MATLAB EXPO

November 13–14, 2024 | Online

6G and AI for Wireless in MATLAB®

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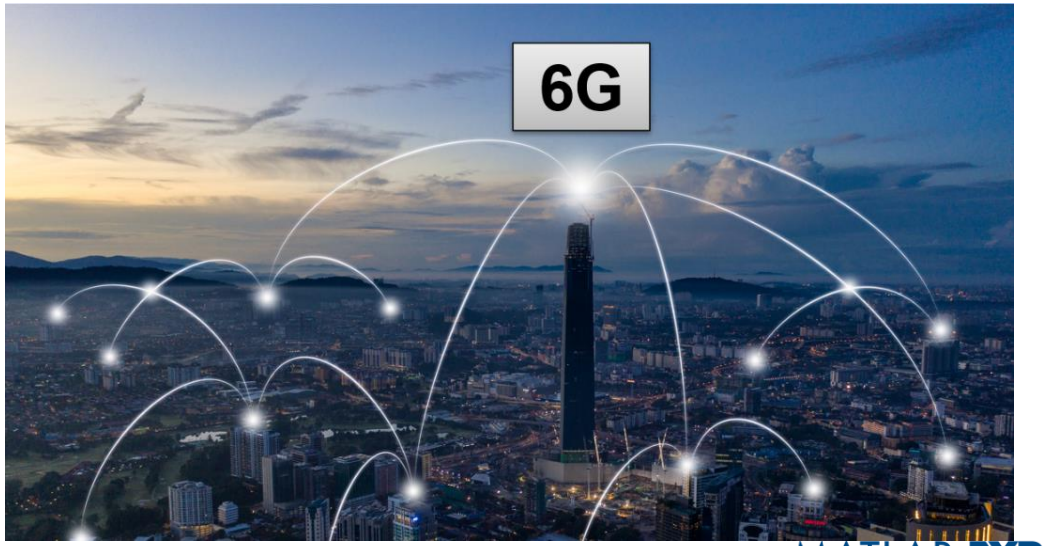
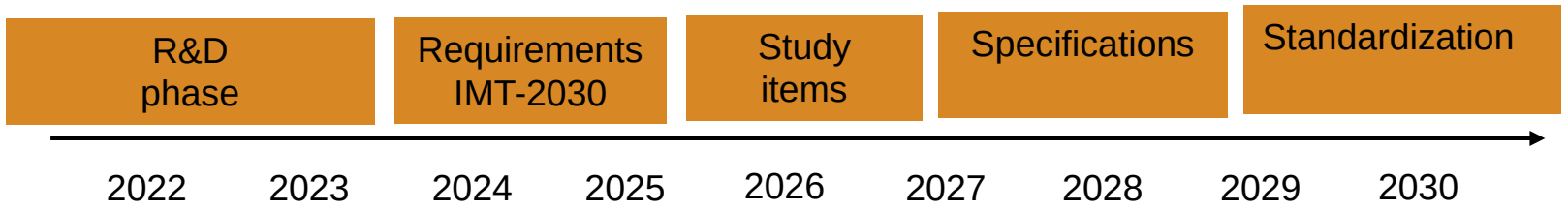
MathWorks

What is 6G?

- 6G: next generation mobile wireless communication system
- Built on the strength of 5G
- Envisioned to provide ubiquitous and sustainable connectivity
- Research and Development is underway.
- Various industry and academic consortiums proposing technologies

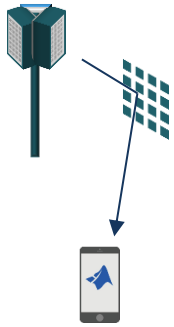


6G Timeline and Enabling Technologies

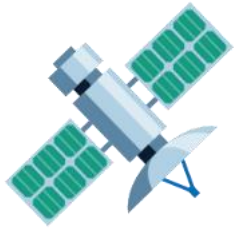


AI/ML

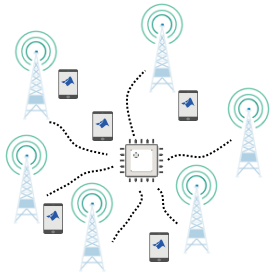
Millimeter-wave & sub-Terahertz



Reconfigurable intelligent surfaces



Non-terrestrial networks



Cell-free massive MIMO

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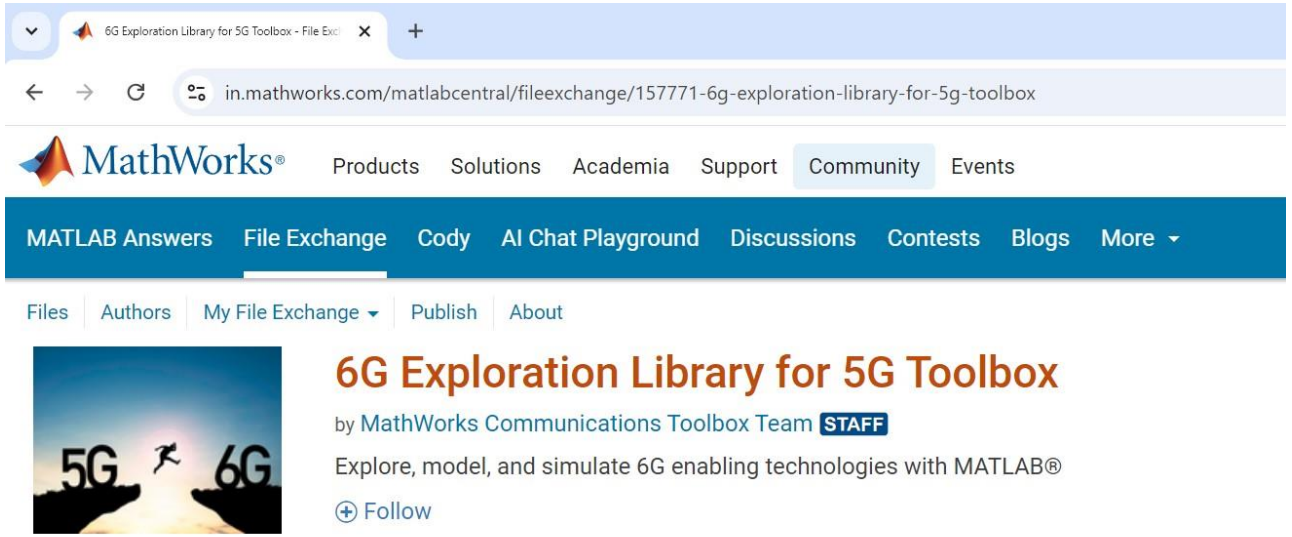
Introducing 6G Exploration Library

- Explore, model, simulate, and test candidate 6G waveforms and technologies.
- Extension of 5G Toolbox
  - Explore options beyond 5G standard
- Full MATLAB source code



6G Exploration Library

Candidate 6G waveform generation and simulations

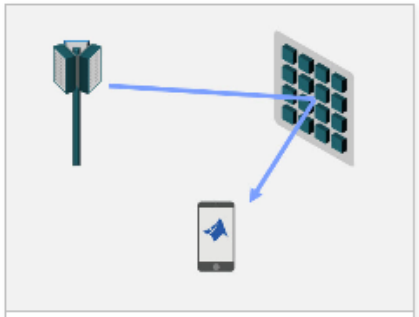
Categories

Get Started with 6G Exploration Library
Learn the basics of the 6G Exploration Library

Waveform Exploration
6G waveform exploration

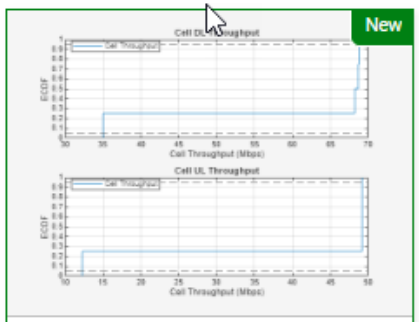
ISAC and RIS
Integrated sensing and communication and reconfigurable intelligent surfaces

AI for 6G
Artificial intelligence applications for 6G



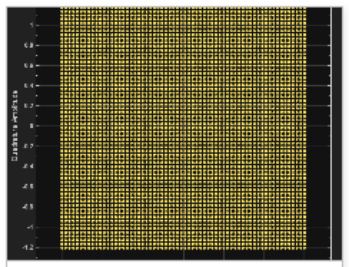
Model Reconfigurable Intelligent Surfaces with CDL Channels
Simulate a RIS channel using two concatenated CDL channel models.

Since R2024a



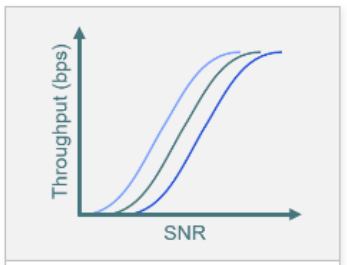
Evaluate Performance of Cell-Free mMIMO Networks
Evaluate the performance of cell-free massive multiple-input multiple-output networks.

Since R2024b



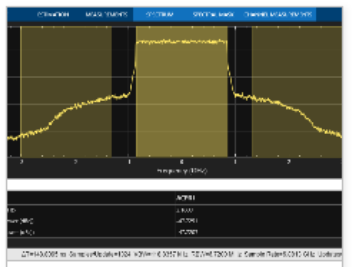
Get Started with 6G Exploration Library
Learn how to use the extended functionality that 6G Exploration Library adds to 5G Toolbox.

Since R2024a



6G Link-Level Simulation
Measure the throughput of a pre-6G link.

Since R2024a



Measure Impact of Sub-THz Hardware Impairments on 6G Waveforms
Measure ACPR and EVM to explore the impact of hardware impairments at sub-THz frequencies on a 6G-like waveform.

Since R2024a

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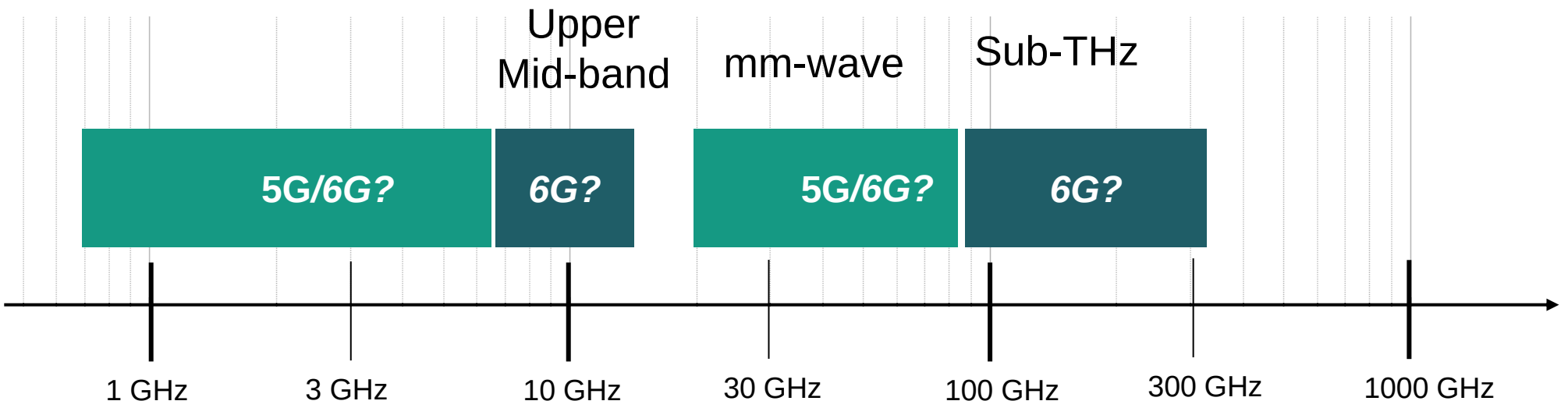
6G New Frequencies and Spectra



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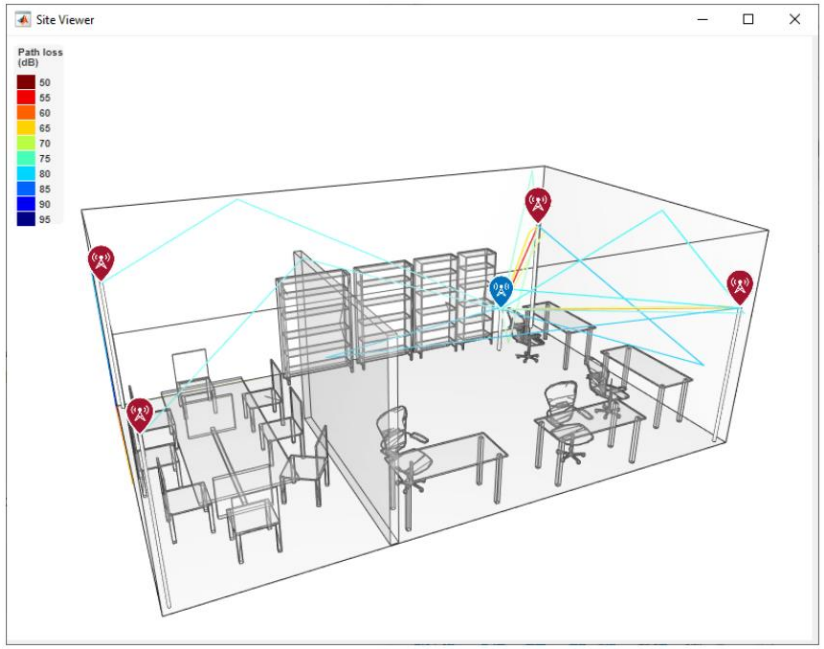
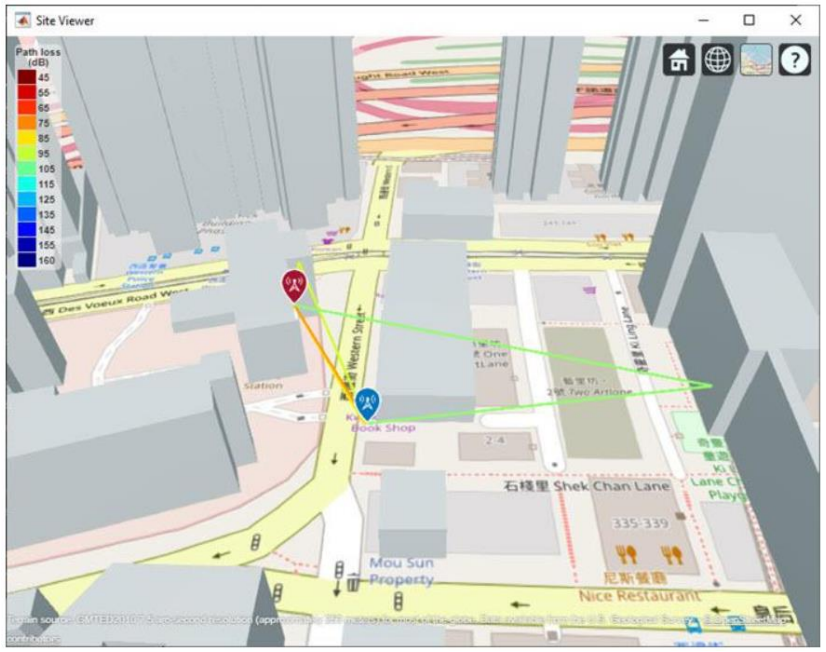
Ray Tracing Channel Modelling with MATLAB

- Used to model channels specific to a 3D environment (indoor, outdoor)
- Ray tracing methods: SBR, image method
- Support for reflection and diffraction





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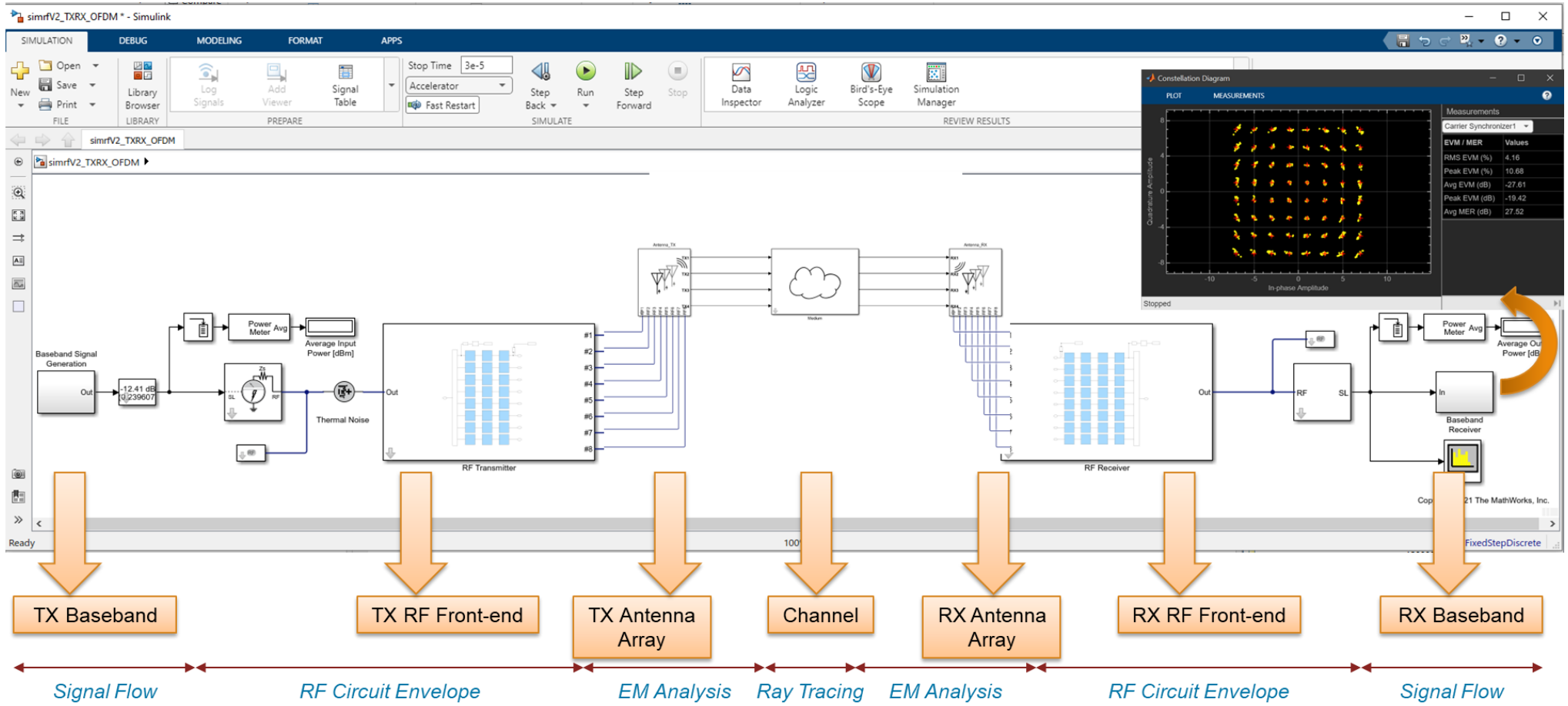
End-To-End MIMO RF Transceiver Simulation



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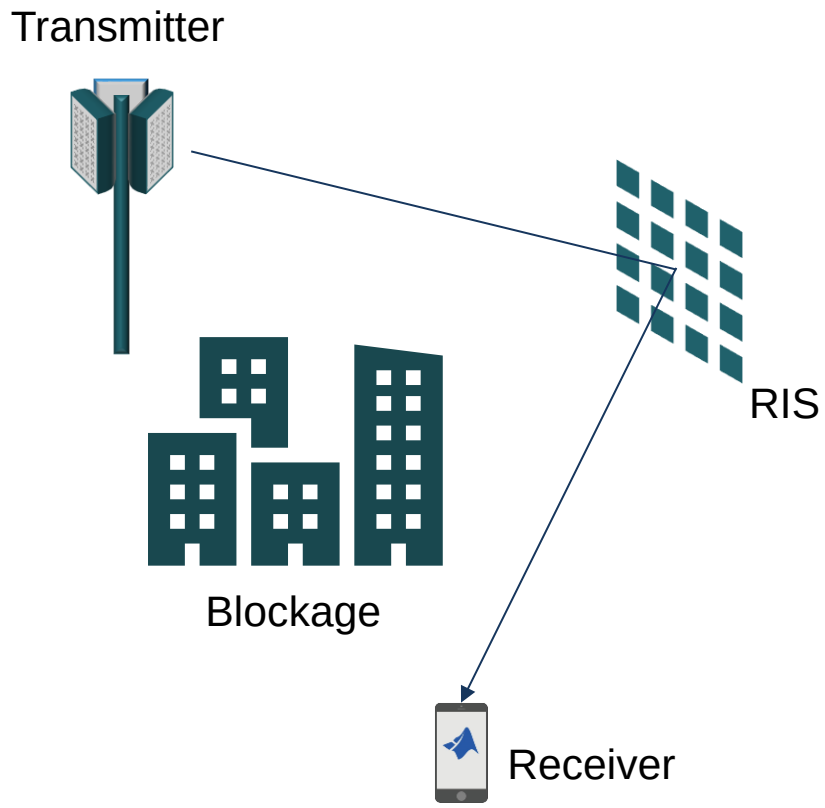
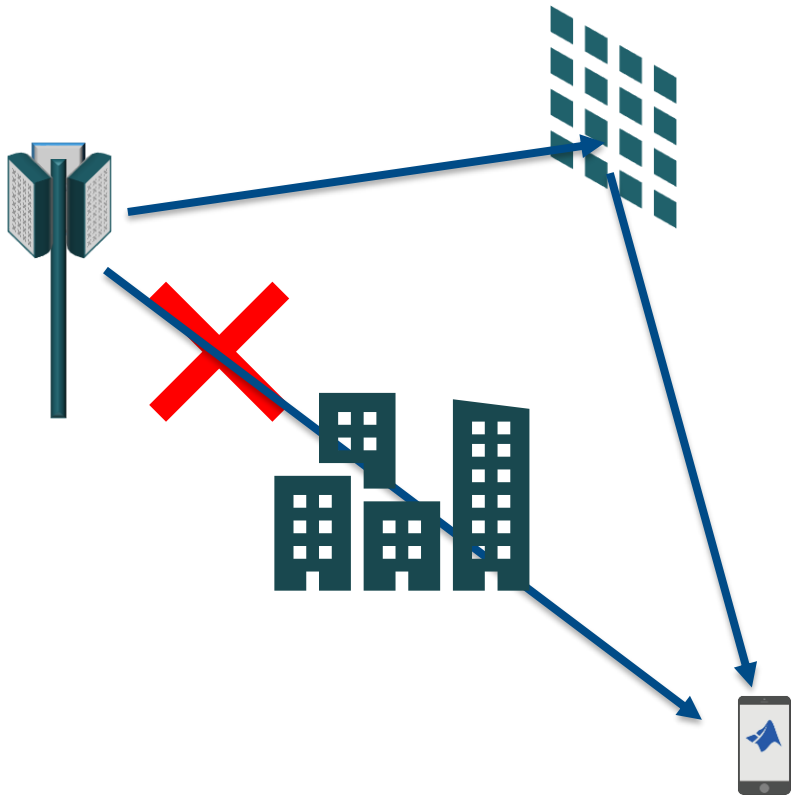
Reconfigurable Intelligent Surfaces (RIS)

- Array of controllable passive low-cost reflecting elements
- Each element can be reconfigured and apply a custom phase shift to the incoming signal
- Careful choice of phase shifts for each element can cause constructive interference at the receiver



RIS, Massive MIMO & Line-of-Sight (LOS) propagation



Massive MIMO for LOS:

- **Active arrays** on tx and rx
- **Beamforming** to improve SNR and capacity

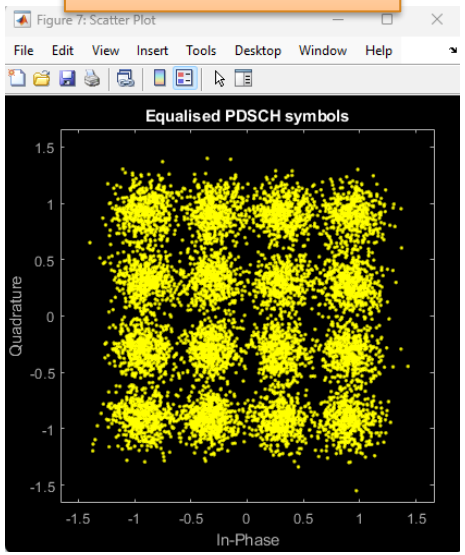
RIS for NLOS:

- **Passive arrays** on surrounding environment
- **Beamforming** to improve channel

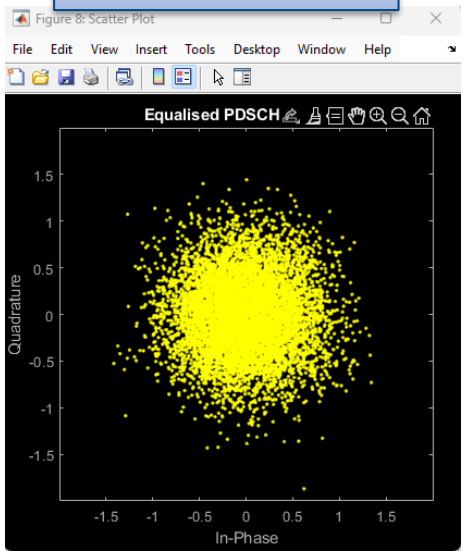
RIS Channel Models and Performance Evaluations

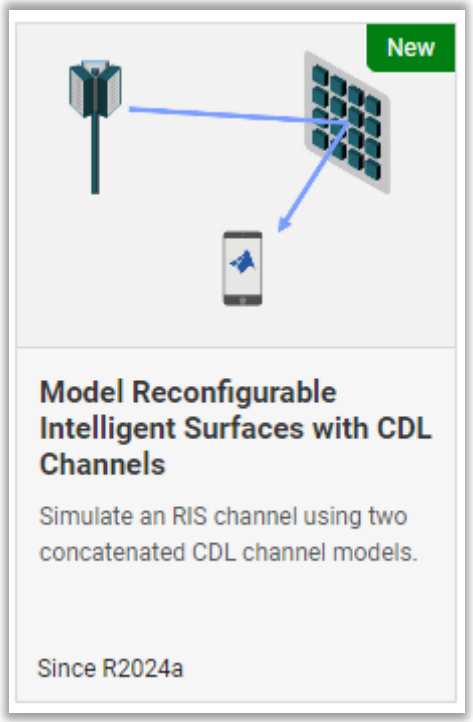
Rx/Tx CDL array and a phase shift models the RIS

RIS enabled



RIS disabled





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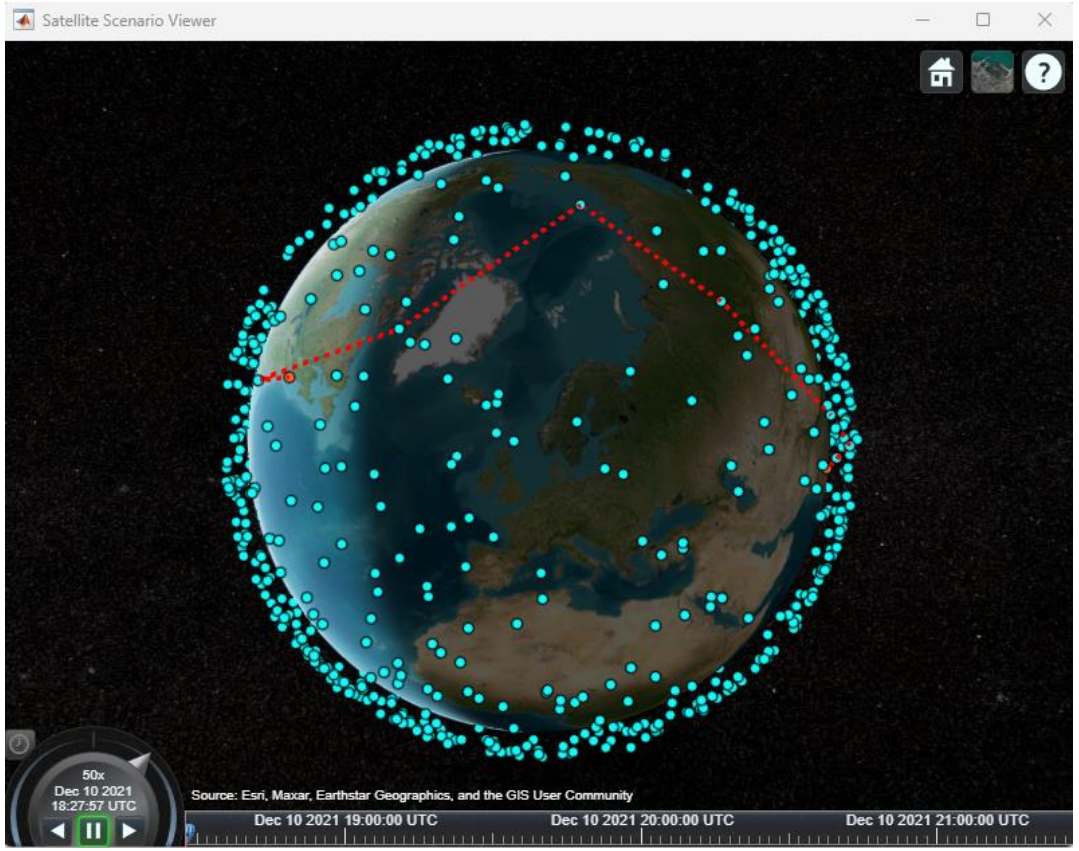
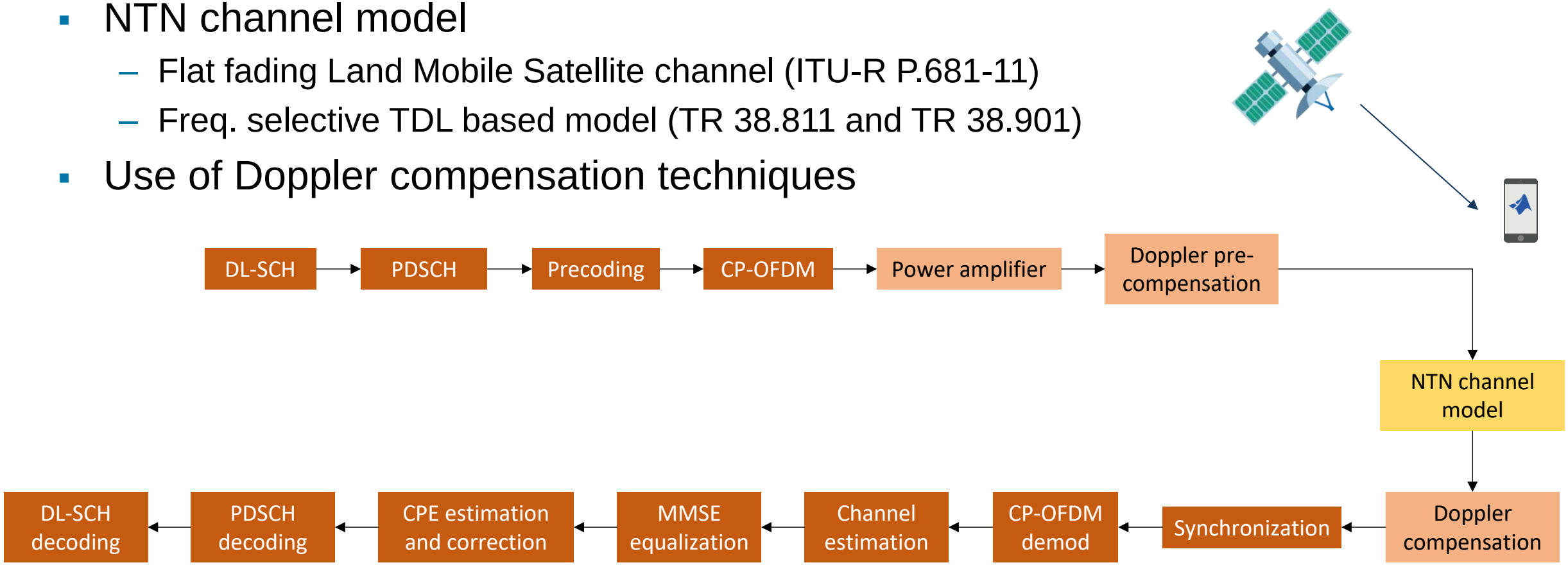
NTN (Non-terrestrial Network)

- Ubiquitous Connectivity: 6G needs solutions for global service coverage
- NTN can provide coverage to large isolated areas at a relatively low cost
- Inter-satellite-link (ISL) hops can increase coverage
- Coverage targets may be:
  - >99% of population reached with >1Mbps
  - 100% of world area covered



NR NTN Link Level Simulation

- MATLAB example to measure the NR NTN link performance
- NTN channel model
  - Flat fading Land Mobile Satellite channel (ITU-R P.681-11)
  - Freq. selective TDL based model (TR 38.811 and TR 38.901)
- Use of Doppler compensation techniques



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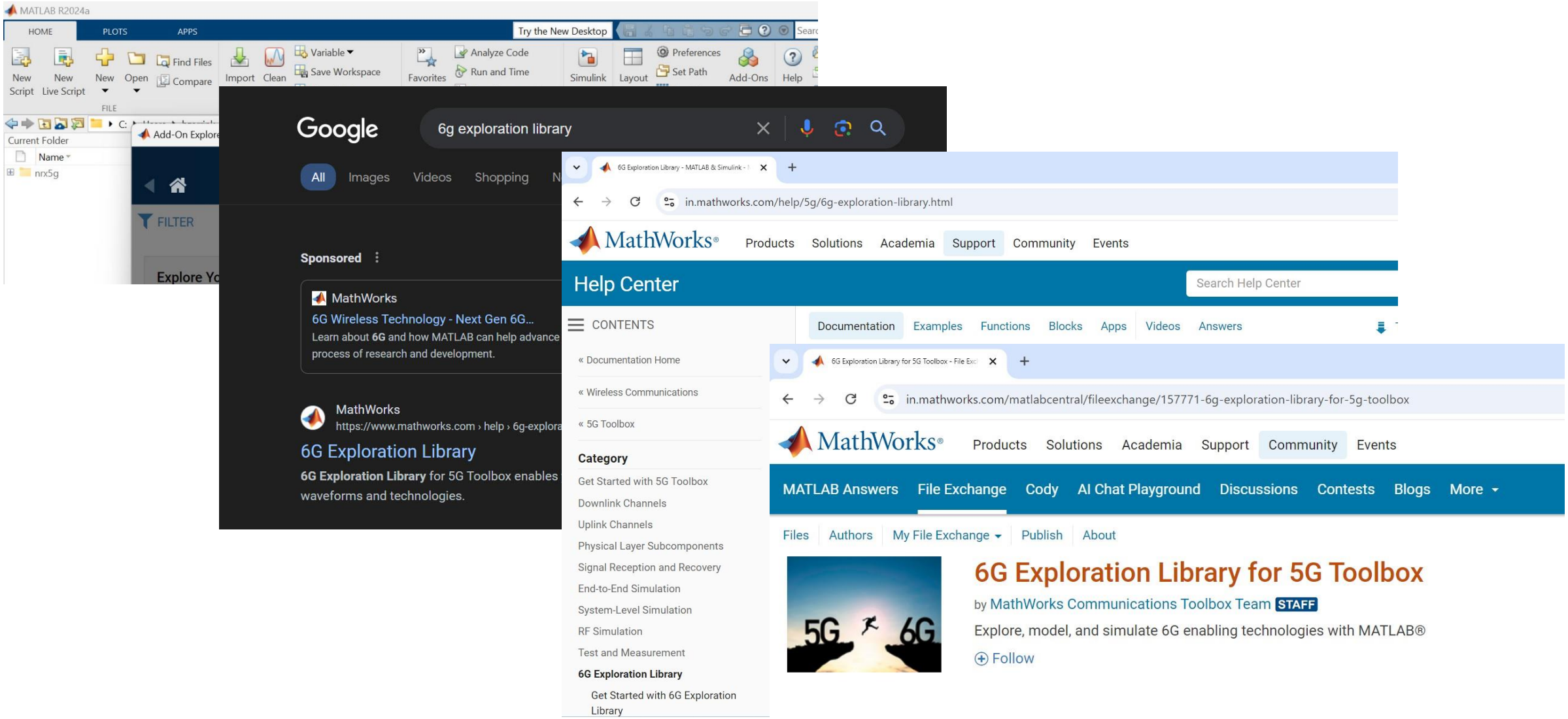
How to Download 6G Exploration Library



Artificial Intelligence (AI) a megatrend. Why is it useful in wireless communications?

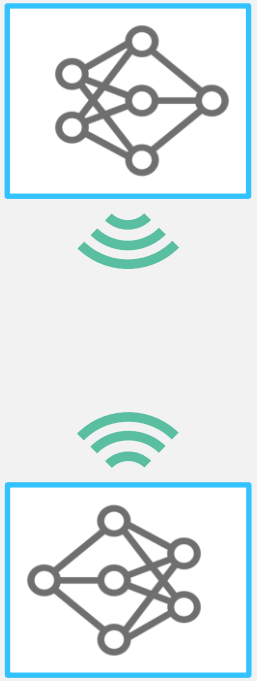
MOTIVATIONS FOR AI IN WIRELESS

- Success of AI in other application areas (image processing, NLP)
- Hardware and computation power advancements

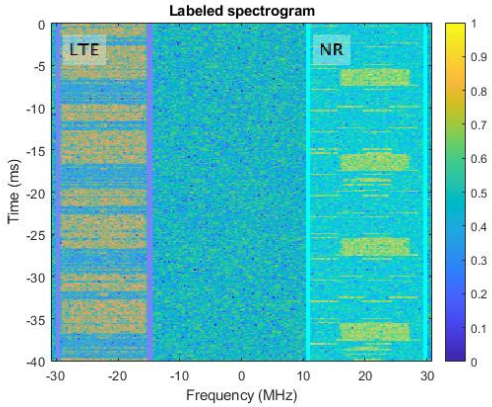
→ Improve performance using data-driven vs model-based approaches

→ Reduce algorithm complexity

→ Facilitate joint optimization of network and device operations

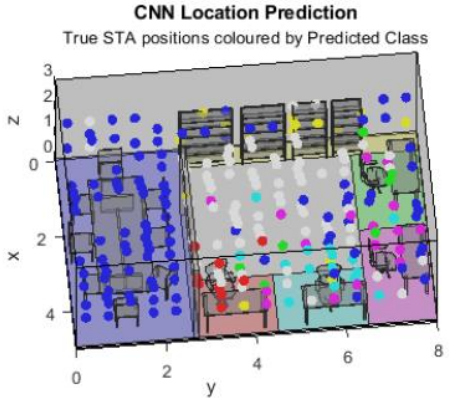


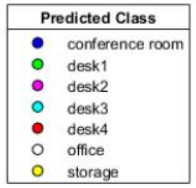
Our investments in AI for Wireless Communications



Improve performance

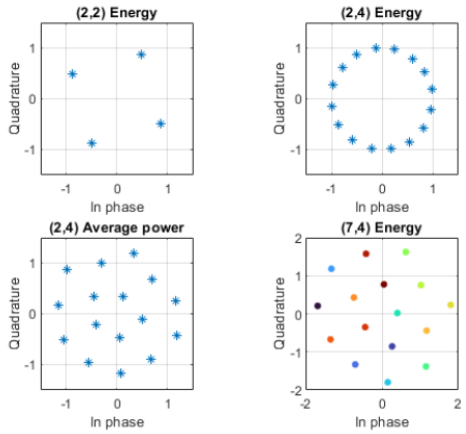
Spectrum Sensing & Signal Classification





Improve performance

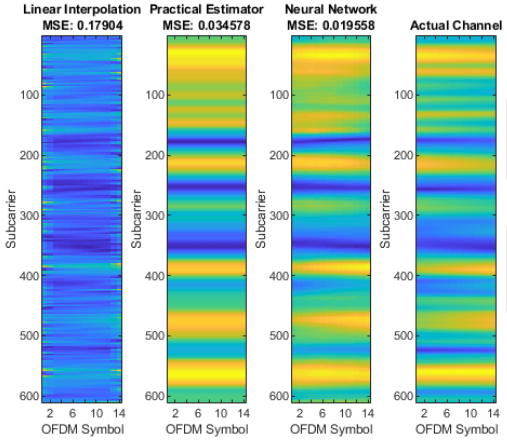
Localization & Positioning



Improve performance

Joint optimization

Transceiver design



Reduce complexity

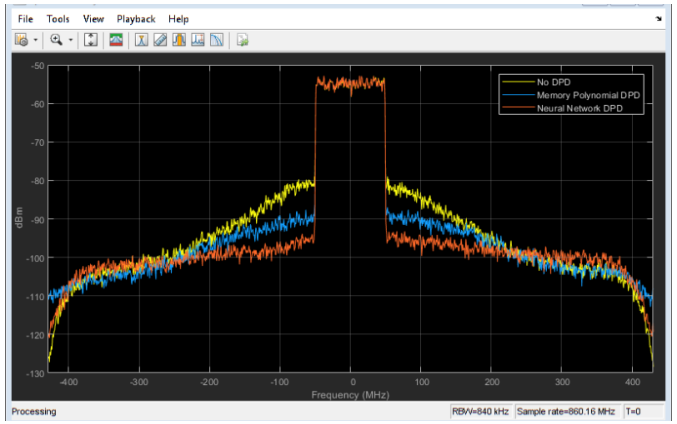
Improve performance

Beam Management & Channel Estimation

Reduce complexity

Improve performance

Device Identification



Improve performance

Digital Pre-Distortion

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AI Workflow Challenges

Data Preparation	AI Modeling	Simulation & Test	Deployment
How can you get good data?	Which model should I use? Training is computationally intensive!	Can I test my network in real world scenarios?	How can I generate code for Hardware devices?

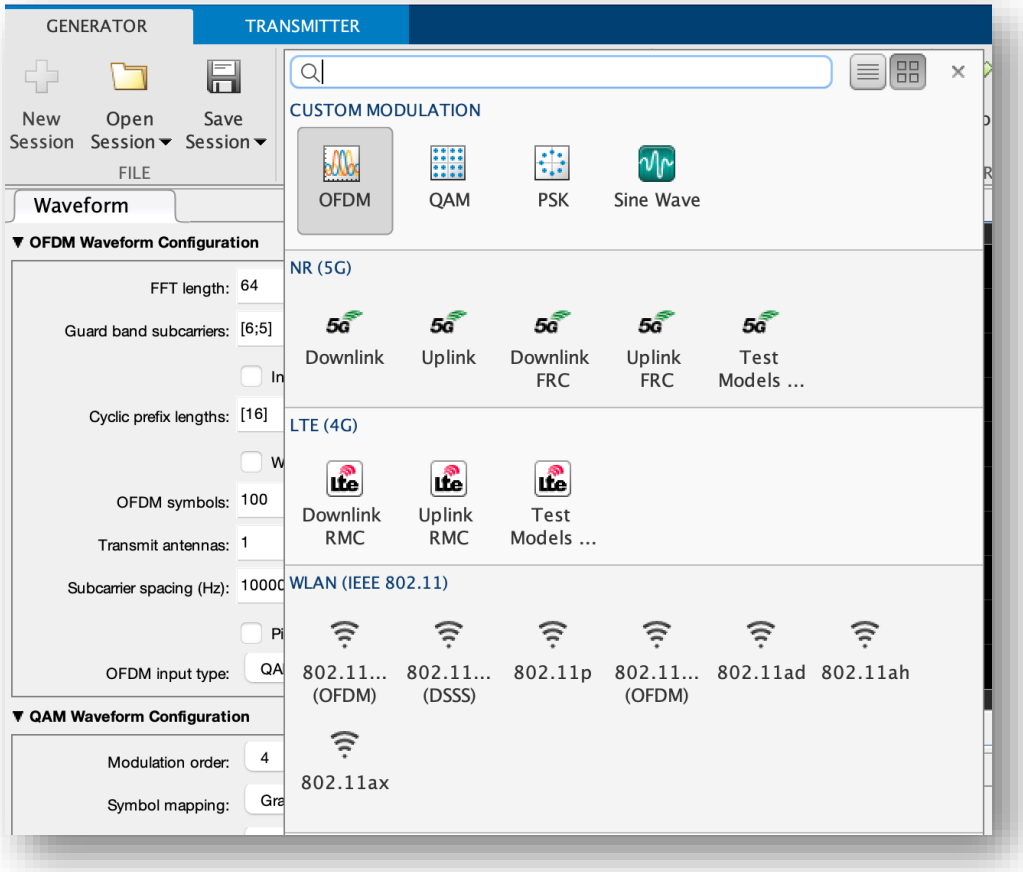
Augment existing data or synthesize additional data

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data
- HW connection Over-the-Air Signal

Wireless Waveform Generator app to create, impair, visualize, and export modulated waveforms

- Interactive waveform generation
- Arbitrary waveforms (OFDM, QAM, PSK)
- Standards-based (5G NR, LTE, WLAN)
- Add signal impairments
- Generate MATLAB script for reuse
- Custom waveforms



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Wireless Waveform Generator - untitled

GENERATOR | TRANSMITTER

New Session | Open Session | Save Session — FILE

Downlink | Uplink | NR Test Models | Downlink FRC | Uplink FRC — WAVEFORM TYPE

Impairments | Visualize | Default Layout | Generate — GENERATION

Export — EXPORT

Main | SSB/SIB1 | PDSCH | PDCCH | CSI-RS

5G Downlink

Label:	Carrier1
Frequency range:	FR1 (410 MHz - 7.125 GHz)
Channel bandwidth (MHz):	50
Cell identity:	1
Subframes:	10
Initial subframe:	0
Windowing source:	Custom
Windowing (%):	0
Sample rate source:	Auto

SCS Carriers

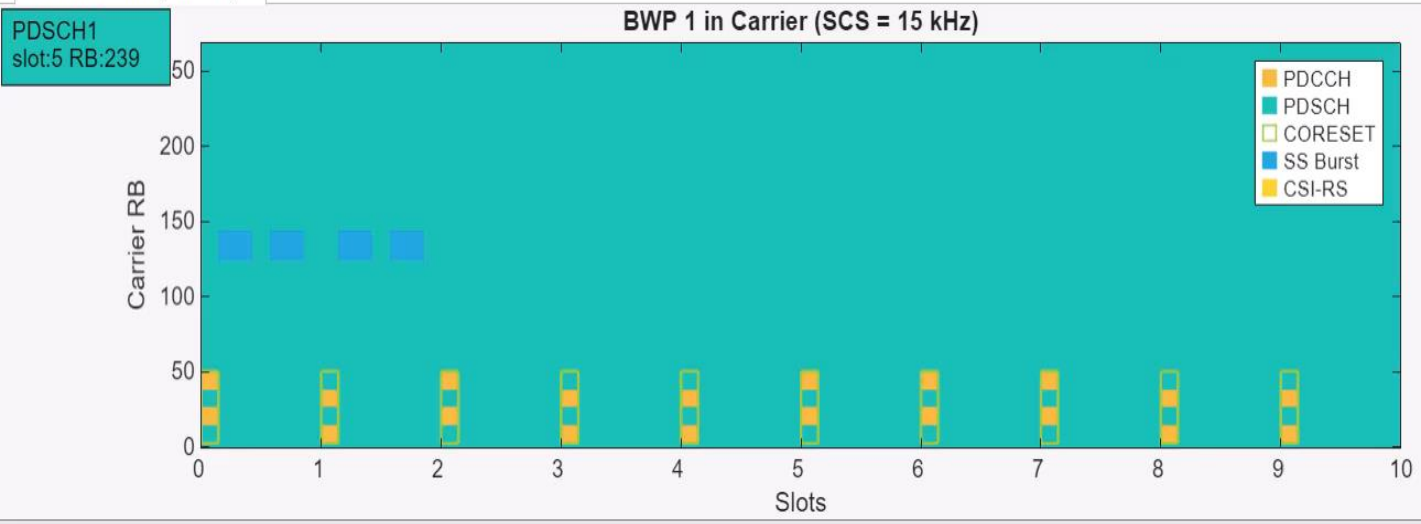
	Subcarrier Spacing	Grid Size (RB)	Grid Start (RB)
1	15 kHz	270	3

Bandwidth Parts

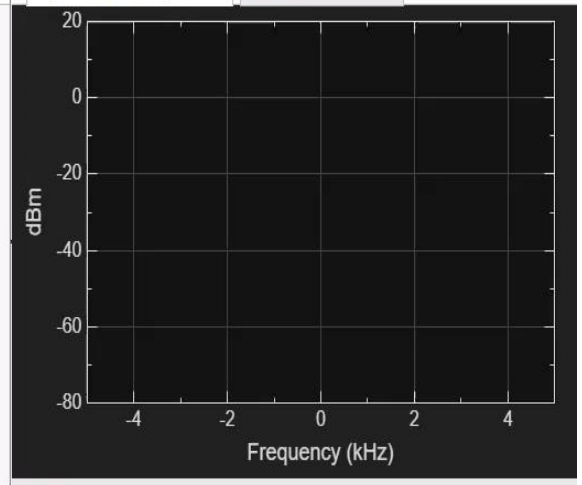
ID	Subcarrier Spacing	Cyclic Prefix	BWP Size (RB)	BWP Start (RB)	Label
1	15 kHz	normal	270	3	BWP1

Resource Grid (BWP#1)

PDSCH1
slot:5 RB:239



Spectrum Analyzer | Channel View



Ready

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Acquire live wireless data

Data Preparation

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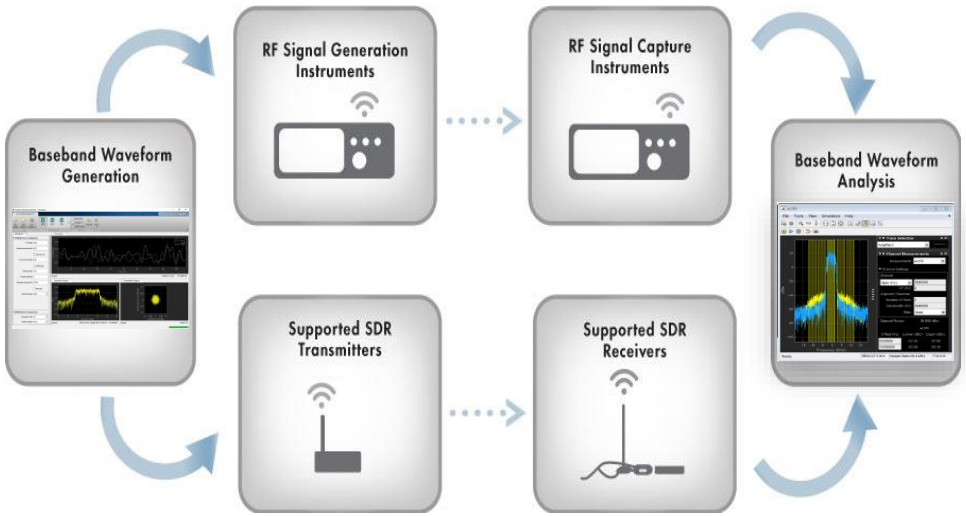
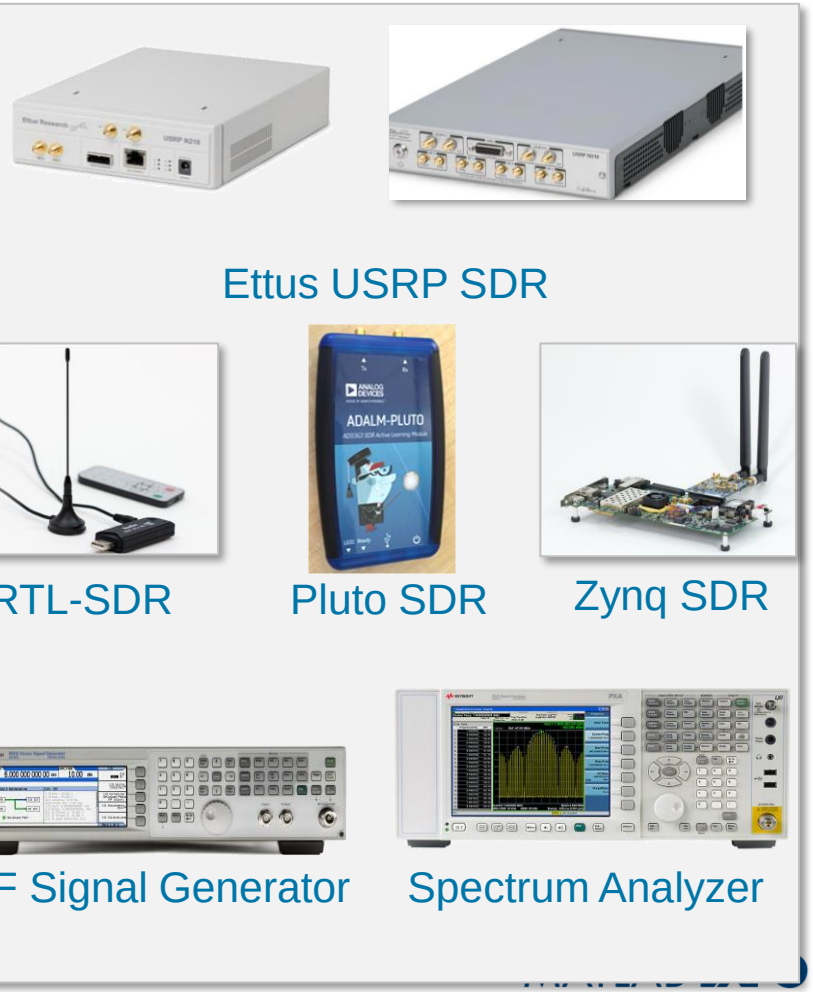
- HW connection Over-the-Air Signal





MATLAB’s role in tackling AI challenges

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

Which model should I use?

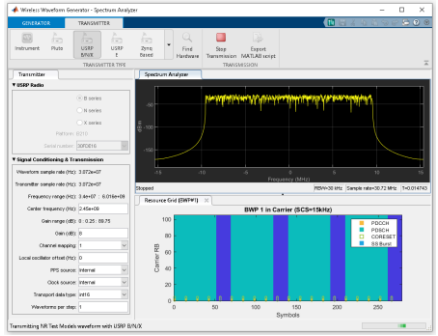
Training is computationally intensive!

Simulation & Test

Can I test my network in real world scenarios?

Deployment

How can I generate code for Hardware devices?



Start AI modeling with a complete set of algorithms and pre-built models

AI Modeling


Model design and tuning


Hardware accelerated training


Interoperability

Algorithms

Machine learning
Trees, Naïve Bayes, SVM…

Deep learning
CNNs, GANs, LSTM, MIMO…

Reinforcement learning
DQN, A2C, DDPG…

Regression
Linear, nonlinear, trees…

Unsupervised learning
K-means, PCA, GMM…

Predictive maintenance
RUL models, condition indicators…

Bayesian optimization

Pre-built models

Image classification models
AlexNet, GoogLeNet, VGG, SqueezeNet, ShuffleNet, ResNet, DenseNet, Inception…

Reference examples

Object detection
Vehicles, pedestrians, faces…

Semantic segmentation
Roadway detection, land cover classification, tumor detection…

Signal and speech processing
Denoising, music genre recognition, keyword spotting, radar waveform classification…

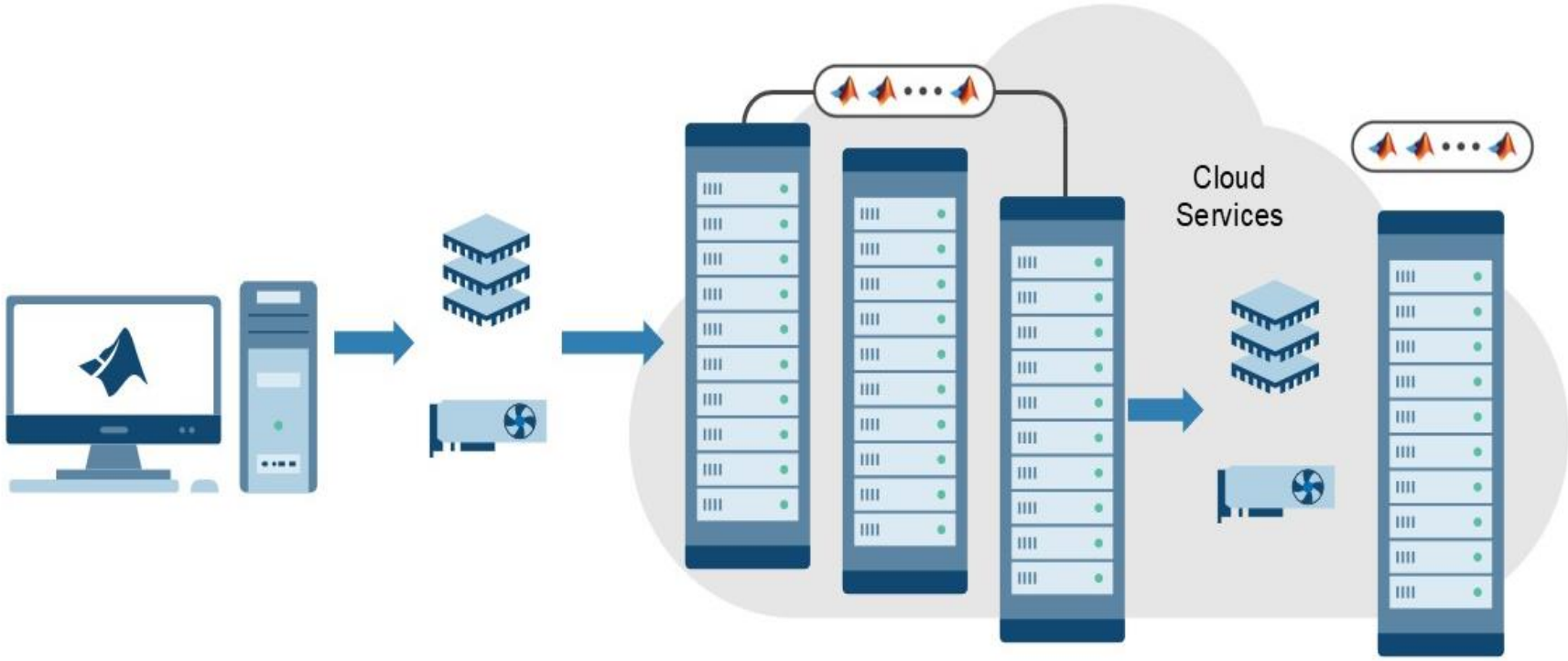
…and more…

Hardware acceleration and scaling are critical for training

Need to accelerate AI training on GPUs, cloud, and datacenter resources without specialized programming.

AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability



MATLAB's role in tackling AI challenges

Data Preparation

- Data cleansing and preparation
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AI Modeling

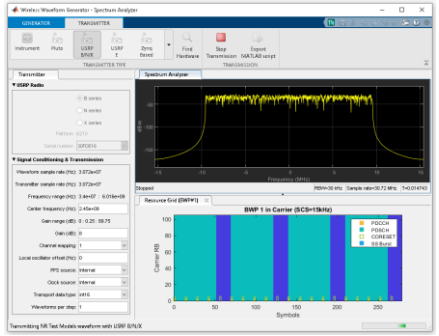
- Model design and tuning
- Hardware accelerated training
- Interoperability

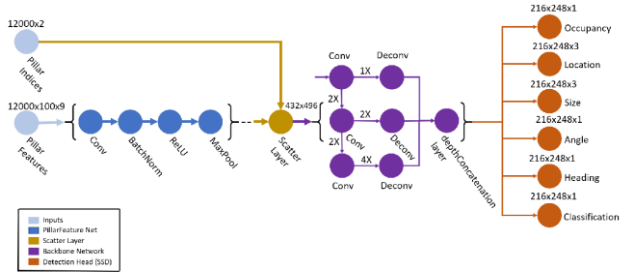
Simulation & Test

Can I test my network in real world scenarios?

Deployment

How can I generate code for Hardware devices?





Simulate with Software, Test with SDRs

Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

MATLAB's role in tackling AI challenges

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

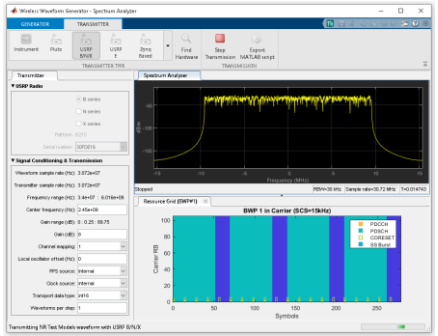
- Model design and tuning
- Hardware accelerated training
- Interoperability

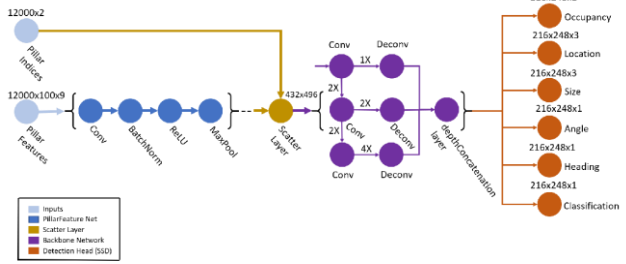
Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

Deployment

How can I generate code for Hardware devices?



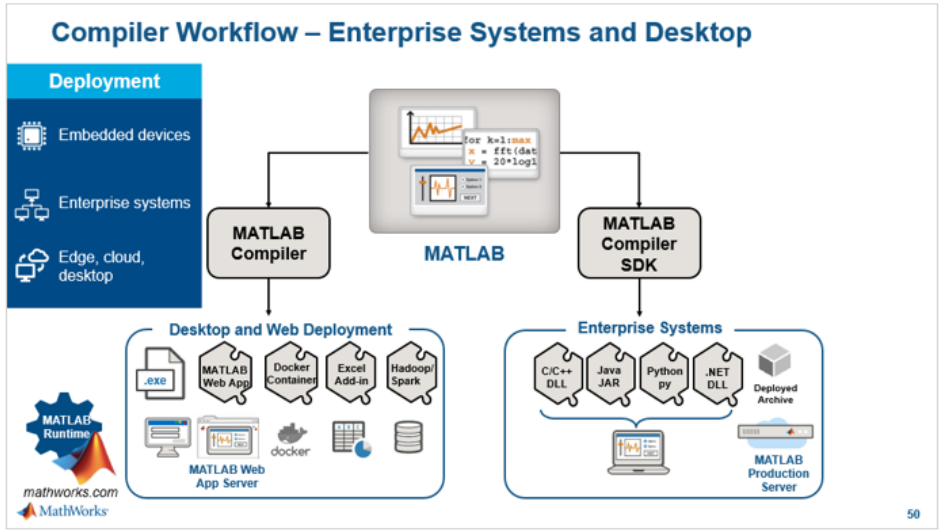


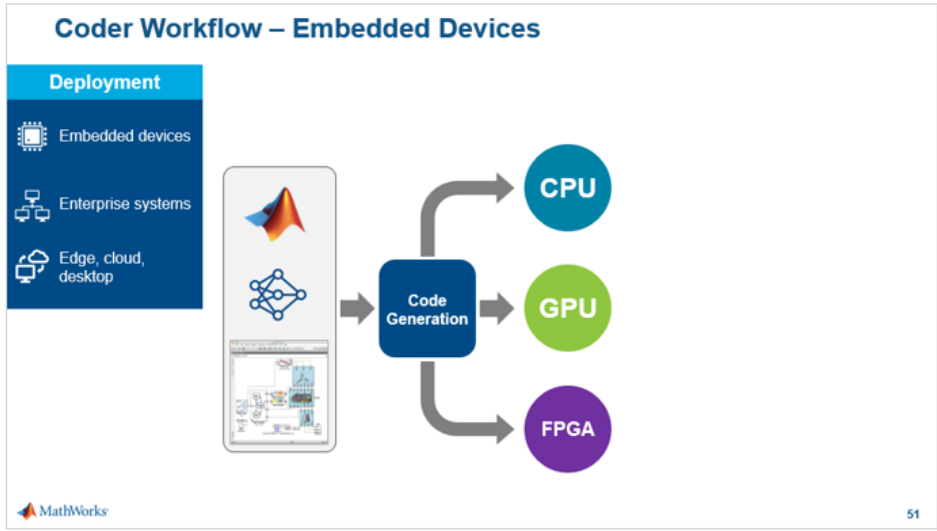
Deploy to any processor with best-in-class performance

AI models in MATLAB and Simulink can be deployed on embedded devices, edge devices, enterprise systems, the cloud, or the desktop.

Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop





AI-Driven Wireless System Design

Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling

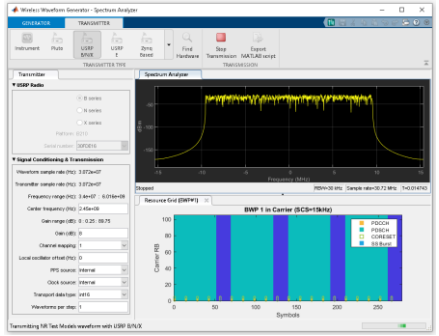
- Model design and tuning
- Hardware accelerated training
- Interoperability

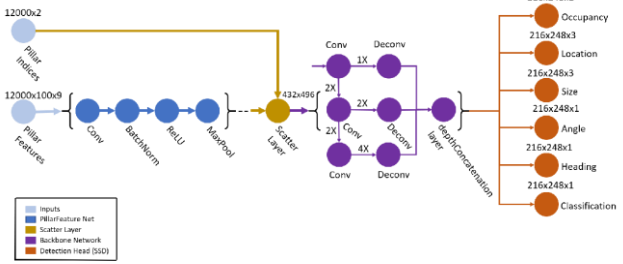
Simulation & Test

- Integration with complex systems
- System simulation
- System verification and validation

Deployment

- Embedded devices
- Enterprise systems
- Edge, cloud, desktop



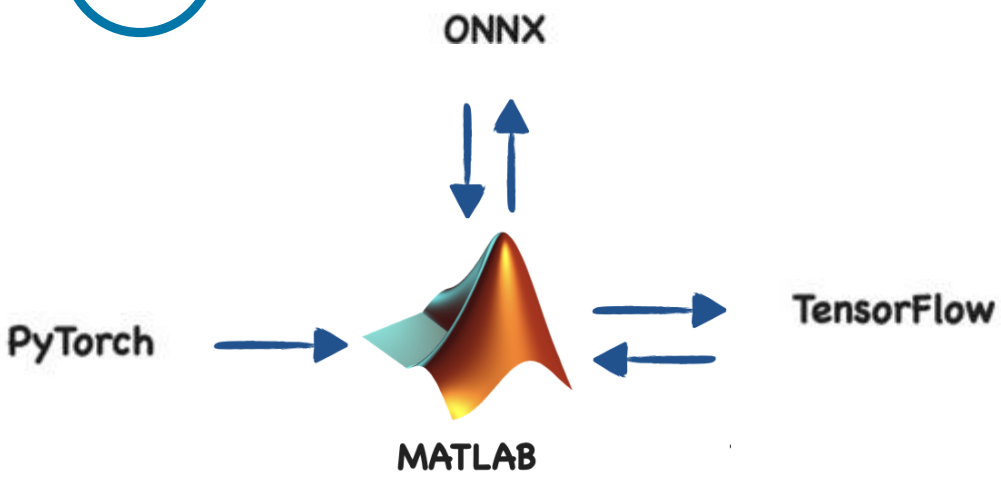


MATLAB EXPO

3 Ways to Integrate with PyTorch and TensorFlow

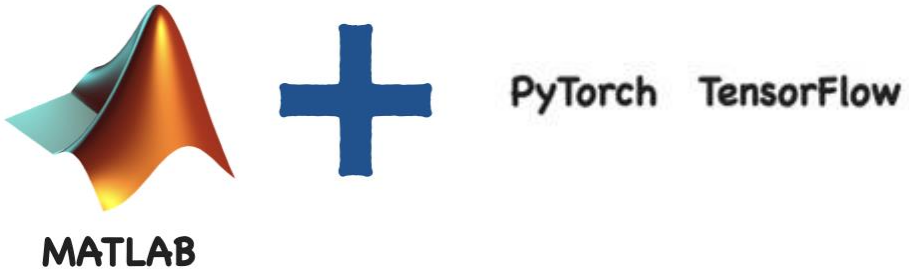
Model Conversion between MATLAB, PyTorch, and TensorFlow

1



Co-execution of PyTorch and TensorFlow models **in MATLAB and Simulink**

2



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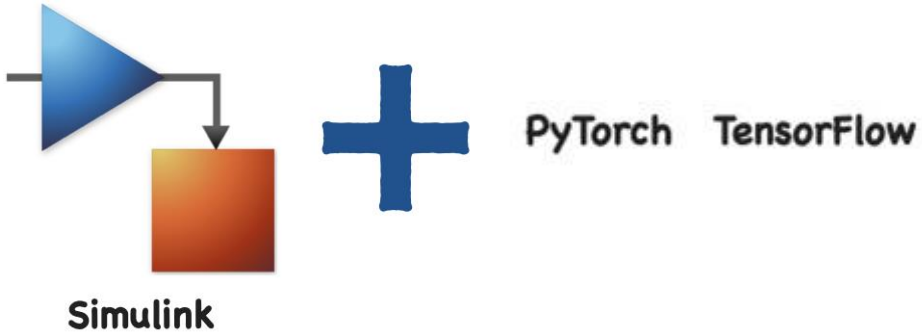
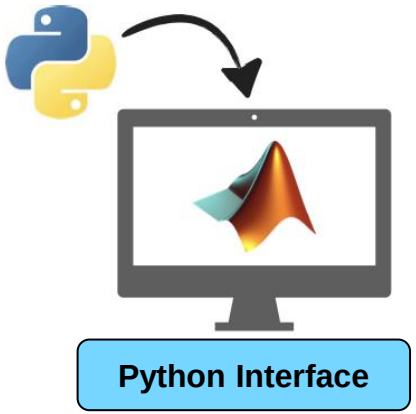


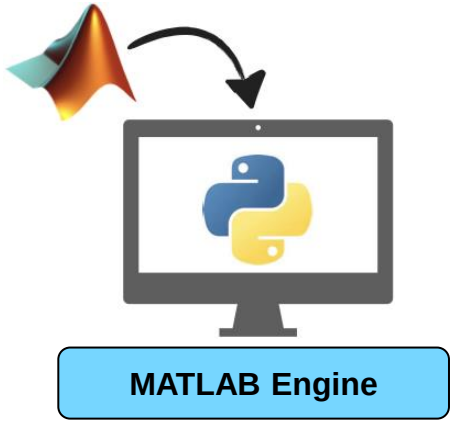
Co-execution allows:

- Calling Python from MATLAB to access any AI framework and network.
- Calling MATLAB from Python to use MATLAB domain-specific processing and other AI tools (e.g., visualizations, explainability).

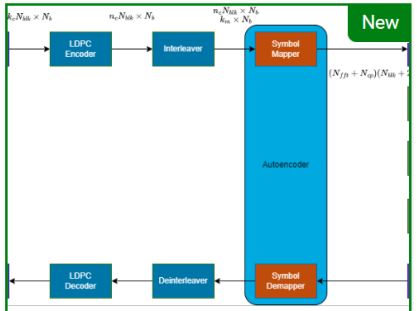
Calling Python from MATLAB



Calling MATLAB from Python



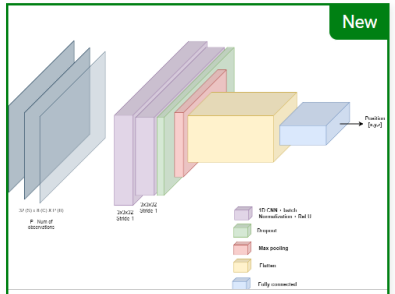
AI and Deep Learning Applications



Model-Free Training of AI-Based OFDM Wireless Systems

Use a custom training loop and loss function for model-free training on an OFDM-based communications system.

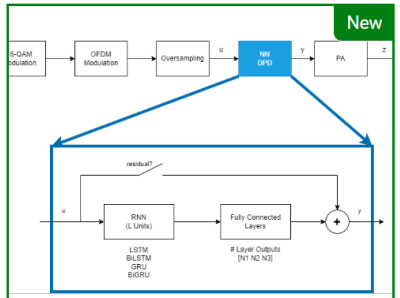
Since R2024b



Bluetooth LE Positioning with Deep Learning

Compute 3-D positioning of a Bluetooth LE node by using RSSI fingerprinting and CNN.

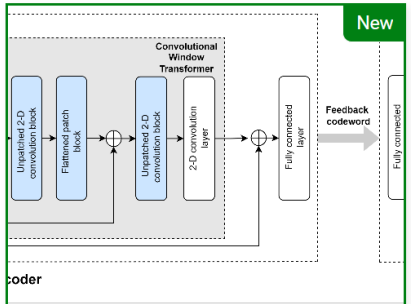
Since R2024b



Compare Residual Recurrent Neural Network Structures for Digital Predistortion Design

Compare residual RNN structures for a digital predistortion (DPD) design.

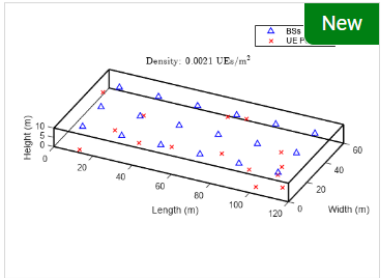
Since R2024b



CSI Feedback with Transformer Autoencoder

Design and train a convolutional transformer deep neural network for channel state information feedback by using a downlink clustered delay...

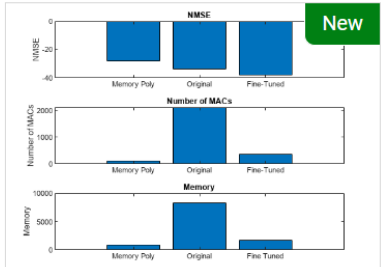
Since R2024b



AI for Positioning Accuracy Enhancement

Use AI to estimate the position of user equipment and compare performance with traditional TDoA techniques.

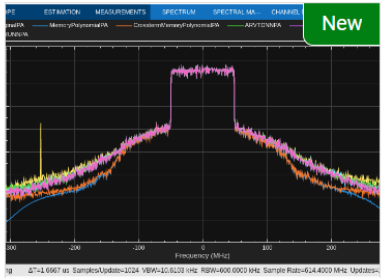
Since R2024a



Structurally Compress Neural Network DPD Using Projection

Structurally compress a neural network DPD to reduce computational complexity and memory requirements using

Since R2024a



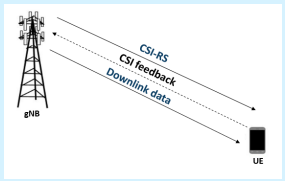
Power Amplifier Modeling using Neural Networks

Model a power amplifier (PA) using several different neural network (NN) architectures.

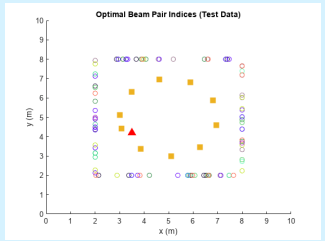
Since R2024a

AI for 6G – How MATLAB can Help

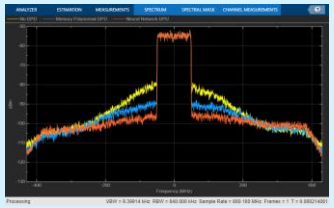
Ready-to-use AI Workflows for Wireless



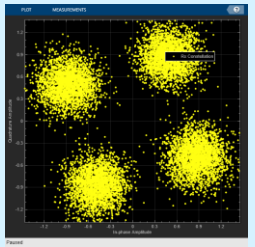
CSI Feedback with Autoencoders



Neural Networks for Beam Selection

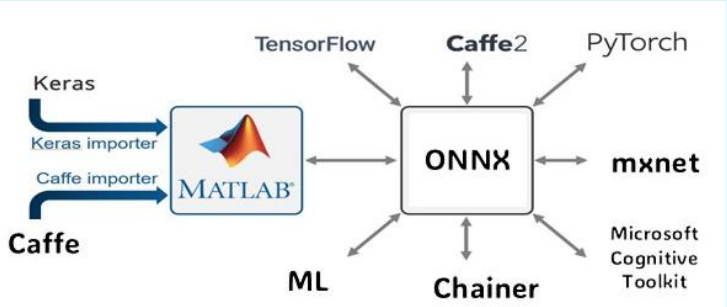


Neural Networks for Digital Predistortion

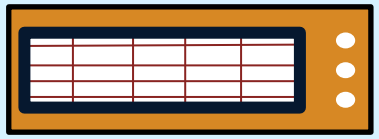


E2E Comms Systems with Autoencoders

Interoperate and Exchange Models with Python and other Frameworks



Capture Over the Air Signals to Train AI Models



Test and Measurement Devices

Software-Defined Radios

How to learn more

6G Exploration Library

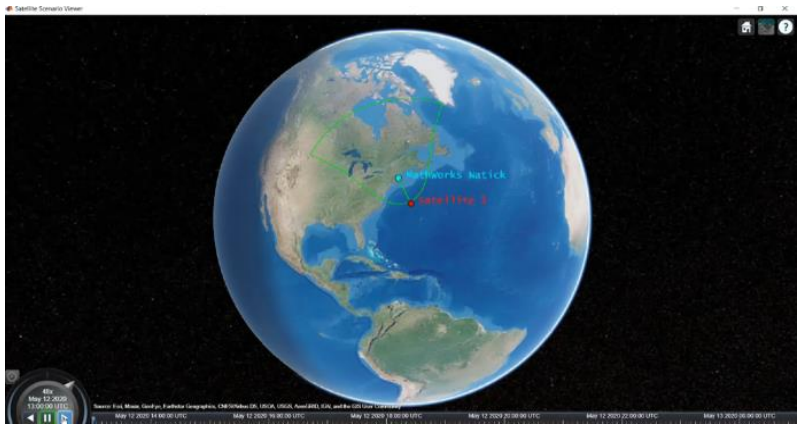
https://www.mathworks.com/products/6g-exploration-library.html

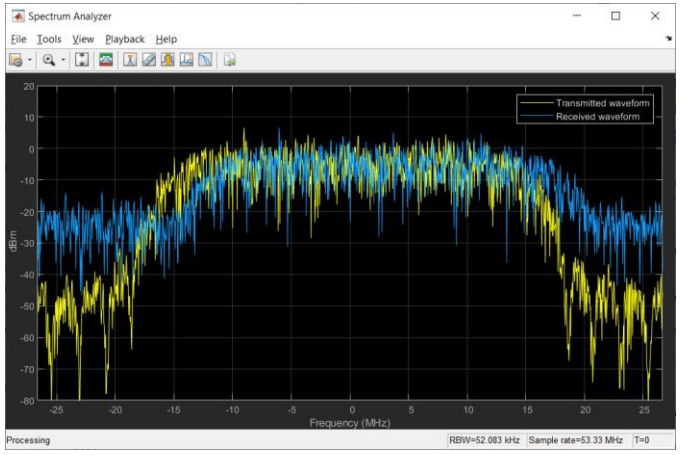
Go to MathWorks 6G page

https://www.mathworks.com/discovery/6G

Go to Wireless Solution Page

https://mathworks.com/solutions/wireless-communications.html





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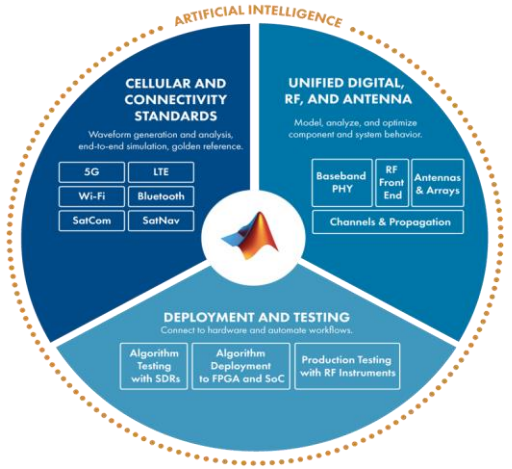
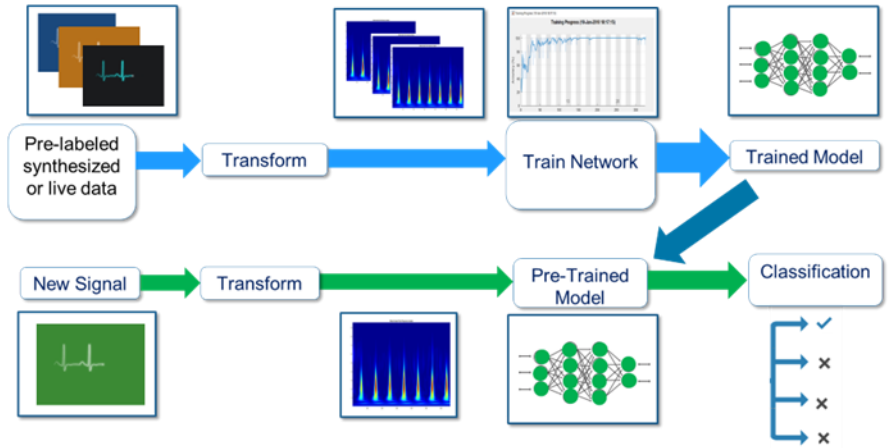
Summary

- 6G Exploration Library can help you model, simulate, and test candidate 6G waveforms and technologies.
- Promising 6G enabling technologies include
  - New frequencies and waveforms,
  - Integrated sensing and communications (ISAC),
  - Reflective Intelligent Surfaces (RIS),
  - AI for Wireless,
  - Non-terrestrial Networks (NTN).
- MATLAB makes AI-based design easier by providing tools for
  - training and test data generation,
  - continuously improving your AI models,
  - integrating them into larger systems for testing and validation,
  - deploying them onto production code,
  - Interoperating with Python and other AI Frameworks.





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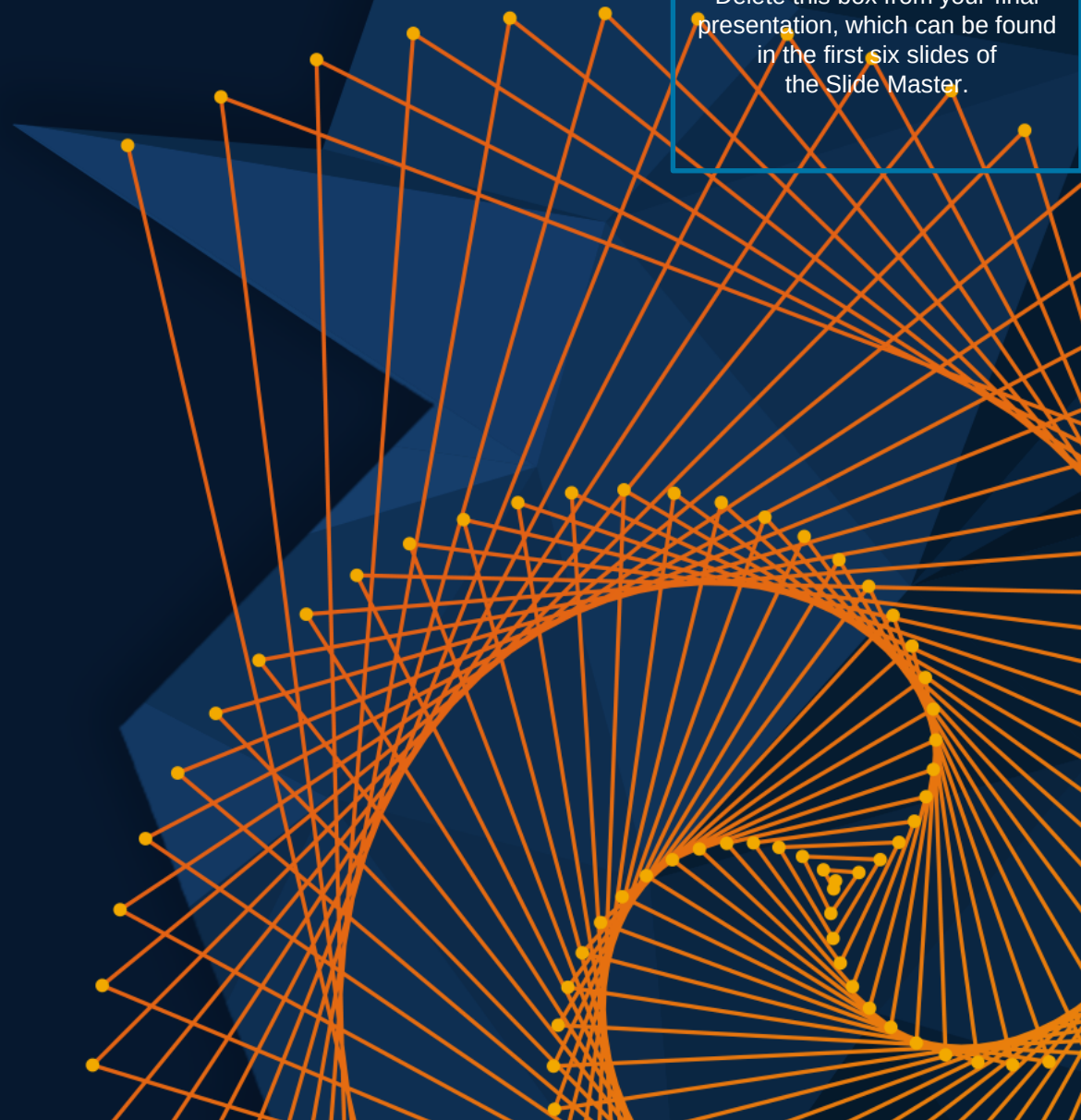
Delete this box from your final presentation, which can be found in the first six slides of the Slide Master.



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