MATLAB EXPO

May 28, 2024 | Beijing

探索未来通信：

用MATLAB加速6G创新研发

Qian Zhang, MathWorks

MathWorks

Ubiquitous Connectivity as a goal

Cellular

Satellite communications

WL

LTE

5G

GNSS

5G advanced

CCSDS

Bluetooth

Wi-Fi

6G

DVB-S*

Personal Area Network

Local Area Network

Wide Area Network

Non-terrestrial Network

What is 6G?

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

Possible 6G New Applications and Use Cases

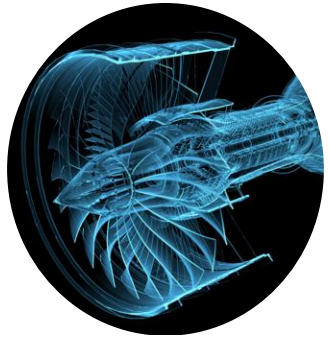
Fixed mobile and broadband evolution

Extended reality

Real time robot command and control

Wide area and micro connectivity

Wireless sensor fusion

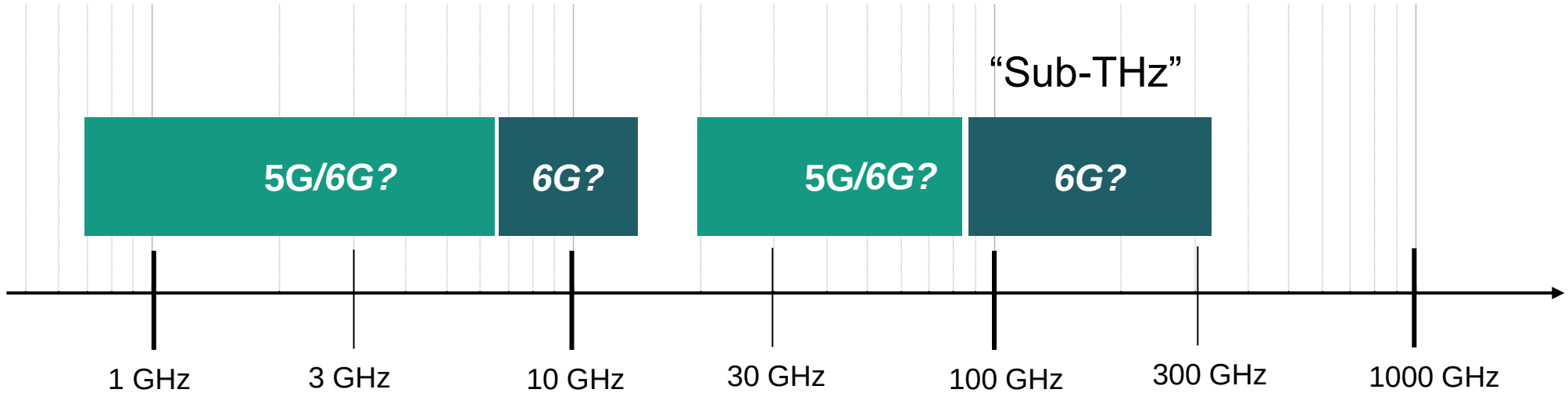


Digital twin

Holograms

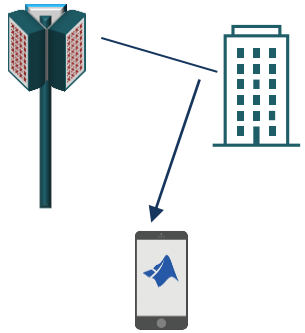
Other new use cases

6G and Future Wireless Spectrum

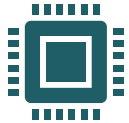


6G Exploration with MATLAB

Waveform exploration

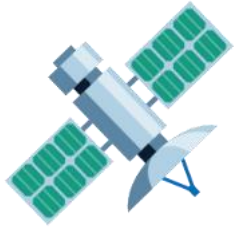


mmWave: propagation loss and channel models

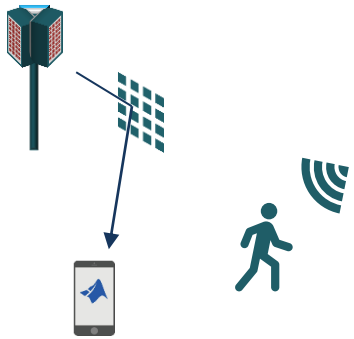


mmWave: RF impairment modelling

AI/ML for wireless



Non terrestrial networks (NTN)



Sensing and RIS

New: 6G Exploration Library for 5G Toolbox

R2024a

Explore, model, simulate, and test candidate 6G waveforms and technologies

- Model waveforms with bandwidths and subcarrier spacings beyond values specified by 5G NR.
- Perform link-level simulations with the extended waveforms.
- Explore the impact of hardware impairments at 7-20 GHz, mm-Wave, and sub-Terahertz carrier frequencies.
- Model reconfigurable intelligent surfaces.
- Explore applications of AI to wireless communications problems.
- Accelerating your simulation by using multicore computers and clusters.

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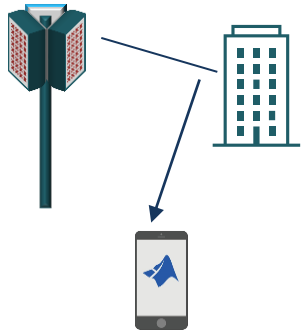

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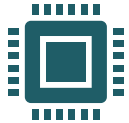

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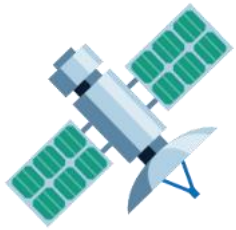

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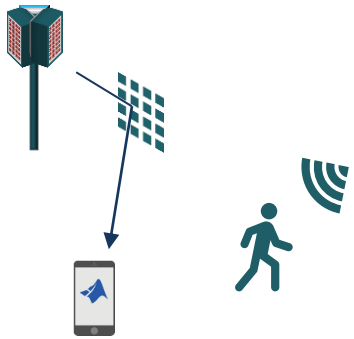
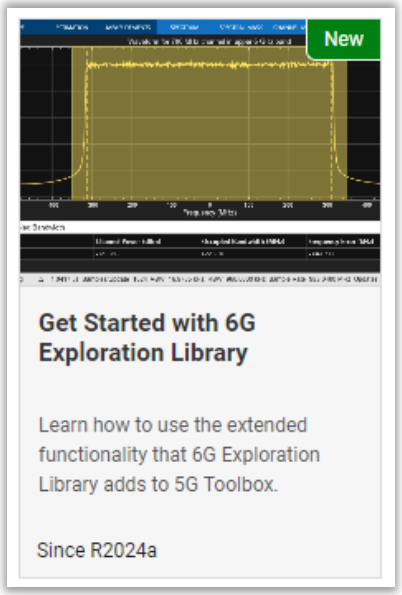
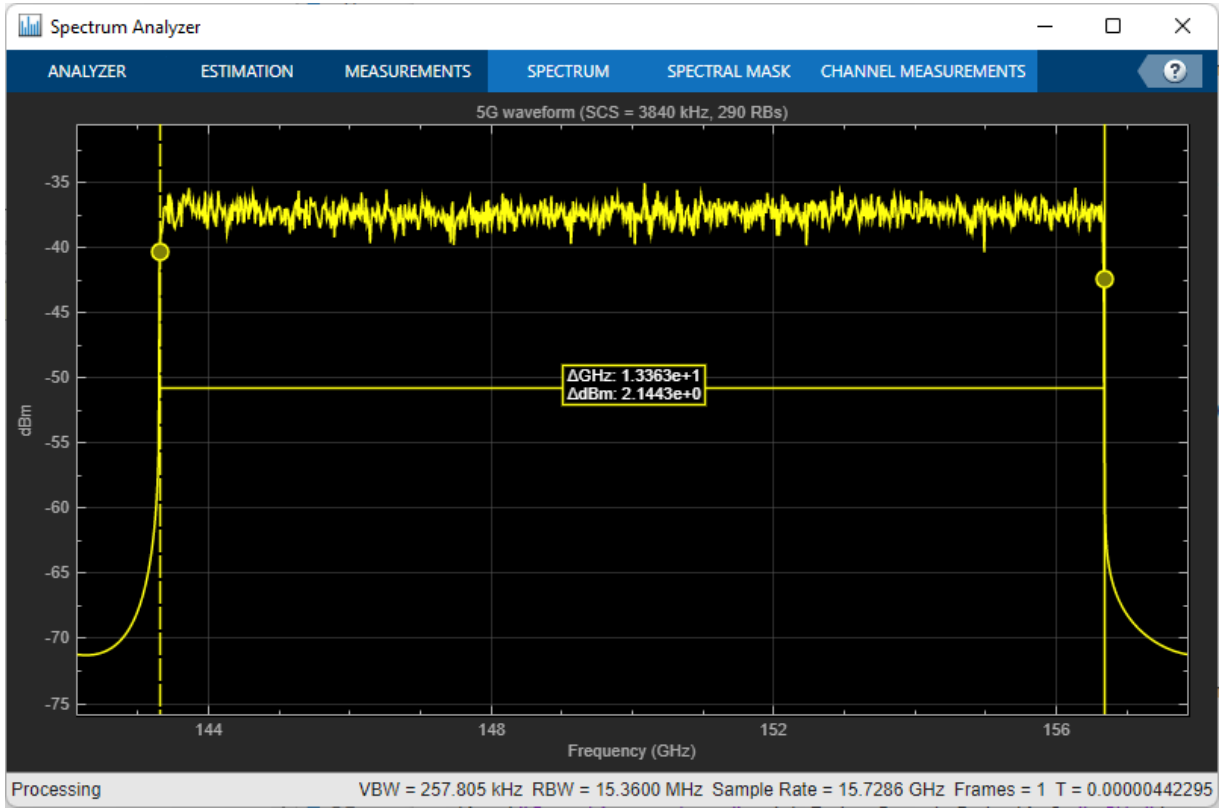


Sensing and RIS

Bandwidth and SCS beyond 5G

- Explore the properties and capabilities of extended 5G-waveforms:
  - Large bandwidths beyond 275 RBs
  - SCS beyond 960 kHz





290 RBs

SCS = 3840 kHz

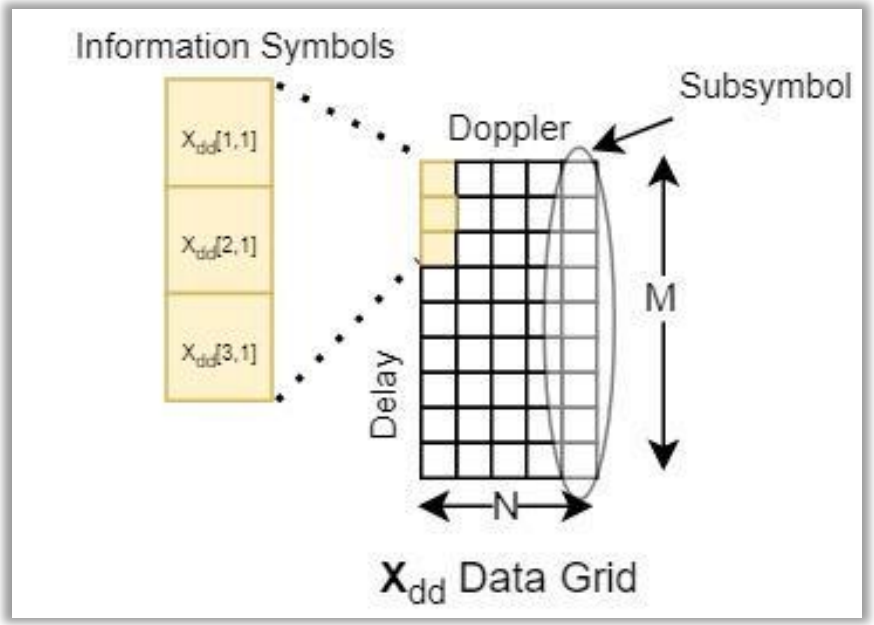
BW = 13.36 GHz

Fs = 15.73 GHz

Orthogonal Time Frequency Space (OTFS) Modulation

- Considered for 6G systems
- OFDM suffers from ICI in high Doppler multipath channels
  - Channel characteristic varies over time
  - Orthogonality between subcarriers is lost

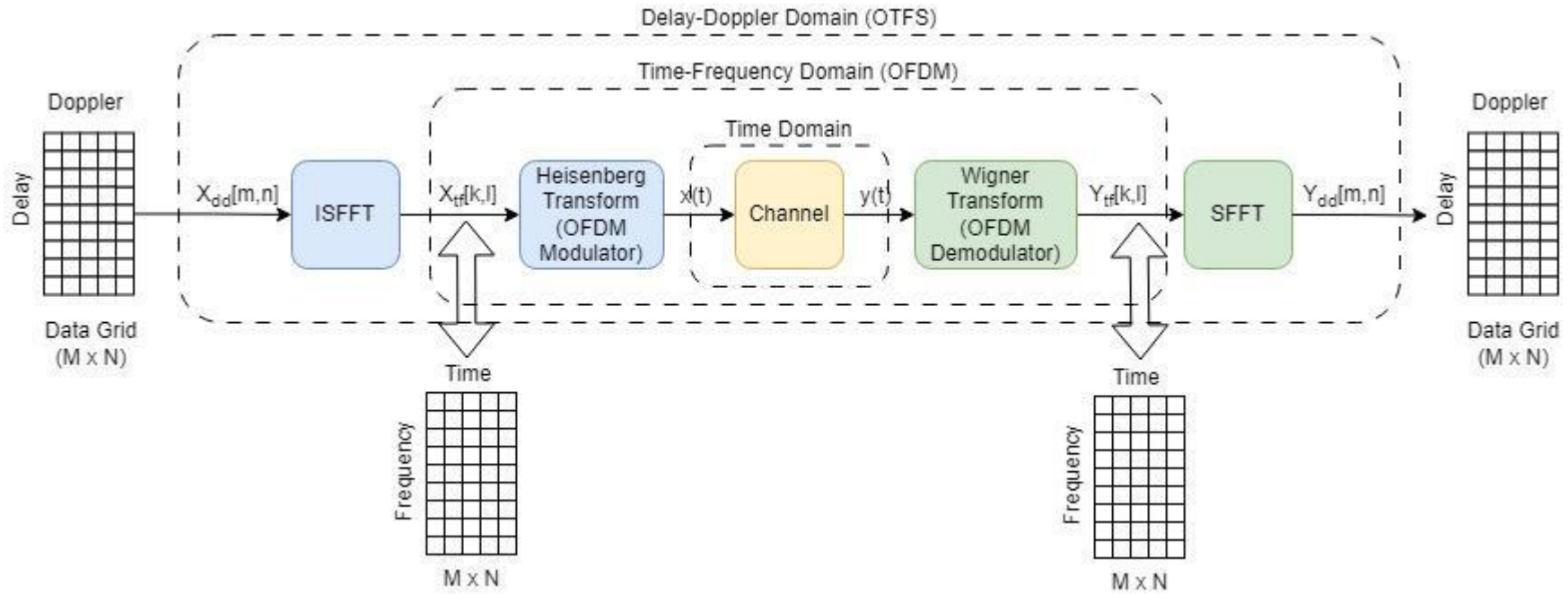
- OTFS represents data in Doppler/Delay space
  - Orthogonality maintained if Doppler & delay constant
  - Even at high Doppler
    - NTN, high-speed car or train,….



ICI = Intercarrier Interference

Correspondence between OFDM and OTFS

- OTFS can be seen as an OFDM code with pre-coding (ISFFT)
  - Equivalence only when Heisenberg Transform identical to OFDM modulation



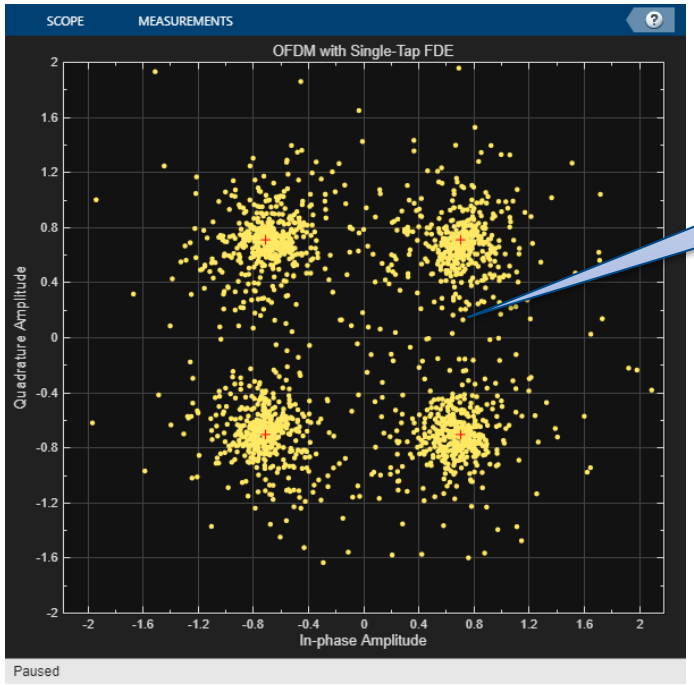
ISFFT = Inverse Symplectic Finite Fourier Transform

✓ Heisenberg Transform is a generalized OFDM with a pulse shaping filter. When pulse shaping filter is rectangular, Heisenberg Transform is identical to OFDM.

Equalization in the Presence of High Doppler

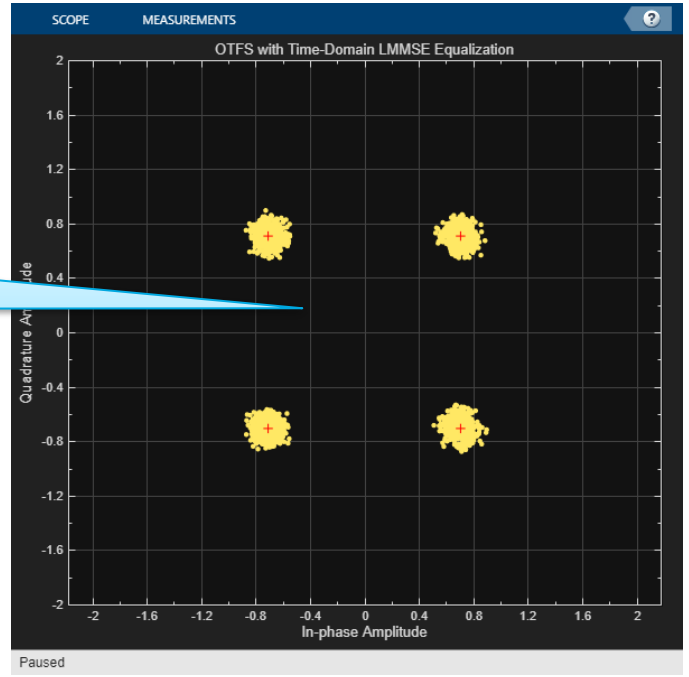
- High Doppler with LOS and 2 additional paths

	Delay (μs)	Doppler (Hz)	Speed (km/h)
Path 1	4.50	-1297	-280
Path 2	7.21	2162	467



OFDM has strong residual ICI

OTFS compensates for Doppler



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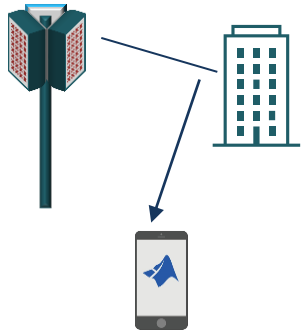

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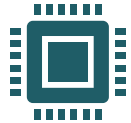

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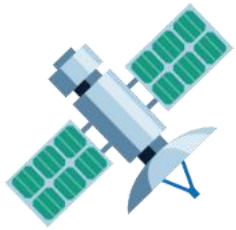

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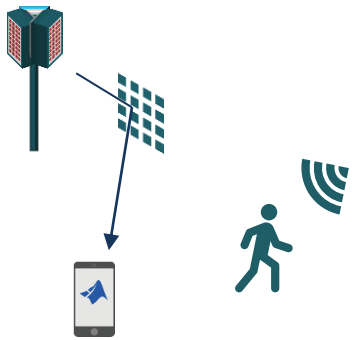
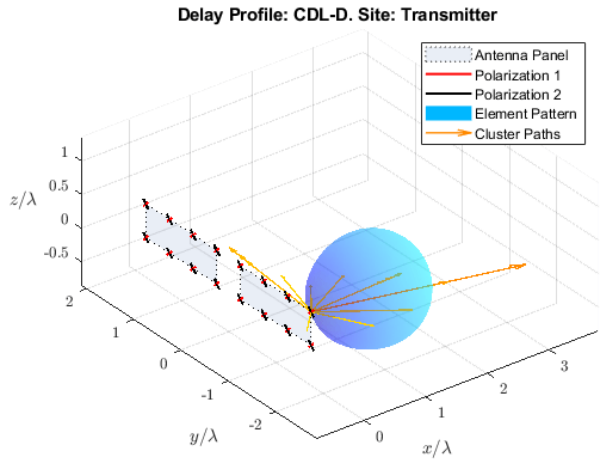
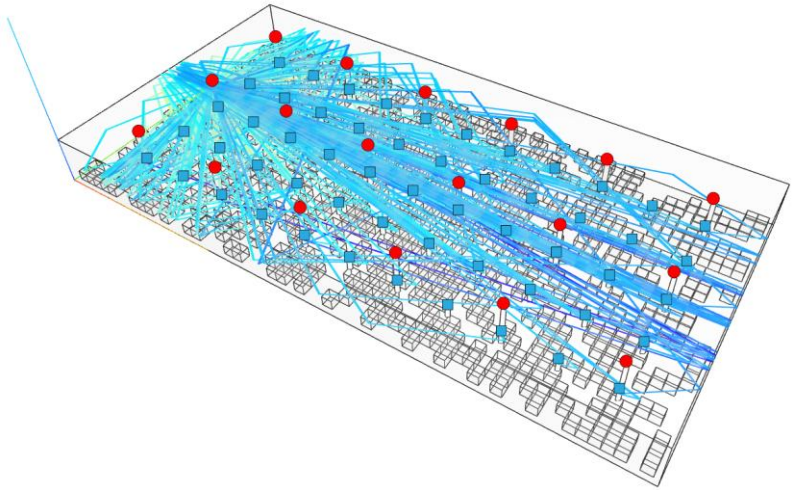
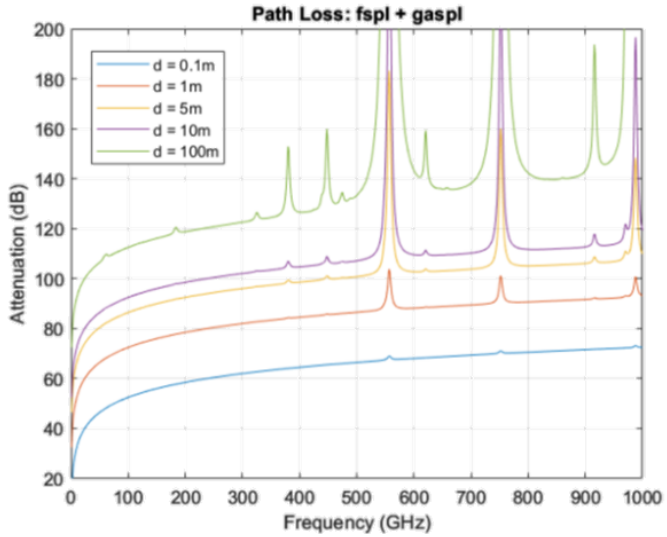


Sensing and RIS

New Frequencies and Higher Bandwidths - Channel Models



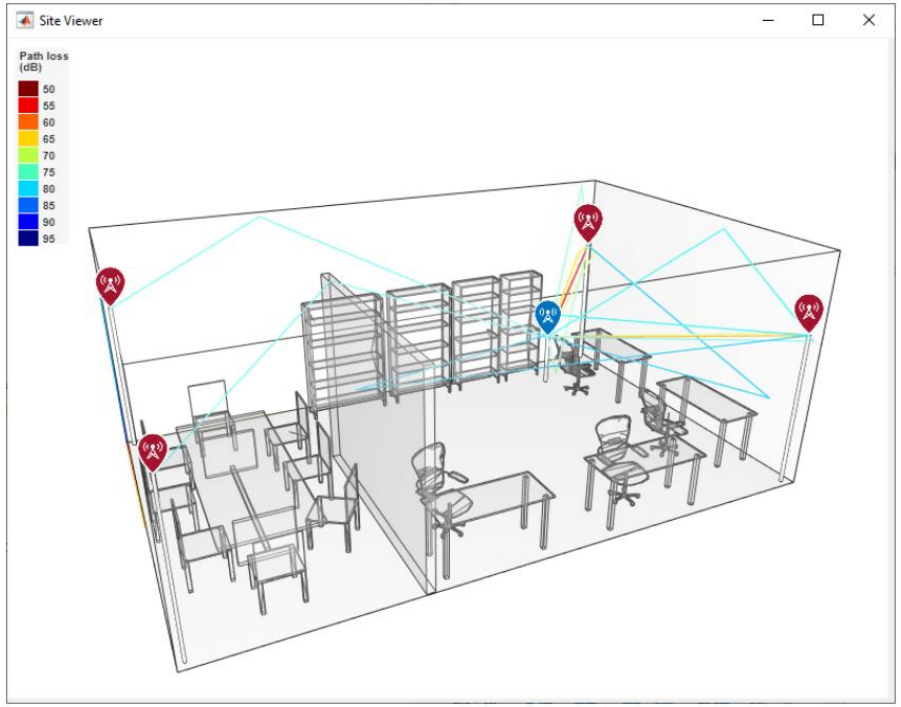


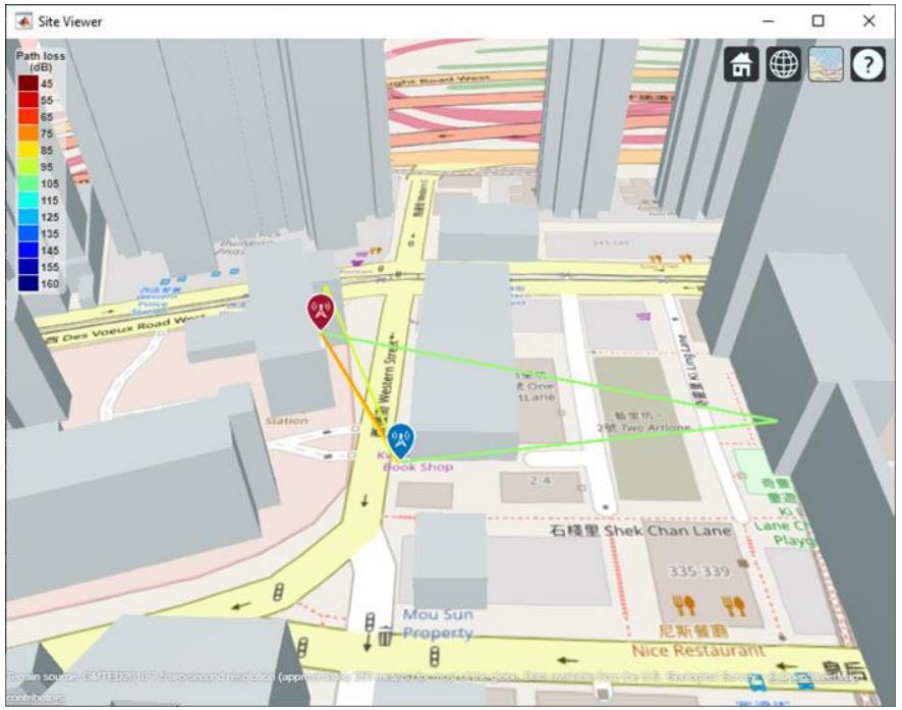


- 3GPP CDL channel model
  - <=100 GHz carrier
- Ray tracing models:
  - <= 100 GHz carrier
- Frequency dependent path loss
  - <= 1 THz carrier

Ray Tracing with MATLAB

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

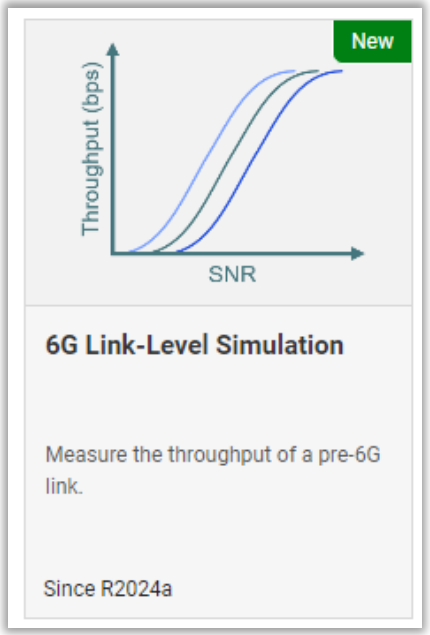




6G Link-Level Simulation

6G Link-Level Simulation

This reference simulation shows how to measure the throughput of a pre-6G link. The example is based on 5G but allows you to explore larger bandwidths and subcarrier spacings than those in 5G systems. The example uses parallel processing to accelerate the simulation by exploiting multiple workers on the desktop or in the cloud.



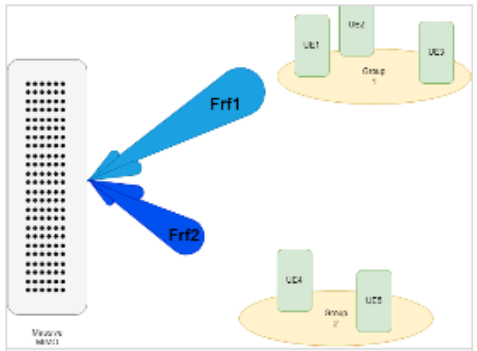
- PDSCH Throughput
- Higher data rates
- Optimized for parallel processing
  - Splits every SNR point on multiple cores / machines

```
(12.25%) (Worker 4) NSlot=195, HARQ Proc 3: CW0: Initial transmission passed (RV=0,CR=0.475897).
(13.00%) (Worker 3) NSlot=207, HARQ Proc 15: CW0: Initial transmission passed (RV=0,CR=0.475897).
(11.81%) (Worker 2) NSlot=188, HARQ Proc 12: CW0: Retransmission #1 passed (RV=2,CR=0.475897).
```

```
[throughput,throughputMbps,summaryTable] = processResults(simParameters,results);
disp(summaryTable)
```

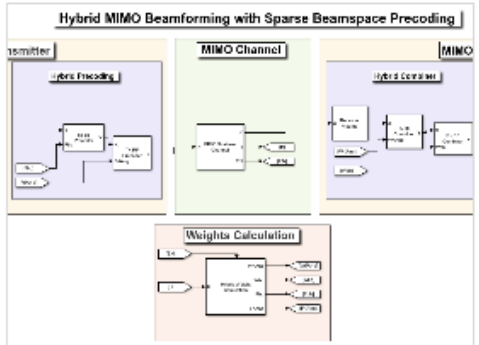
SNR	Simulated bits	Tr Block errors	Number of Tr Blocks	Number of frames	Throughput (%)	Throughput (Mbps)
-10	4.7514e+07	1680	6400	10	73.75	350.41
-9	4.7514e+07	433	6400	10	93.234	442.99
-8	4.7514e+07	174	6400	10	97.281	462.22
-7	4.7514e+07	90	6400	10	98.594	468.45
-6	4.7514e+07	30	6400	10	99.531	472.91

mmWave – Hybrid Beamforming Examples



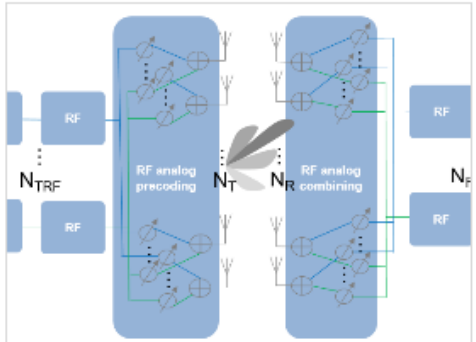
Massive MIMO Hybrid Beamforming

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



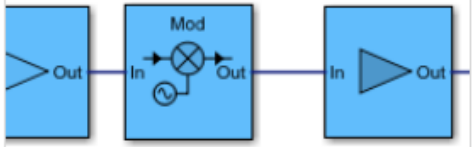
Hybrid MIMO Beamforming with QSHB and HBPS Algorithms

Presents a Simulink® model of a multiple input multiple output (MIMO) wireless communication system. The wireless system uses



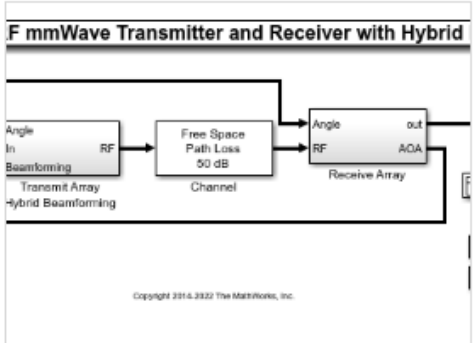
Introduction to Hybrid Beamforming

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



Massive MIMO Hybrid Beamforming with RF Impairments

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

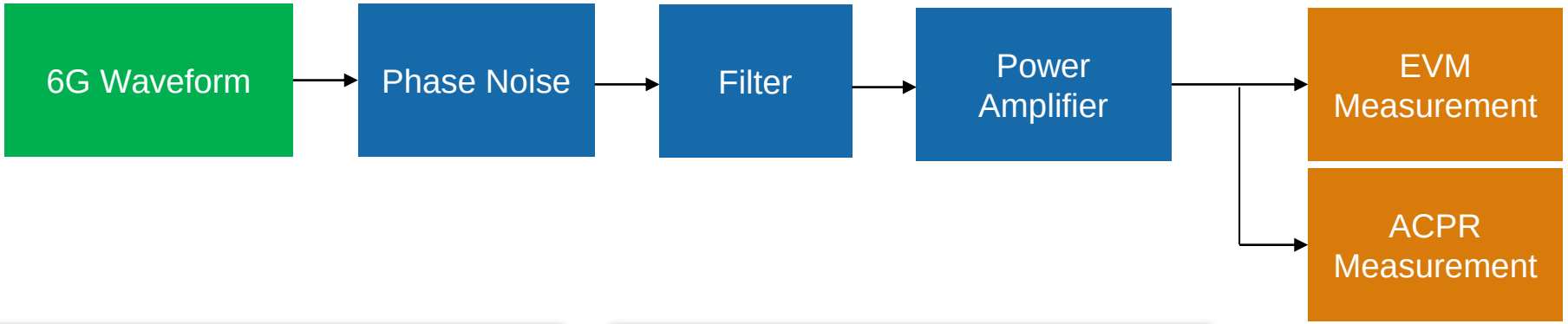


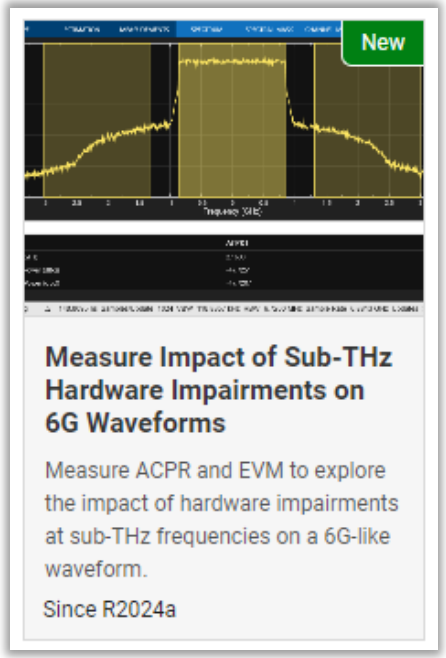
Modeling RF mmWave Transmitter with Hybrid Beamforming

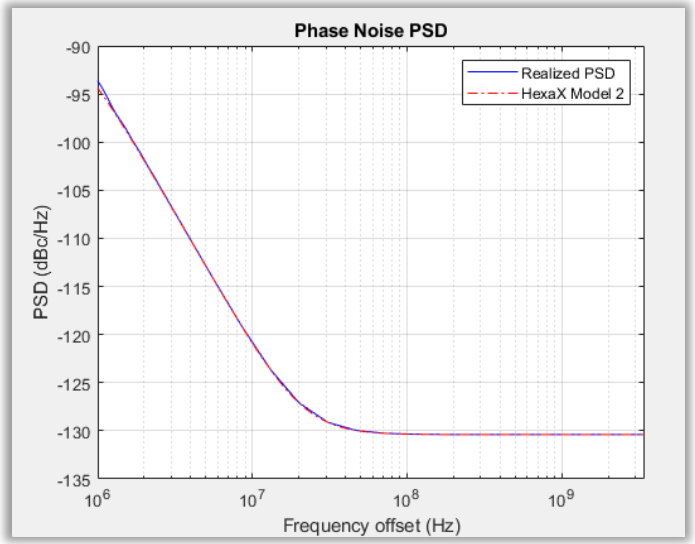
System-level modeling and simulation of a 66 GHz QPSK RF transmit and receive system with a 32-element hybrid beamforming

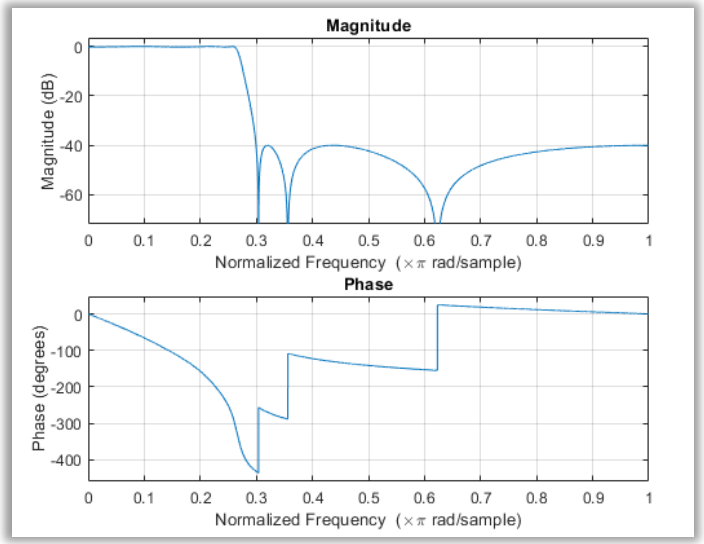
EVM and ACPR Measurement

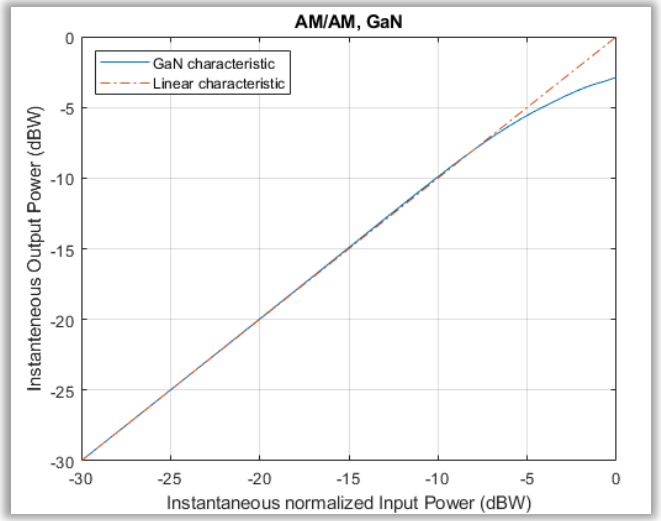
- Evaluate impact of RF impairments on system performance









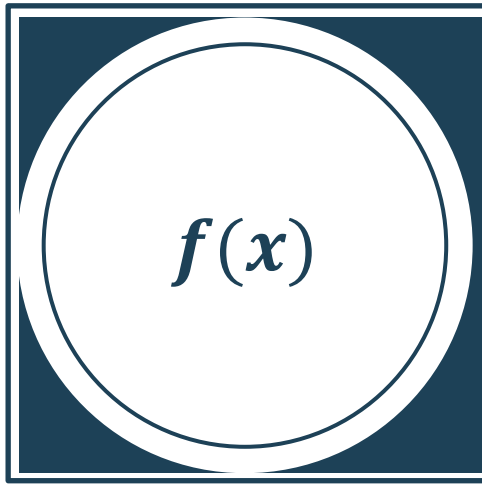


mmWave RF Modeling

We provide 2 levels of fidelity for different use cases

Circuit envelope

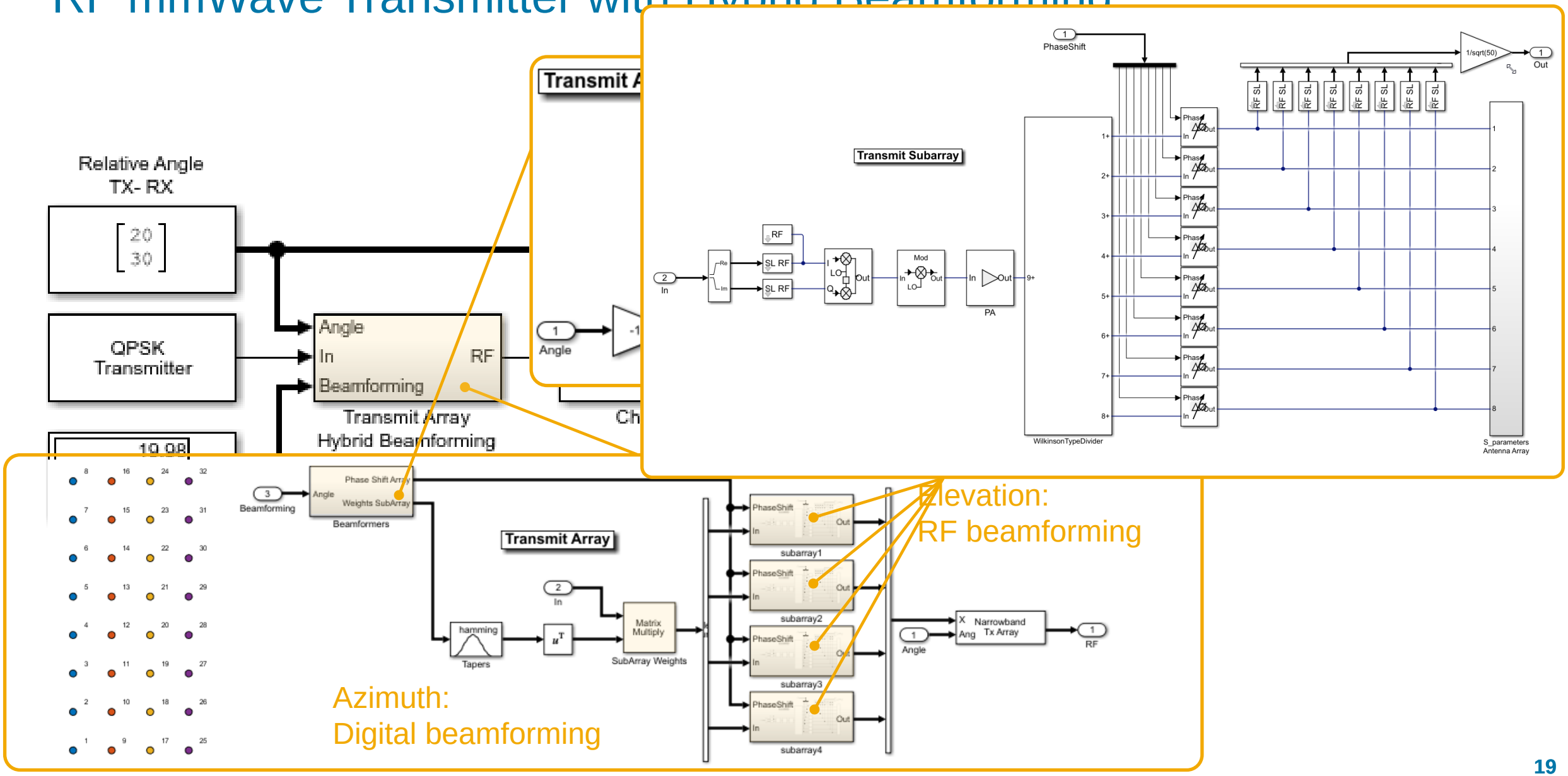
- High fidelity
- Multicarrier simulation
- Arbitrary and cascaded RF networks
- Model impedance mismatches



Idealized baseband

- Mathematical model
- Single carrier simulation
- Complex baseband representation
- Assumes perfect impedance matching

RF mmWave Transmitter with Hybrid Beamforming



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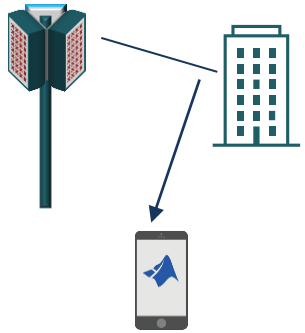

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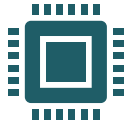

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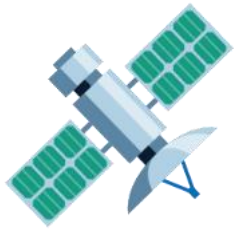

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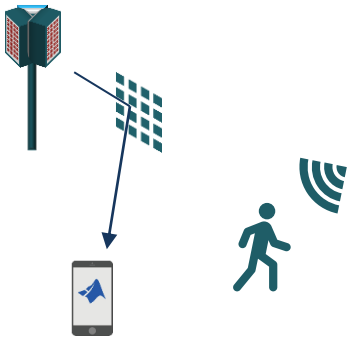
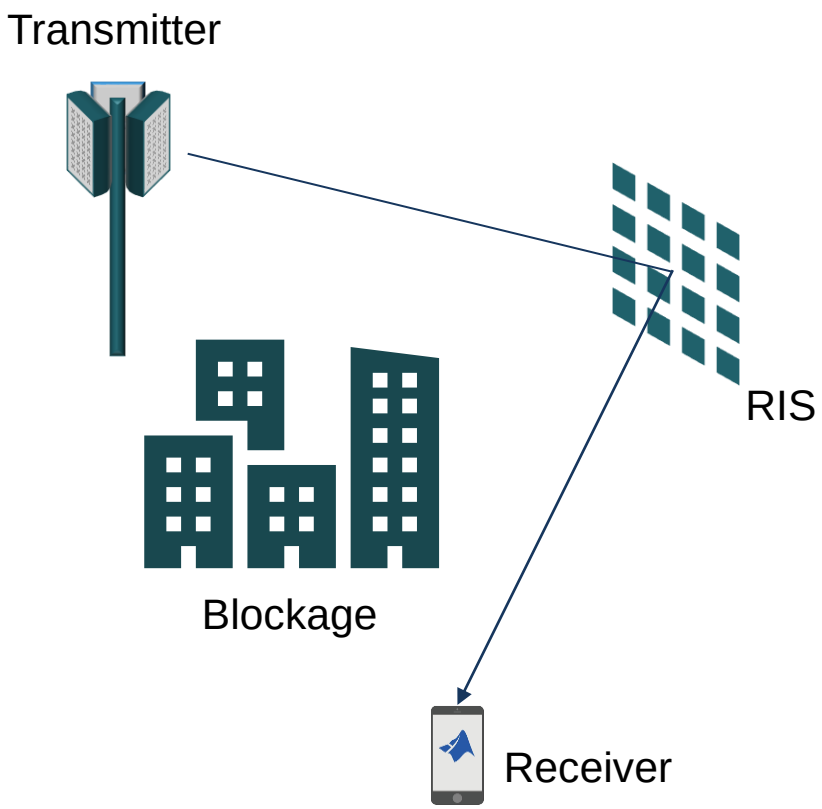


Sensing and RIS

Reconfigurable Intelligent Surfaces (RIS)

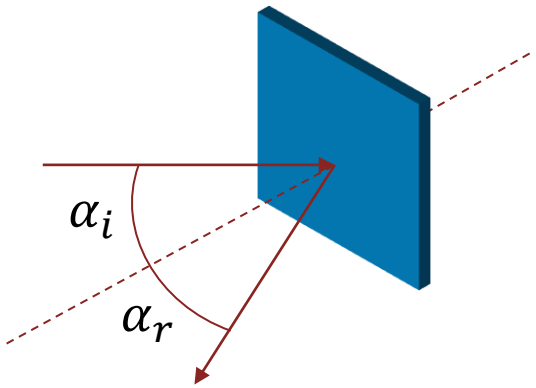
- Array of controllable quasi passive low-cost reflecting elements
- Each element can be reconfigured and apply a custom phase shift to the incoming signal
- Careful choice of phase shifts for each element can cause constructive interference at the receiver



RIS Response

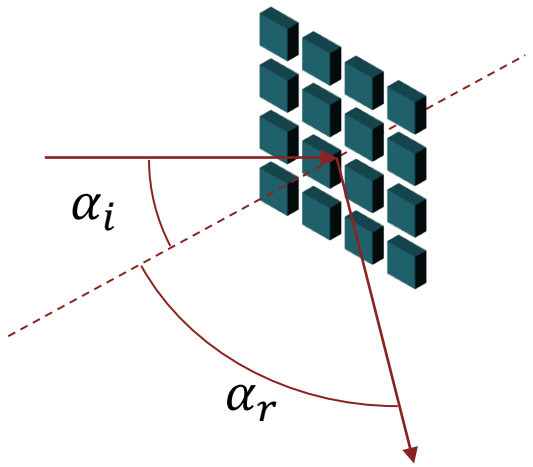
- RIS response can be adapted to the channel conditions

Traditional material



deterministic reflection angle

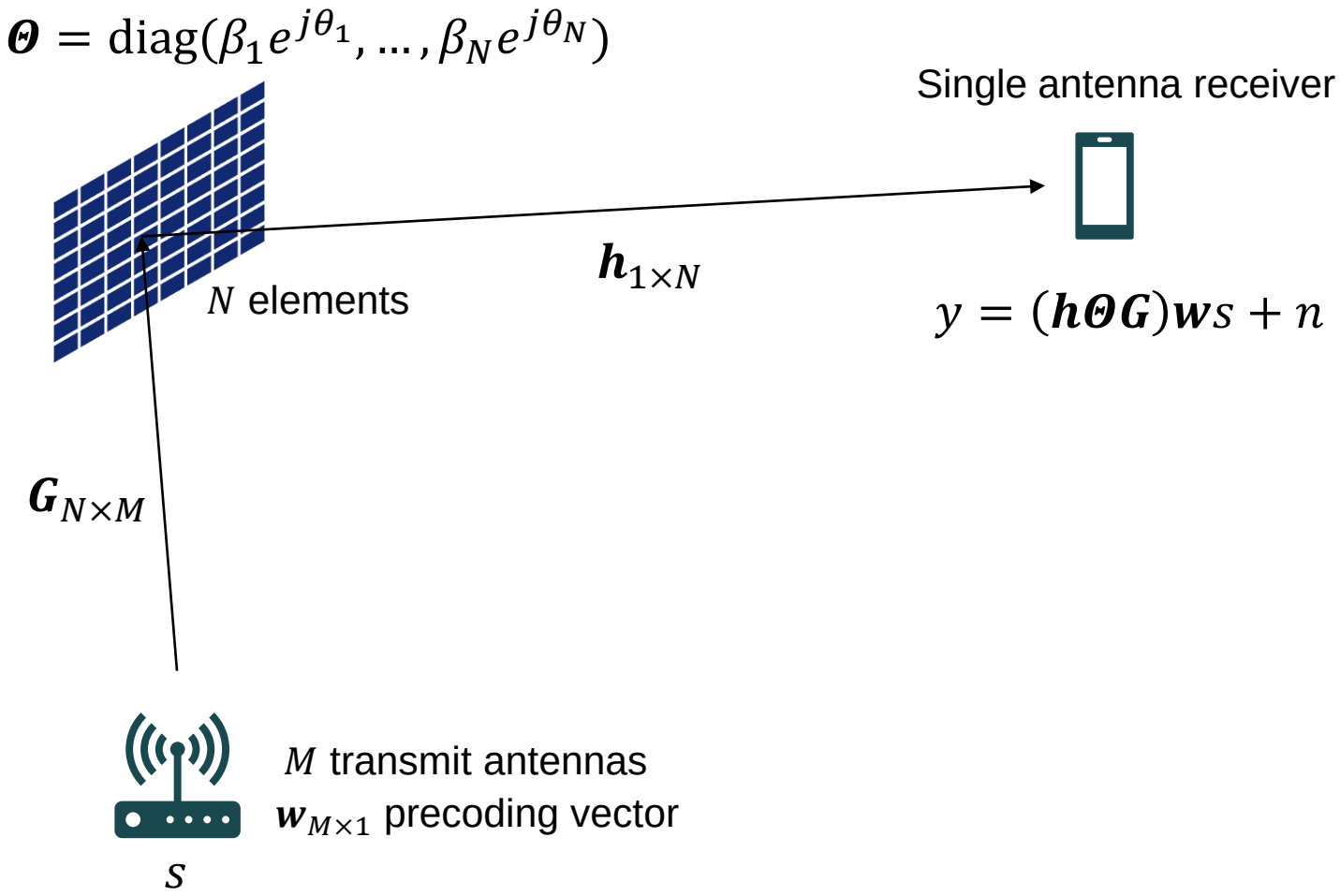
Metasurface



configurable reflection angle

- More suited to scenarios with NLOS between transmitter and receiver.
- Can increase coverage at a low cost

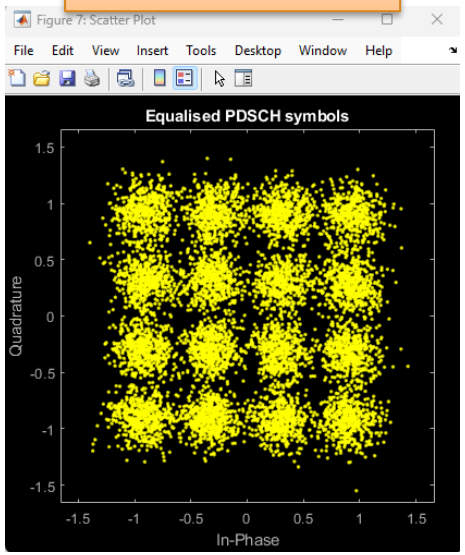
RIS example


$\boldsymbol{\Theta} = \mathrm{diag}(\beta_1 e^{j\theta_1}, \ldots, \beta_N e^{j\theta_N})$
Single antenna receiver
N elements
$\boldsymbol{h}_{1\times N}$
$y = (\boldsymbol{h\Theta G})\boldsymbol{w}s + n$
$\boldsymbol{G}_{N\times M}$
M transmit antennas
$\boldsymbol{w}_{M\times 1}$ precoding vector
s

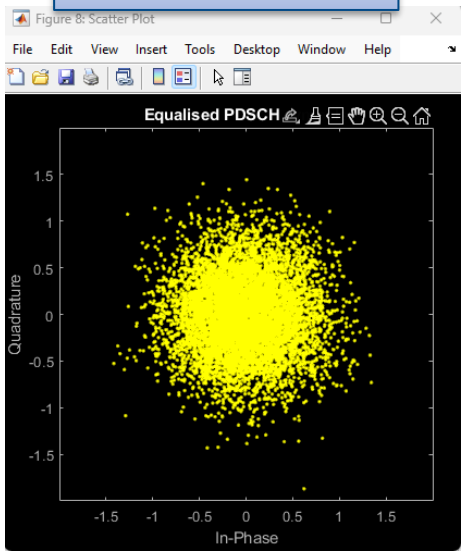
Stochastic and Deterministic Channel Model

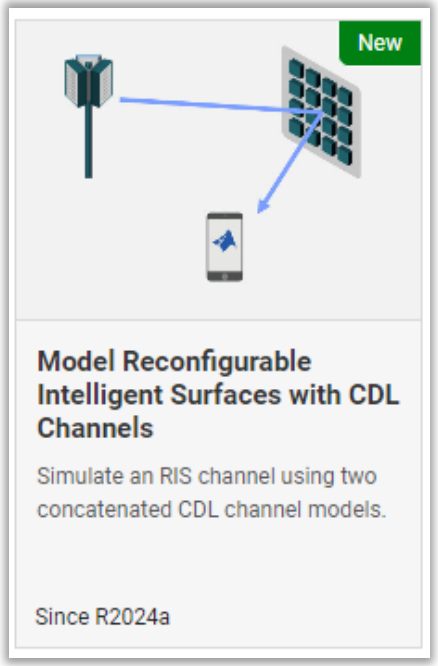
Rx/Tx CDL array and a phase shift models the RIS

RIS enabled



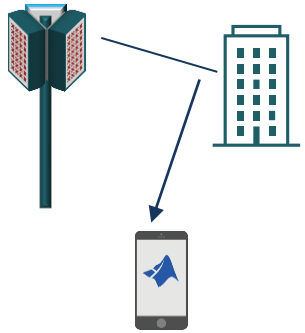
RIS disabled



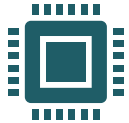


6G Exploration with MATLAB

Waveform exploration

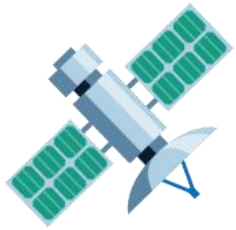


mmWave: propagation loss and channel models

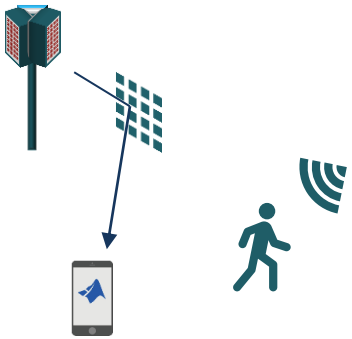


mmWave: RF impairment modelling

AI/ML for wireless

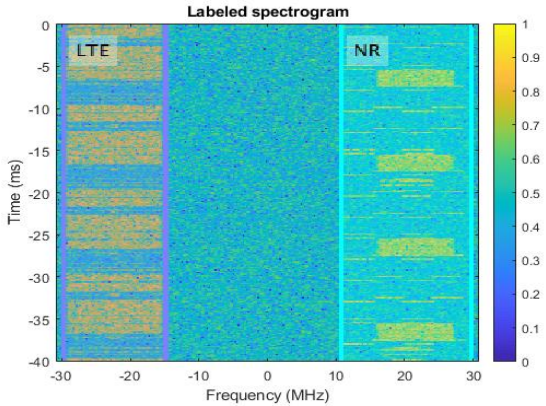


Non terrestrial networks (NTN)



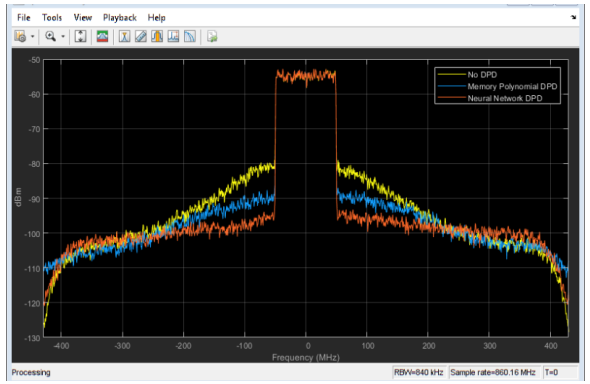
Sensing and RIS

Typical Applications of AI for Wireless Communications

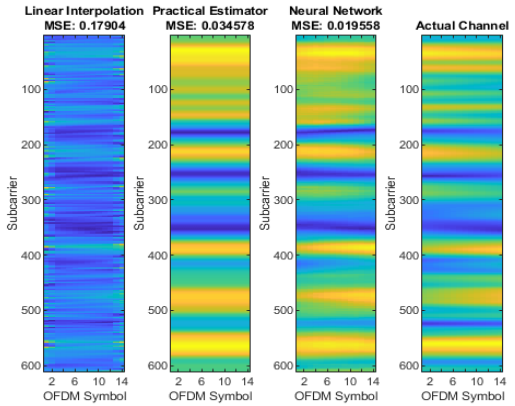


Spectrum Sensing & Signal Classification

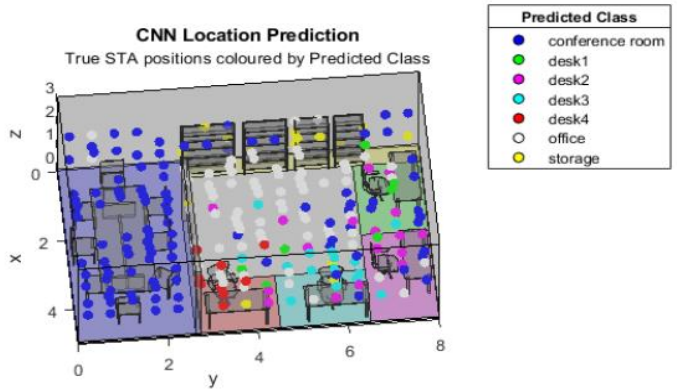
Device Identification



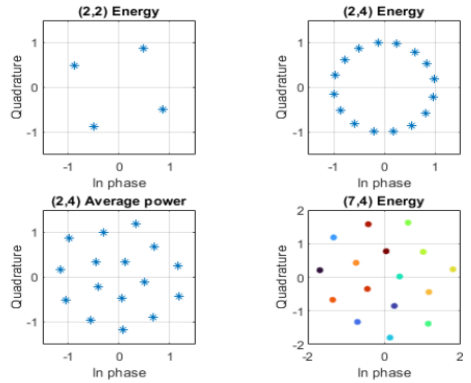
Digital Pre-Distortion



Beam Management & Channel Estimation



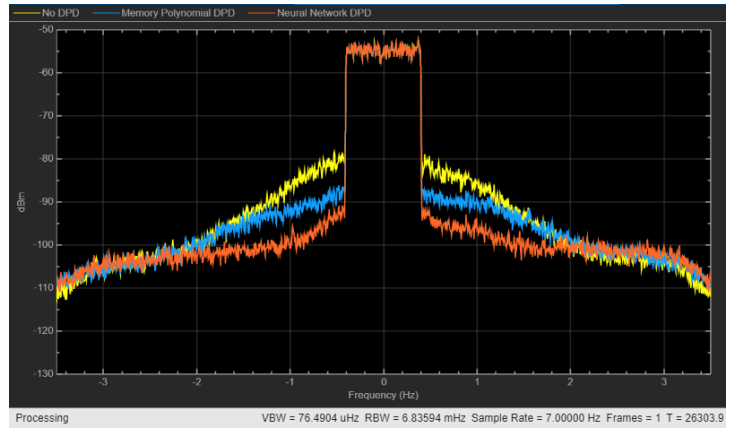
Localization & Positioning



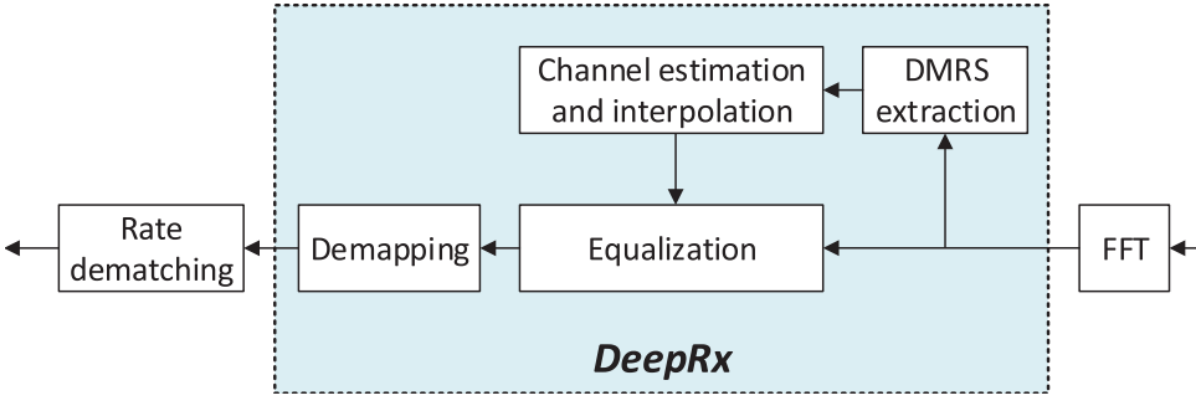
Transceiver design

AI/ML for Future Wireless

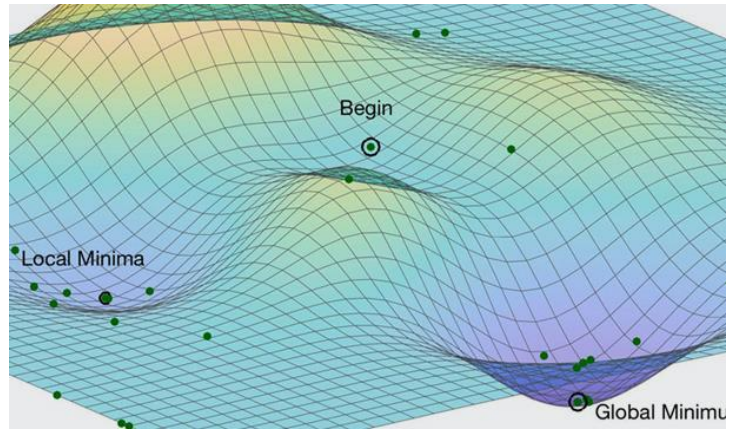
Network management & optimization



RF optimization

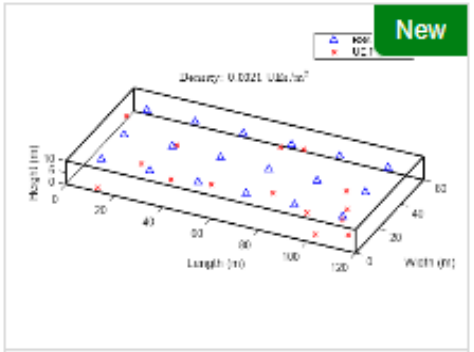


AI-native air interface



End-to-end system optimization

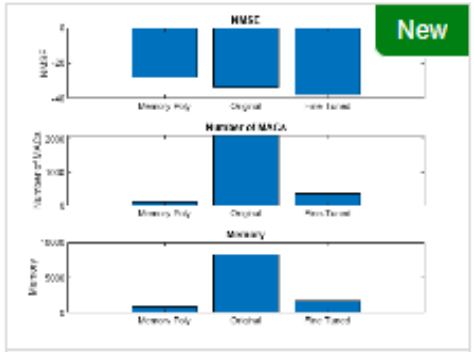
Featured Examples



AI for Positioning Accuracy Enhancement

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

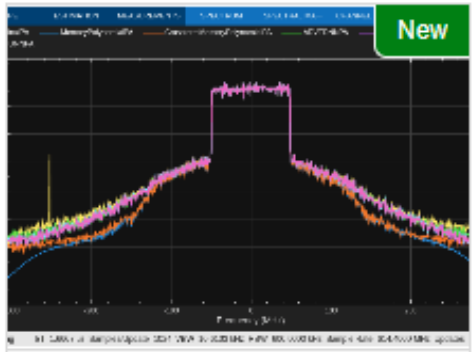
Since R2024a



Structurally Compress Neural Network DPD Using Projection

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

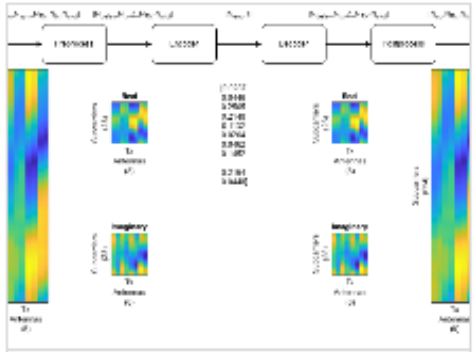
Since R2024a Open Live Script



Power Amplifier Modeling using Neural Networks

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

Since R2024a Open Live Script



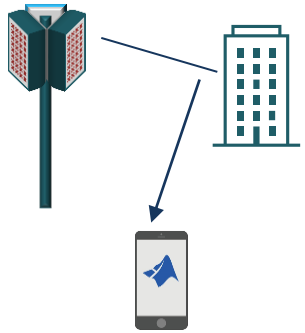
CSI Feedback with Autoencoders

Compress downlink channel state information (CSI) for 5G systems by using an autoencoder neural network.

Open Live Script

6G Exploration with MATLAB

Waveform exploration



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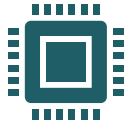

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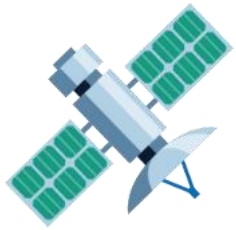

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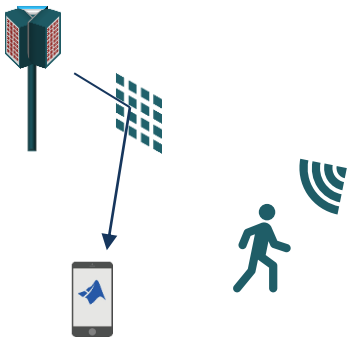
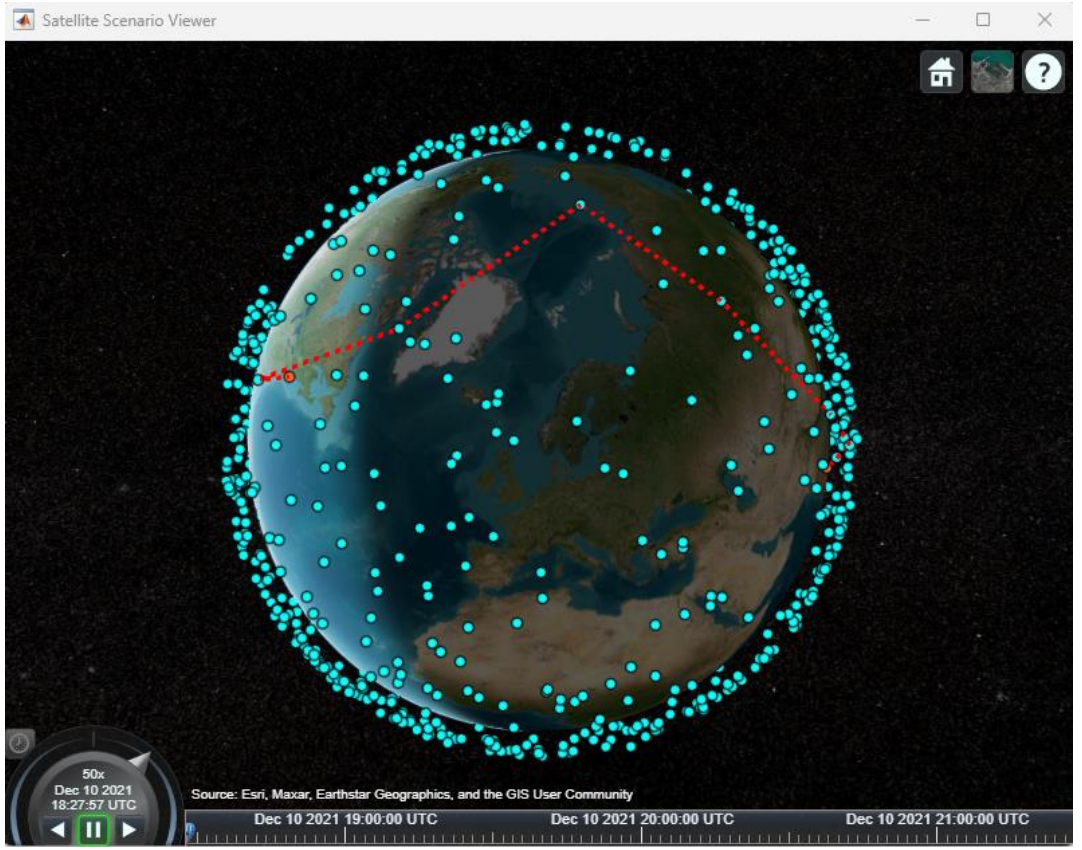


Sensing and RIS

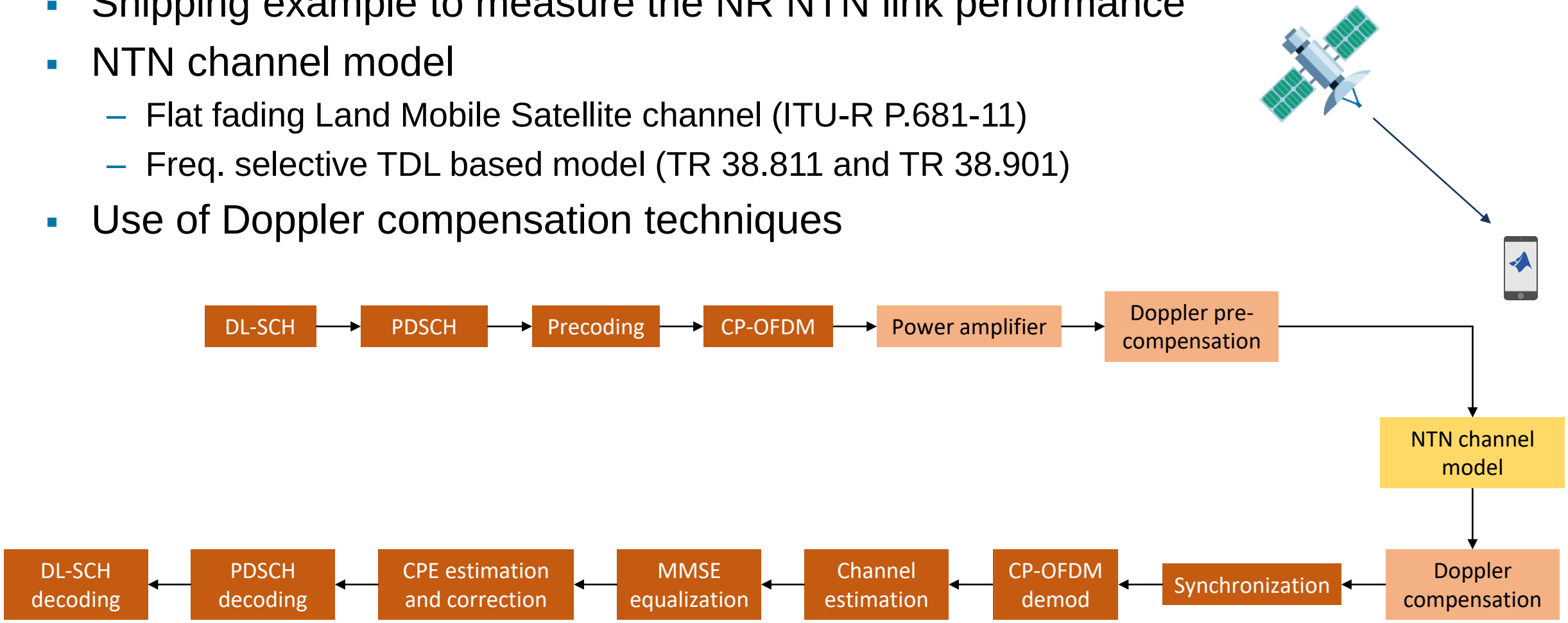
6G NTN Motivation

- 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
- As an example, Hexa-X is studying these coverage targets:
  - >99% of population reached with >1Mbps
  - 100% of world area covered



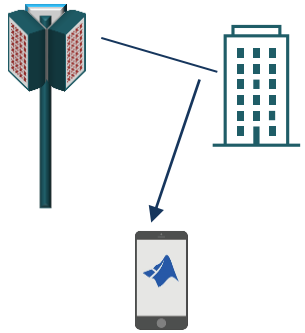
NR NTN Link Level Simulation

- Shipping 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



Summary

Waveform exploration



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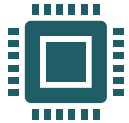

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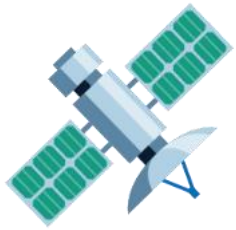

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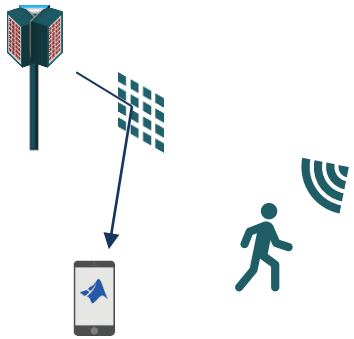


Sensing and RIS

How to learn more

6G Exploration Library

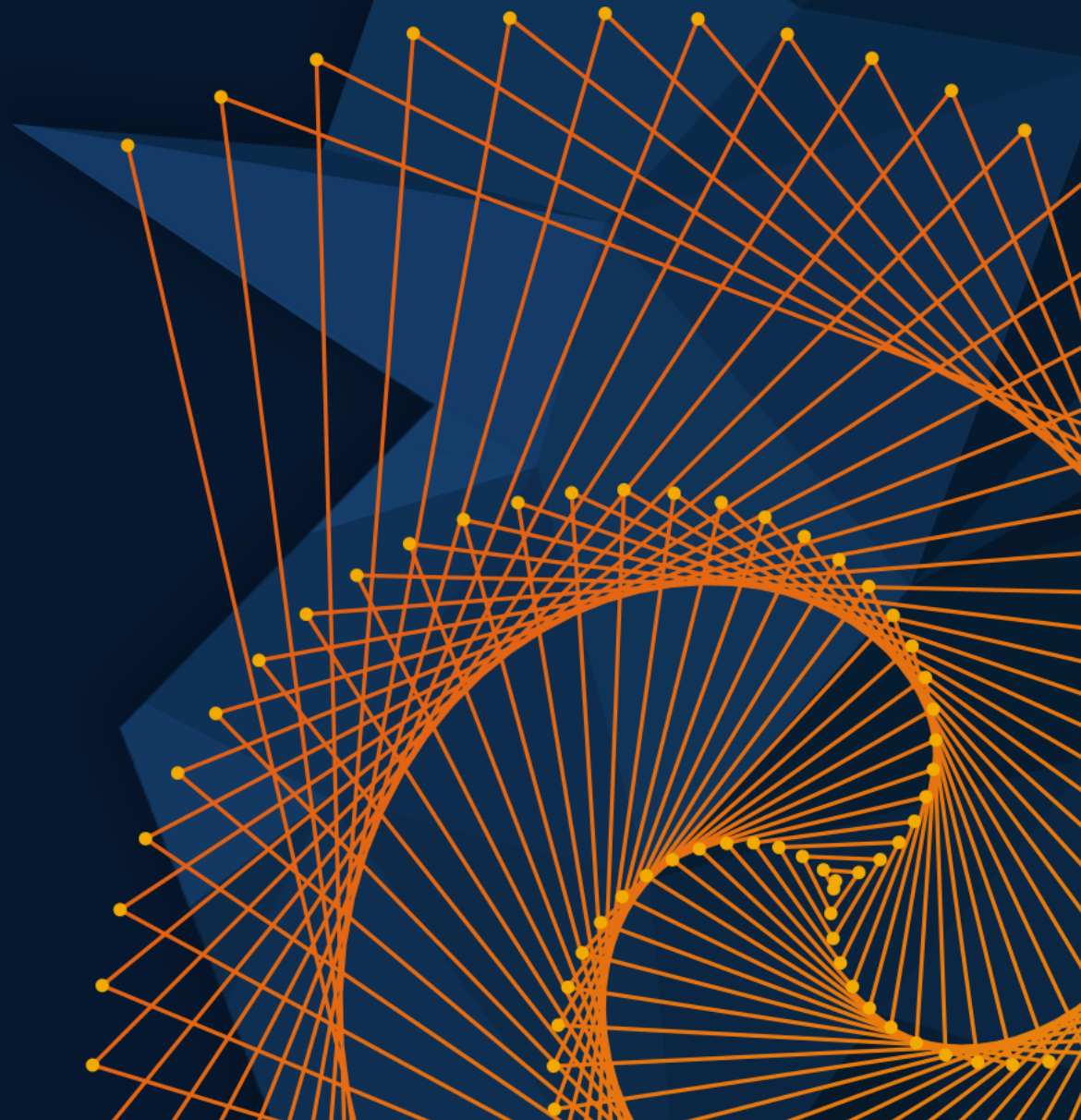
MathWorks 6G page

Related webinars and white papers

- What is 6G Technology?
- AI for Wireless Communication
- 6G Design with MATLAB whitepaper
- 6G Wireless Technology: Accelerate your R&D with MATLAB

MATLAB EXPO

Thank you



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