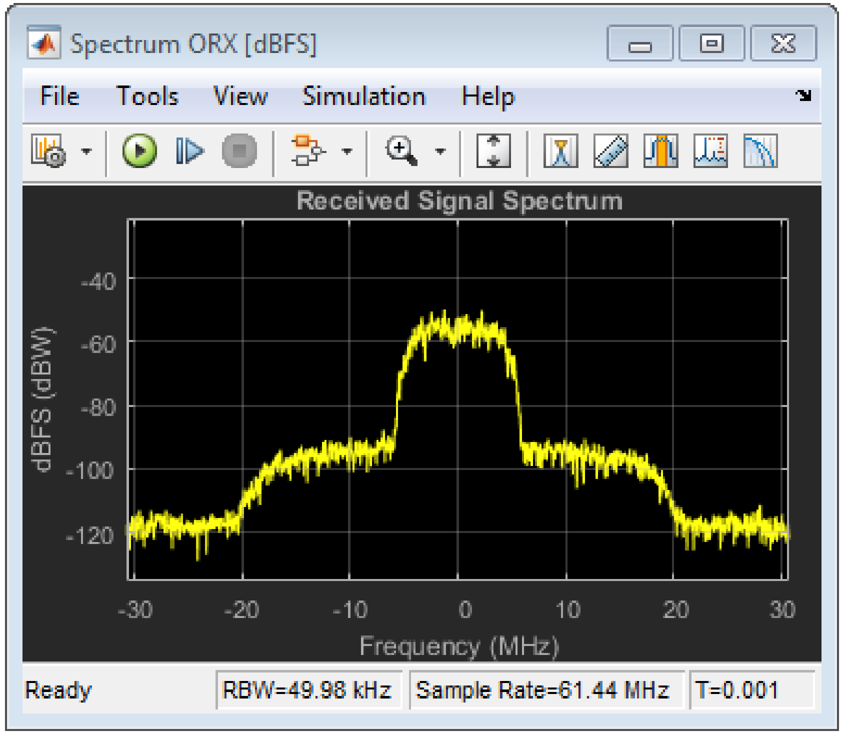
Key 5G Technologies

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



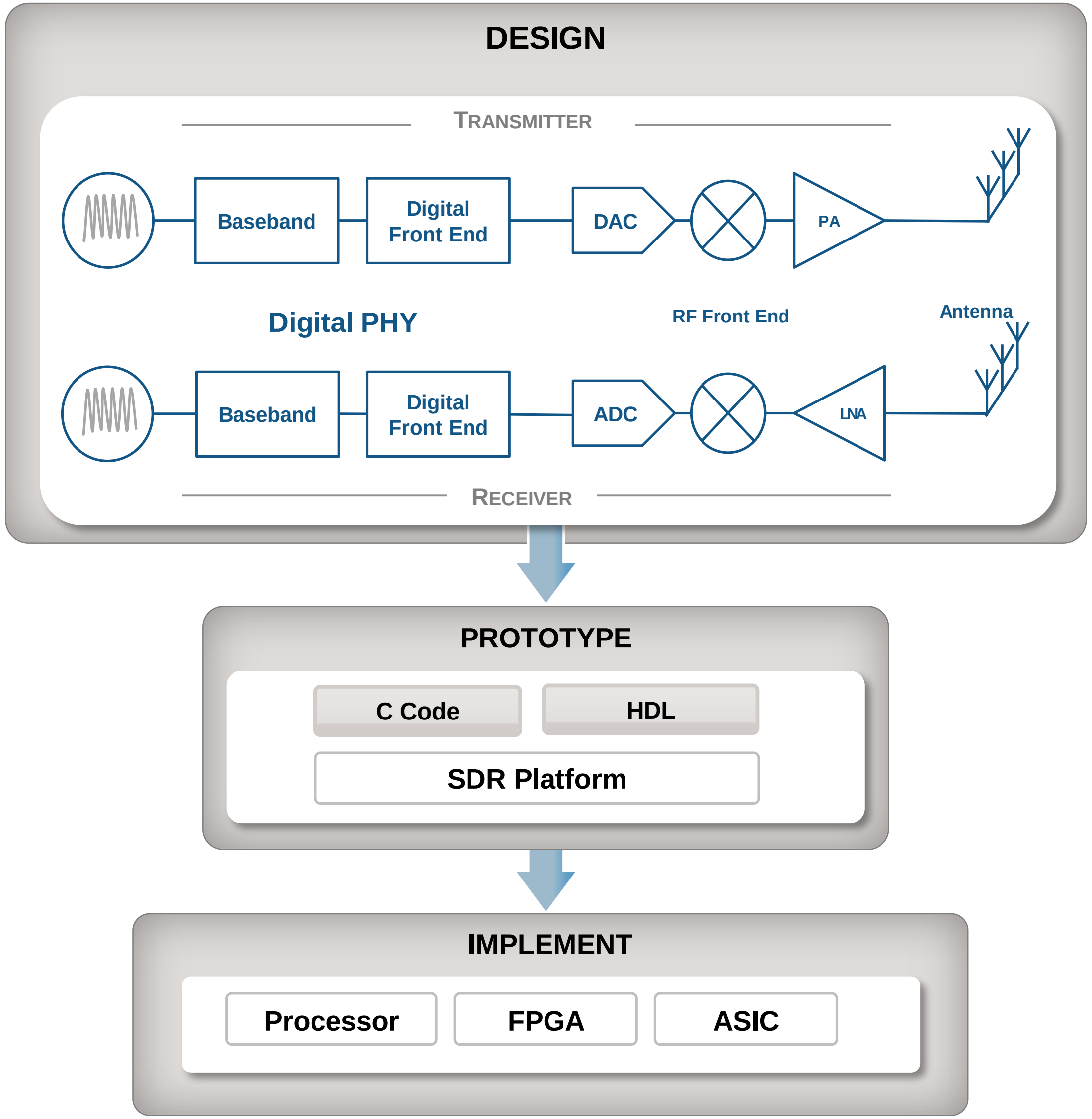




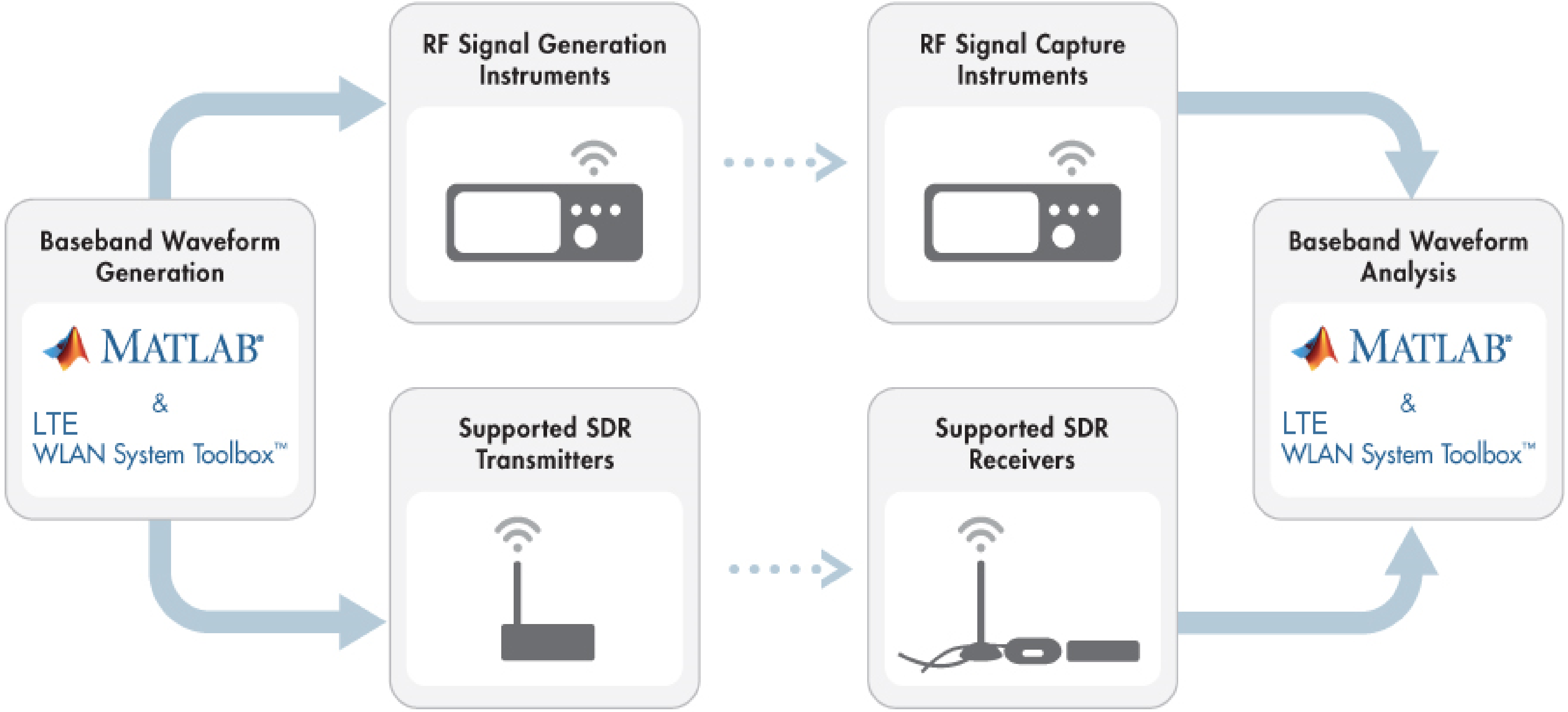


Implementation and Prototyping

using Model-Based Design



Over-the-air testing with SDRs & RF instruments



Generate custom waveforms

Transmit with SDR devices or RF instruments

Capture signals with SDR or instruments

Recover original data

Prototyping Workflow Using SDR Platforms

Algorithm design
Simulation Model

↓

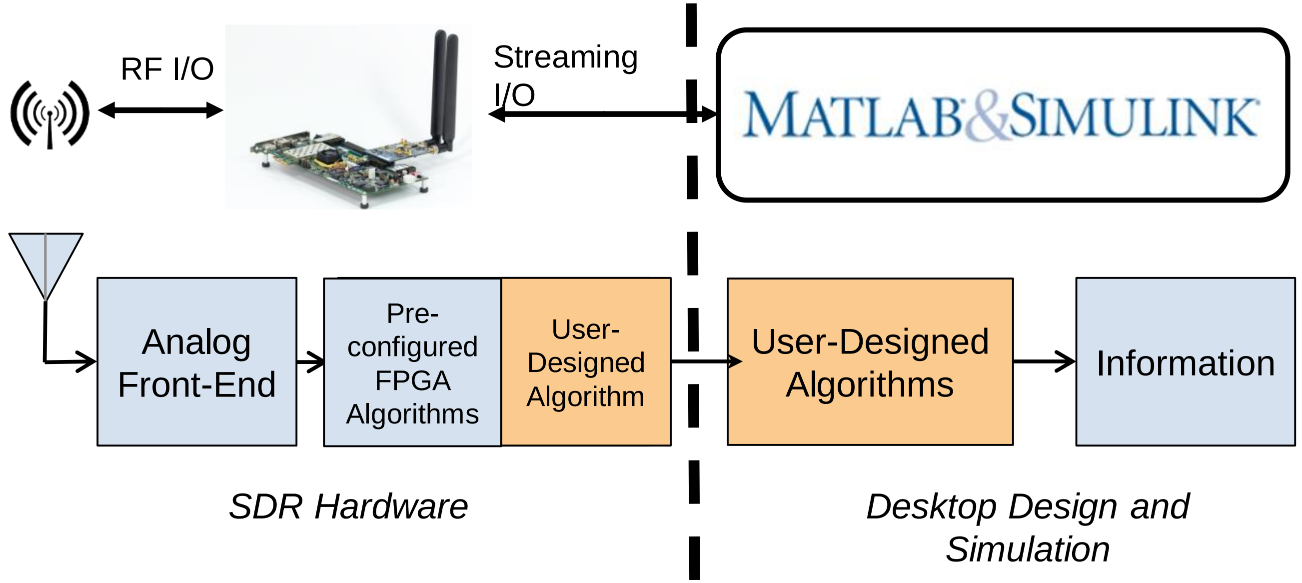
SDR testing with live signal I/O

↓

Generate HDL Code
Implementation Model

↓

Verify on SDR hardware



[***Webinar:*** 5G/LTE/WLAN: Waveform Generation, Simulation, Measurement and Over-the-Air Testing]()

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

Radio Testbed 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

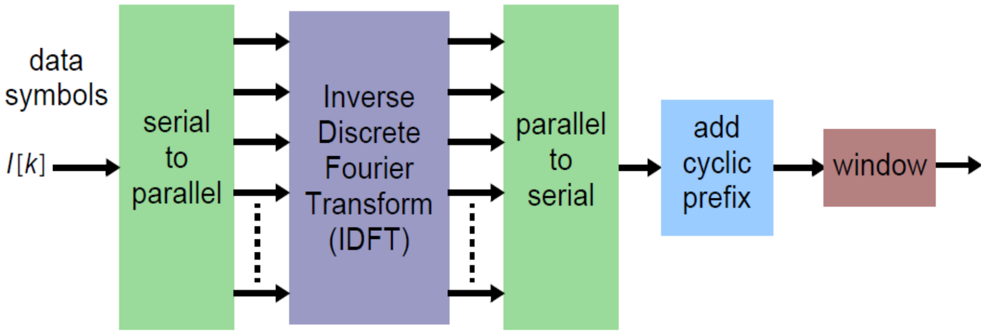
- Successful implementation running on FPGA
- Generated code easy to integrate into main design
- Very short lead time for changes in design

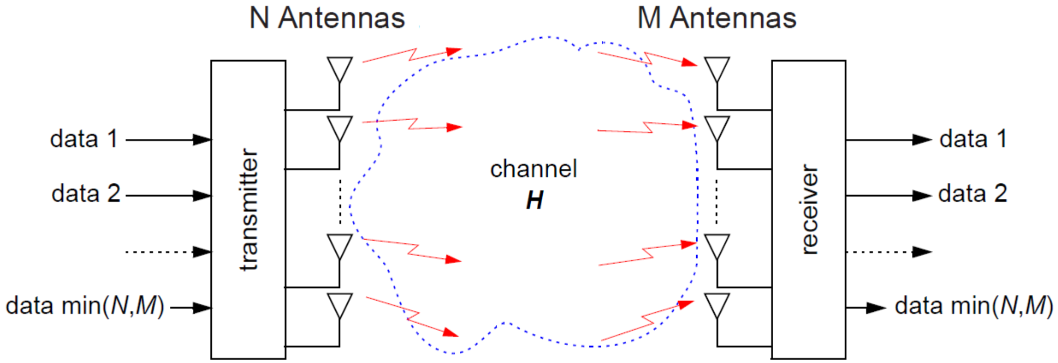
ERICSSON

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

Updated: Communication Systems Design with MATLAB

- Advanced communications topics
  - MIMO / OFDM
  - LDPC / Turbo Codes / OSTBCs
  - Examples using IEEE 802.11 (Wi-Fi) & LTE-bas 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



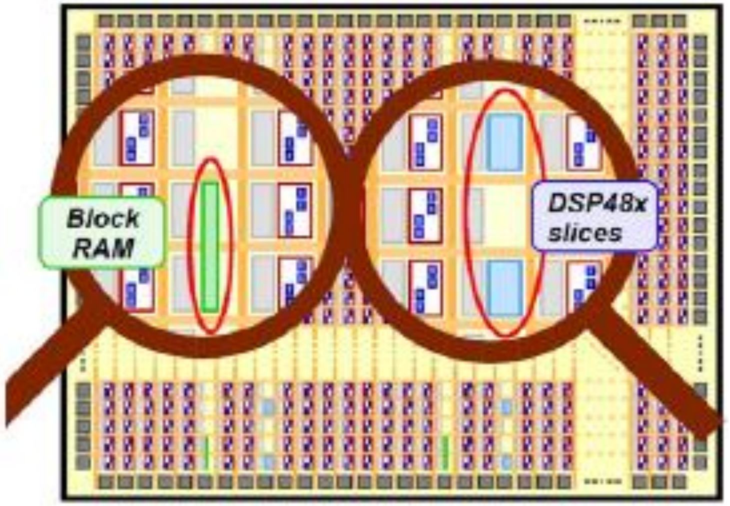


RTL-SDR (RX) USRP (TX & RX)

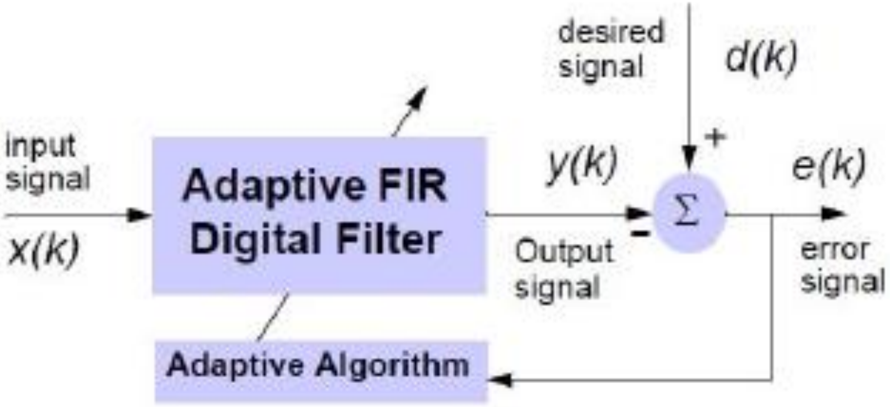
MathWorks® | *Training Services*

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

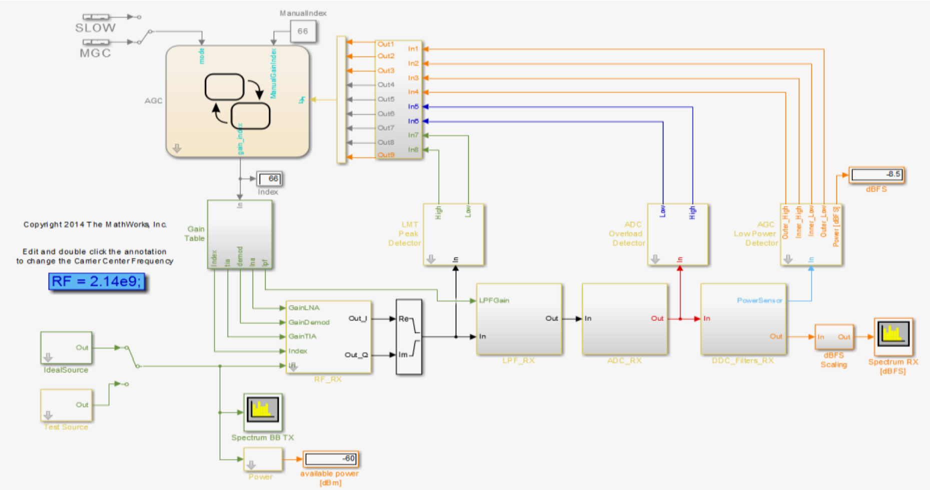


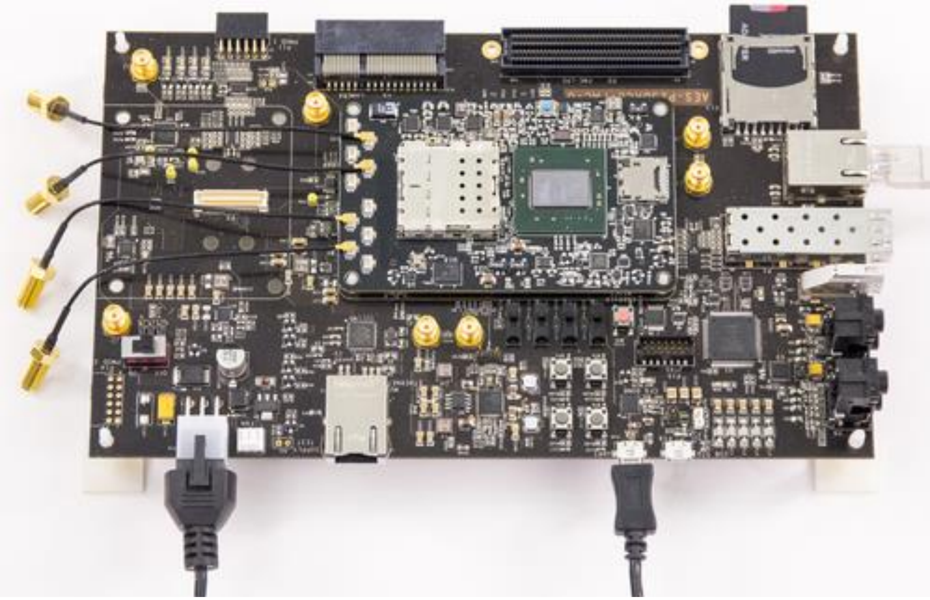
- Design and implementation of adaptive algorithms such as LMS and QR algorithm
- Techniques for synchronisation and digital communications timing recovery

MathWorks | Training Services

New: Software Defined Radio with Zynq using Simulink

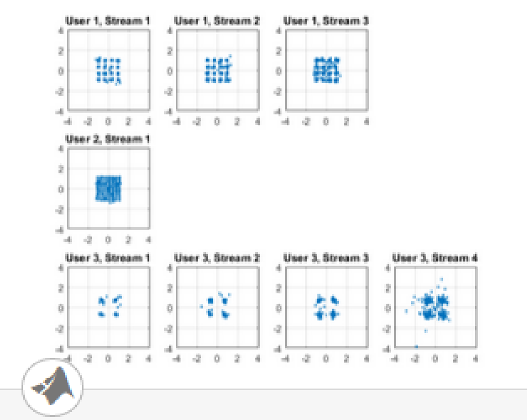
- Learn the Model-Based Design workflow from simulation of RF chain, testing with Radio I/O to moving design to chip
- Get hands-on experience with PicoZed
  - Setting up and communicating with board
  - Capture over-the-air signal and process in MATLAB
  - AD9361 configuration
  - HW/SW co-design for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





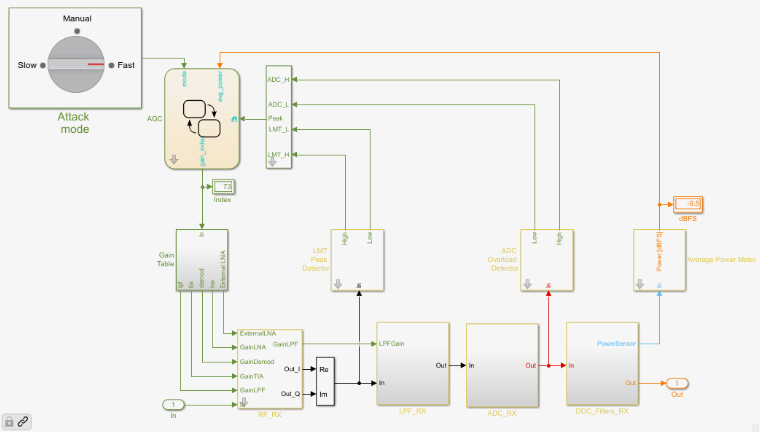
What's New for Wireless System Design

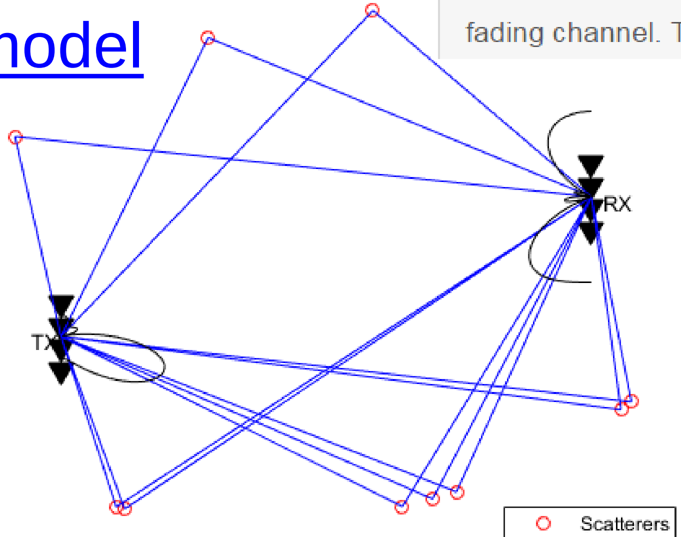
- [WINNER II Channel Model]
- [Support for USRP® E310 SDRs]
- [Support for ADALM-PLUTO® SDRs]
- [Synchronize multiple USRP® radios]
- [Scattering MIMO channel model]
- [AD9371 Transceiver model]

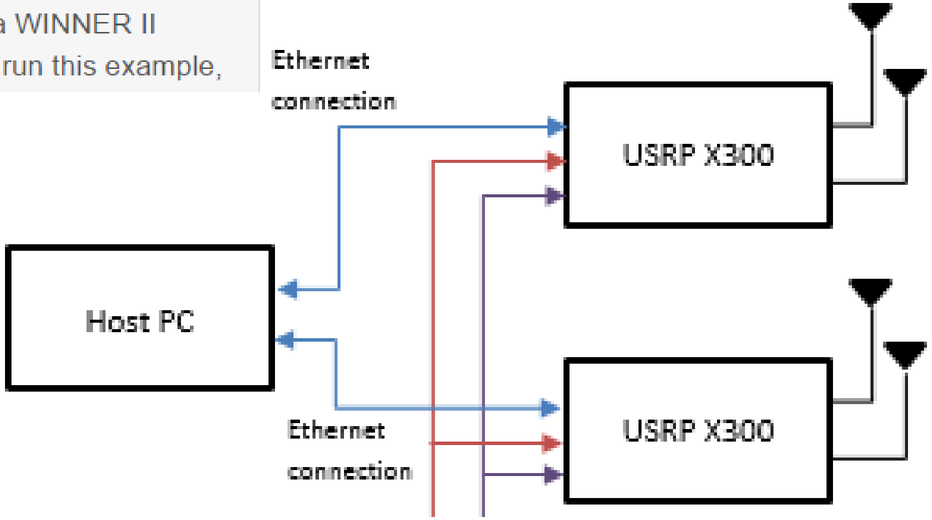


802.11ac Multi-User MIMO Precoding with WINNER II Channel Model

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

Accelerating the pace of engineering and science

Speaker Details

Email: Amod.Anandkumar@mathworks.in

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

Twitter: @_Dr_Amod

Contact MathWorks India

Products/Training Enquiry Booth

Call: 080-6632-6000

Email: info@mathworks.in

Your feedback is valued.

Please complete the feedback form provided to you.