Sensors Converge

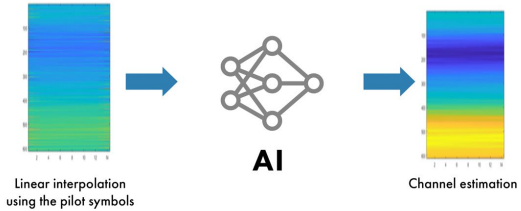
AI and machine learning: A must-have for 5G/6G wireless connectivity and sensor design

June 20–22, 2023 | Santa Clara, CA

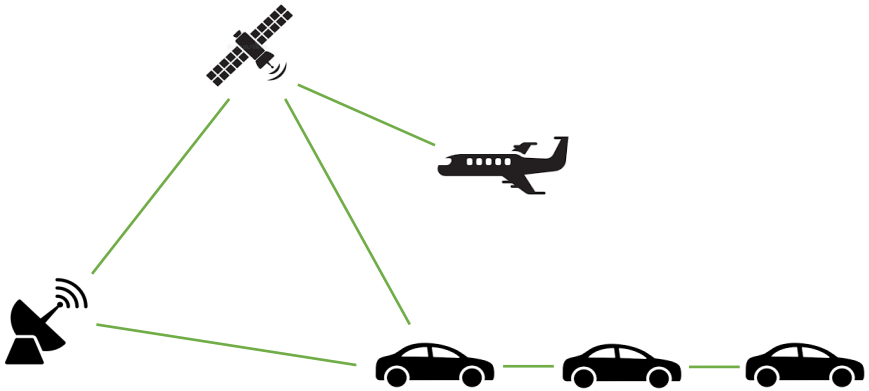
#SensorsConverge

Agenda

- Introduction
- Wireless sensor design
- 5G/6G, Wi-Fi perspective
- Challenges of sensor networks
- AI/ML for wireless sensing
- Wireless sensing/detection example
- Summary



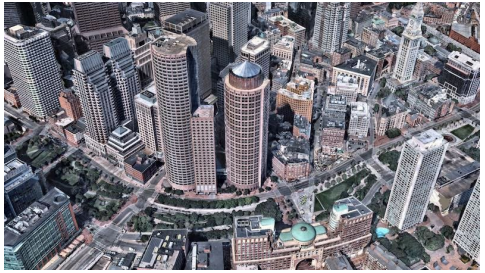
Digital Twin: Authoring multi-domain wireless sensor scenarios



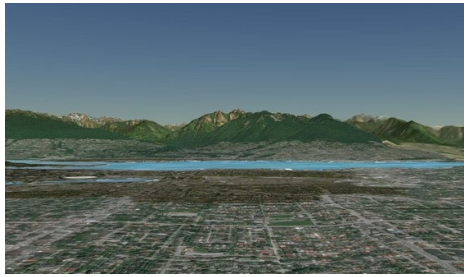
Multi-domain for actors: mixes different types of actors, e.g., land-, sea-, air-, or space-based

Multi-domain for sensors: mixes different types of sensor systems, e.g., radar, comms, lidar, navigation, sonar

Urban & Terrestrial Outdoor Scenes



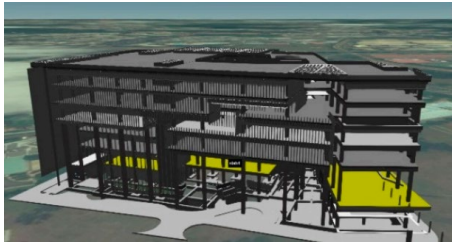
Urban



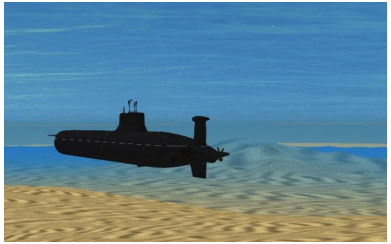
Terrestrial / aerial (UAV)

Space (Satellite)

Indoor



Hybrid outdoor/indoor

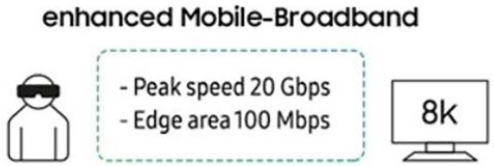


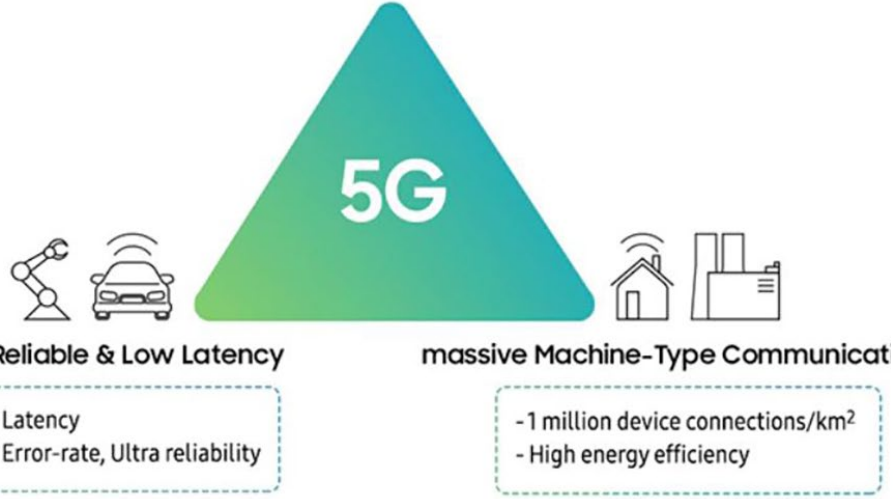
Underwater

Space (Non-Earth)

5G, Satellite and Connectivity (Wi-Fi, BLE, UWB)

5G Cellular Service
CESSI



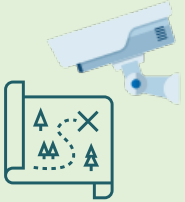


Objective: 6G

Applications & Scenarios

Fully immersive extended reality

Access for everyone



Integrated sensing

Digital twins

Critical & massive communication

KPIs

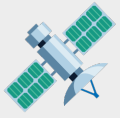
Aggressive improvements in coverage, throughput, latency, reliability, security, sustainability…

Enabling Technologies

AI/ML

mm-wave & terahertz

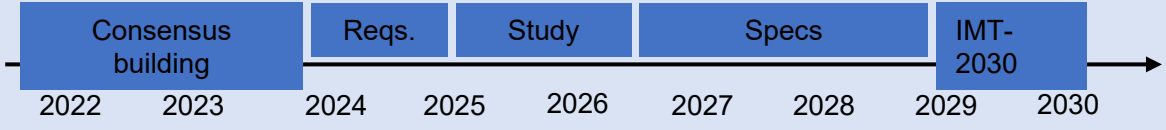
Intelligent reflective surfaces



Non-terrestrial networks

Others…

Progress

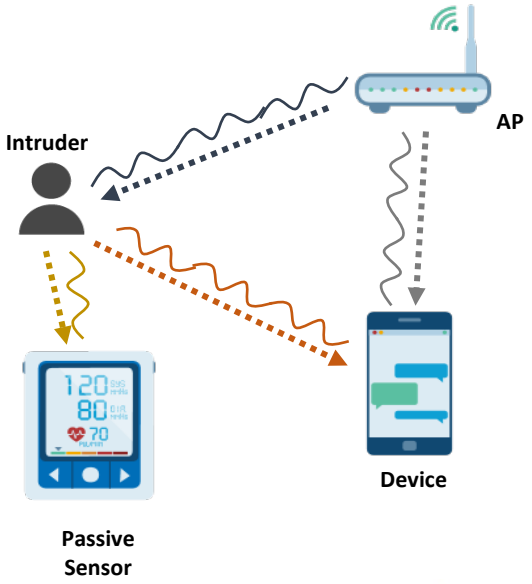


Hexa-X 6G-ANNA NEXT G ALLIANCE 6G 6GPP (one6G)

Progress based on presentation by Nokia at WCNC 2023

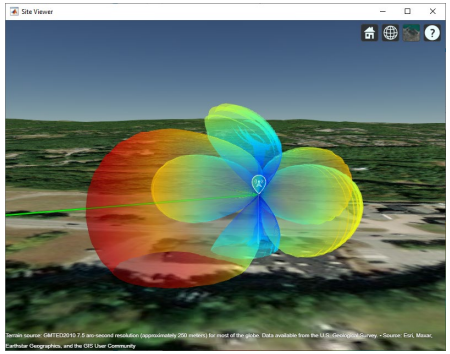
Emerging WLAN standards

- **802.11be** – Extremely high throughput (Wi-Fi 7)
- **802.11bf** – Wireless sensing
- **802.11bn** – Ultra-high reliability (Wi-Fi 8)
- **TG-AIML** – Topic Interest Group for Artificial Intelligence and Machine Learning

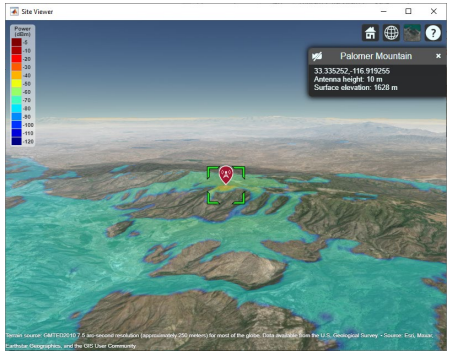


Leverage AI/ML

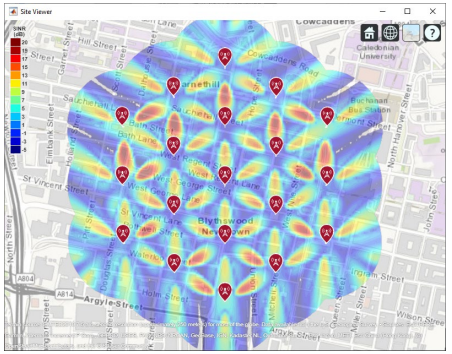
Challenges: RF Propagation, Scenario Modeling & Visualizations



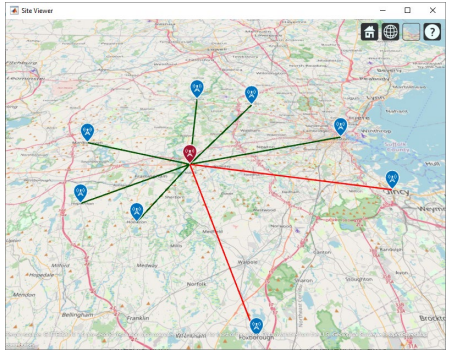
Antenna Pattern



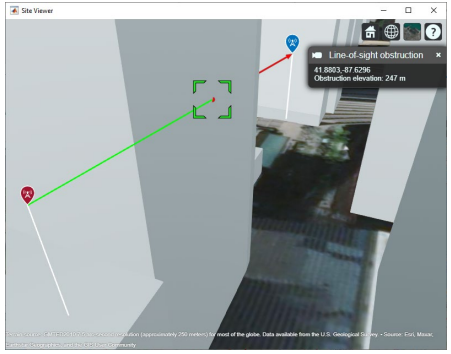
Coverage Map



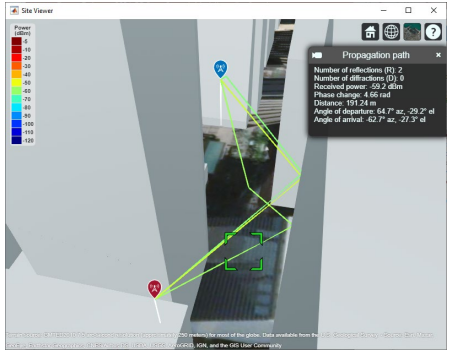
SINR Map



Comm Link



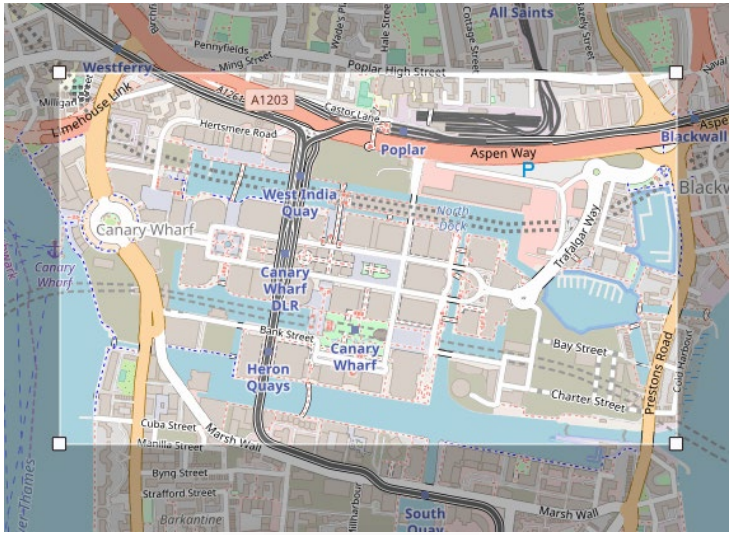
Line-of-Sight

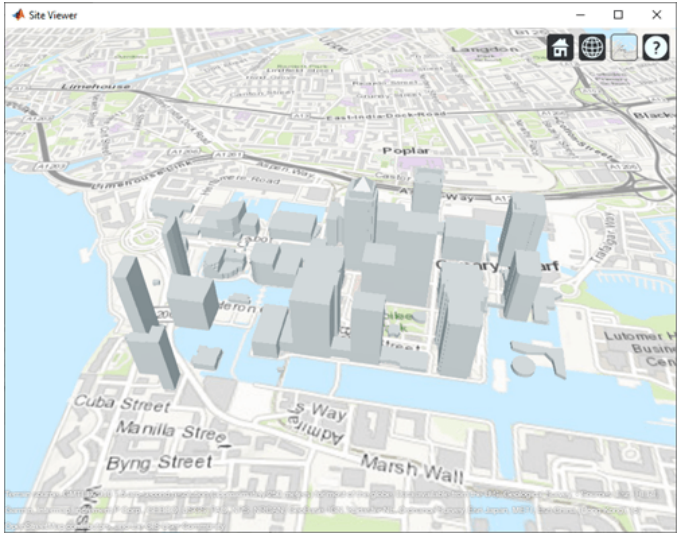


Ray Tracing

Urban Environment for Ray Tracing

- You can download data from OpenStreetMap
  - Free, open, crowd-sourced database
- Import buildings from OpenStreetMap file in Site Viewer



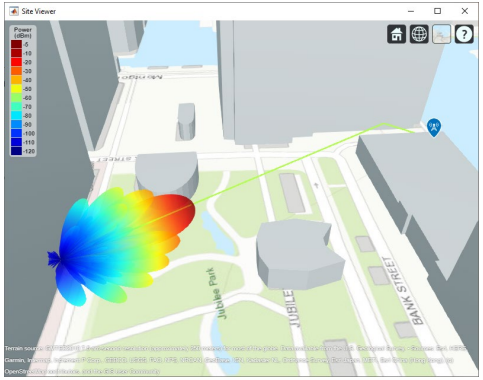


OpenStreetMap

```
siteviewer("Basemap","topographic", ...
           "Buildings","canarywharf.osm");
```

Programmatic Access to Rays

- Returned ray object contains properties for geometry and RF Propagation values
- Use rays to:
  - Re-compute path loss with different materials using raypl
  - Compute Phased Array beam steering vectors
  - Configure channel models




```
rays = raytrace(tx,rx);
disp(rays{1}(1))
```

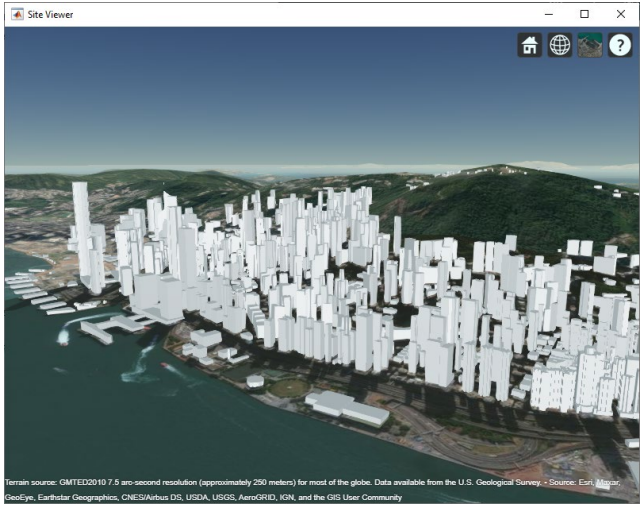
```
  Ray with properties:

      PathSpecification: 'Locations'
       CoordinateSystem: 'Geographic'
    TransmitterLocation: [3×1 double]
       ReceiverLocation: [3×1 double]
             LineOfSight: 0
           Interactions: [1×1 struct]
              Frequency: 2.8000e+10
         PathLossSource: 'Custom'
               PathLoss: 115.4896
             PhaseShift: 4.0976

  Read-only properties:
      PropagationDelay: 6.6488e-07
   PropagationDistance: 199.3261
      AngleOfDeparture: [2×1 double]
        AngleOfArrival: [2×1 double]
       NumInteractions: 1
```

Site Viewer Map Data Layers

RF Propagation Environment

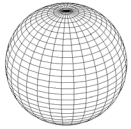



```
siteviewer("Terrain","gmted2010", ...
           "Buildings","hongkong.osm");
```

Building Geometries

Basemap Imagery

Terrain Elevation



Earth Ellipsoid (WGS84)

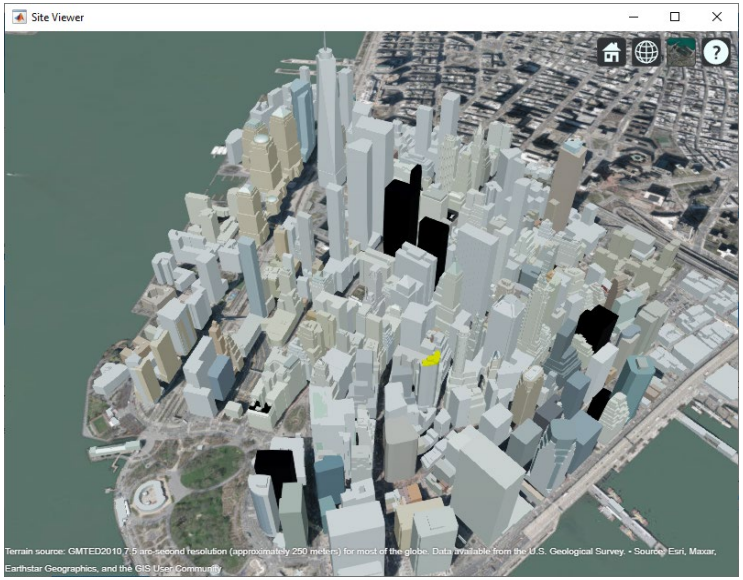
Effect of Environment/Material on Sensor Connectivity

- Support building materials specified in OpenStreetMap file
  - Technology leverage: 3D Geometry Library (material attributes on scene mesh)
- MATLAB API to import & edit buildings

```
% Read OSM buildings into table (Mapping Toolbox required)
bldgs = readgeotable("manhattan.osm",Layer="buildings");

% Update building materials, colors, or geometries
bldgs(1,:).Material = "glass";
bldgs(2,:).Material = "metal";
bldgs(3,:).Material = "concrete";

% Pass buildings to Site Viewer
sv  = siteviewer(Buildings=bldgs);
```



Artificial Intelligence (AI)

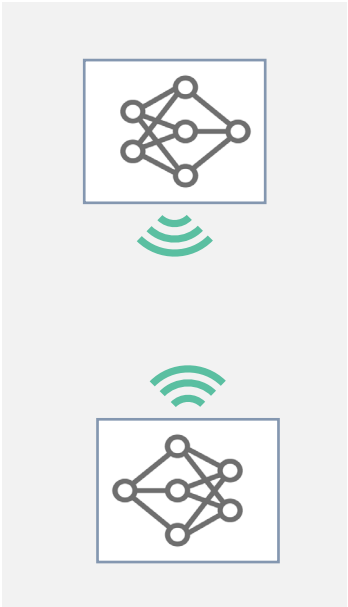
MOTIVATIONS FOR AI IN WIRELESS

- 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



Workflow of AI-driven Wireless System Design

Data Preparation

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

AI Modeling

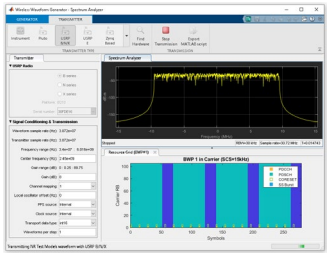
- Model design and tuning
- Hardware accelerated training
- Interoperability

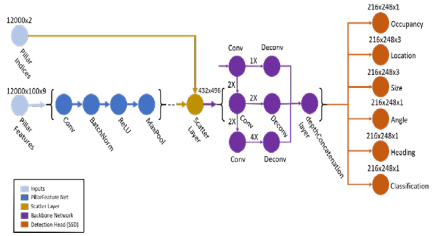
Simulation & Test

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

Deployment

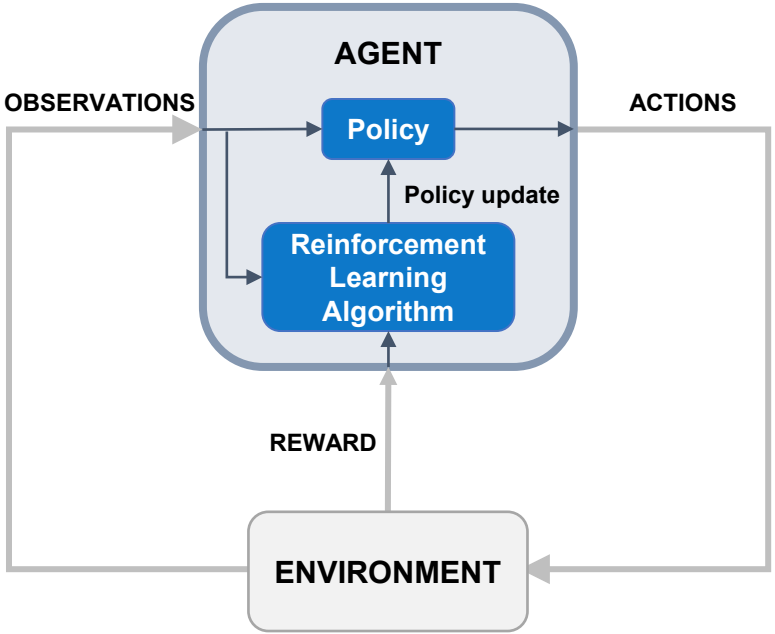
- Embedded devices
- Enterprise systems
- Edge, cloud, desktop





Reinforcement Learning

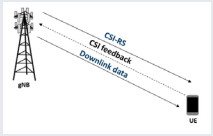
Training a self-driving car



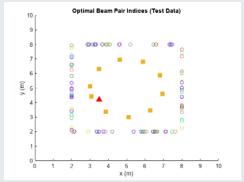
- Vehicle's computer…
  (**agent**)
- is reading sensor measurements from LIDAR, cameras…
  (**observations**)
- that represent road conditions, vehicle position…
  (**environment**)
- and generates steering, braking, throttle commands…
  (**action**)
- based on an internal state-to-action mapping…
  (**policy**)
- that tries to optimize, e.g., lap time & fuel efficiency…
  (**reward**)
- The policy is updated through repeated trial-and-error by a **reinforcement learning algorithm**

AI for 6G – How MATLAB Can Help

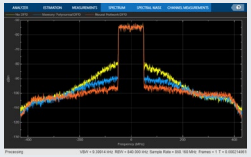
Ready-to-use AI Workflows for Wireless



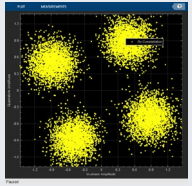
CSI Feedback with Autoencoders



Neural Networks for Beam Selection

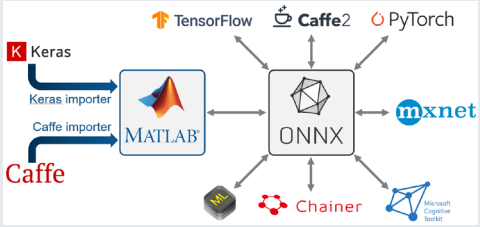


Neural Networks for Digital Predistortion



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

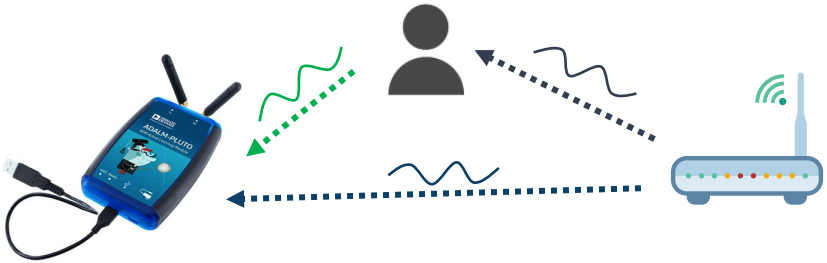
Software-Defined Radios

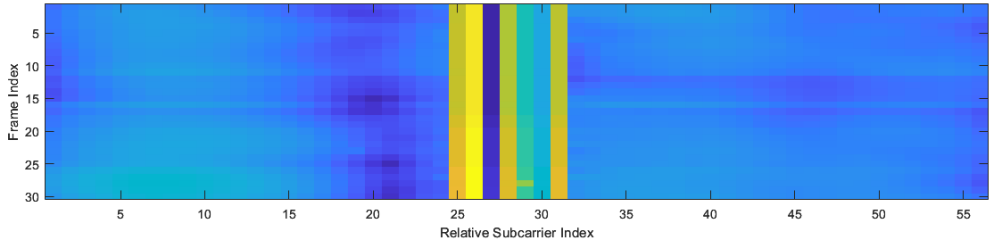
Presence Detection Using Wireless Sensing

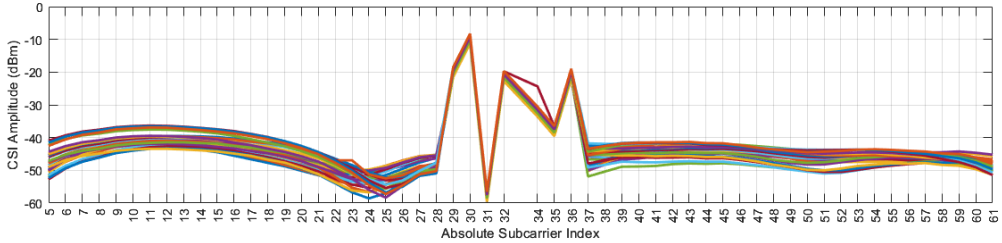
R2023a

Use Wi-Fi channel state information to detect the presence of people in a room

- Capture Wi-Fi beacon CSI with SDR and WLAN Toolbox with and without movement to create a data set or use downloaded 3P data set
- Train a neural network to classify presence







Sensors Converge

Summary

- Operation of sensor networks rely heavily on “situational awareness” and “Localization and Positioning” of sensors in use
- 5G/6G and Wi-Fi evolution requires modeling the channel models and their real-time dynamics
- Joint wireless communications and sensing combines spatial awareness, link analysis and channel modeling
- MATLAB tools in RF propagation, Ray tracing and Reinforcement leaning can jointly optimize Digital, RF and Antenna parts of your sensor network design.