Wireless Research Introduction

Sarah LaSelva

Chief Product Marketing Manager

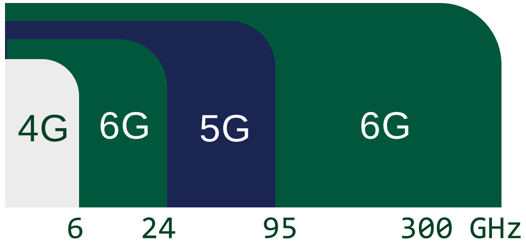
RF & Wireless

Industry Update

6G Trends

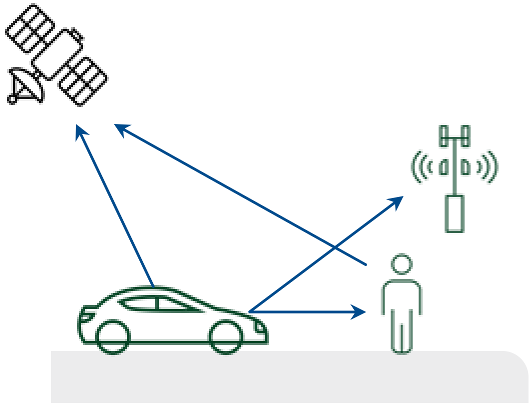
An Introduction to 6G

Spectrum Expansion



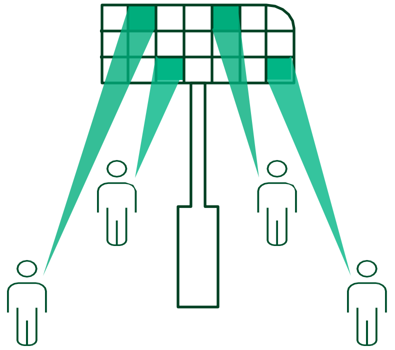
7 – 24 GHz “FR3”
Sub-THz

New Applications

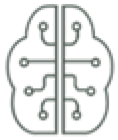


Non-Terrestrial Networks
Integrated Comms and Sensing

Network Optimization

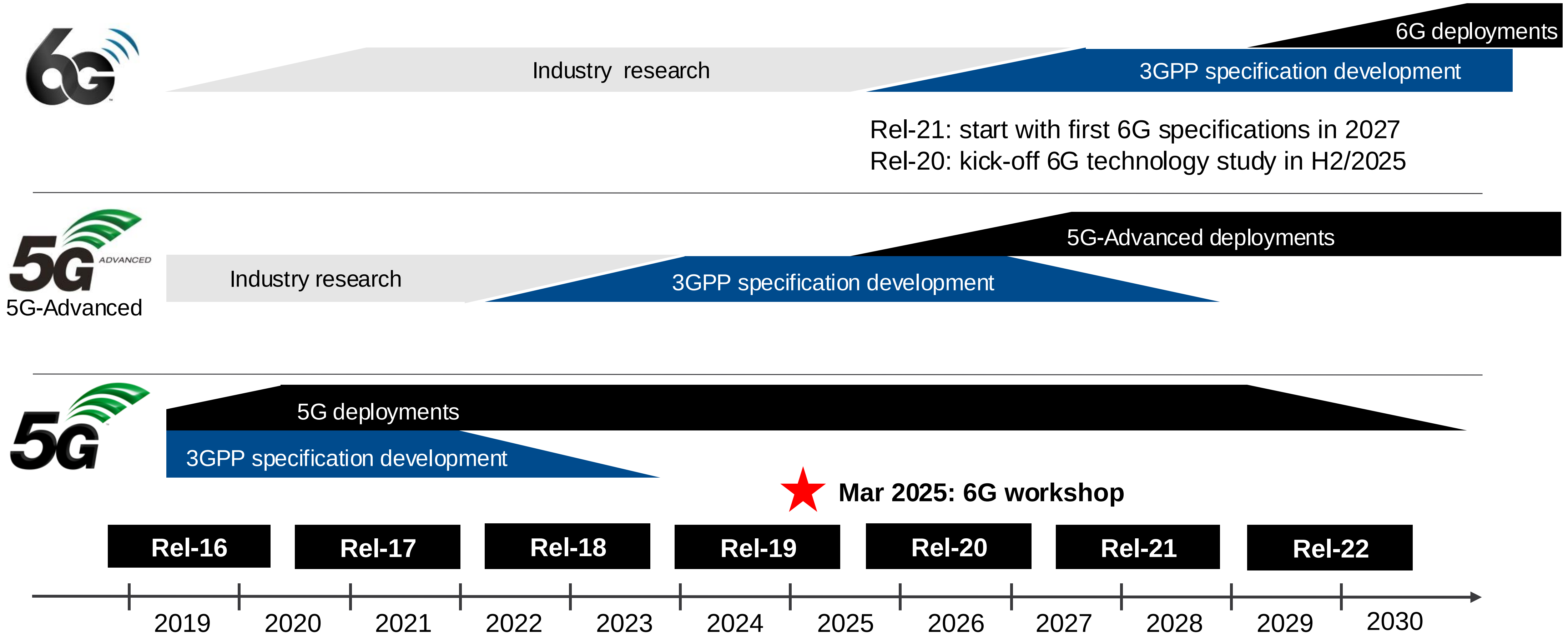


Next Generation MIMO
Open RAN Evolution



Embedded, Trustworthy AI

Road From 6G Research To 6G Standard



Spectrum Overview

Active channel modeling ongoing

<1 GHz | <7 GHz | <24 GHz | <100 GHz

Low Band	Lower Mid Band	Upper Mid Band	mmWave	Sub-THz, THz & above

ITU & 3GPP Prioritized:

- 4.4-4.8 GHz
- 7.125-8.4 GHz
- “FR1-like”, digital beamforming, conducted measurements
- Up to 128 antenna elements per polarization (BS)
- 14.8-15.35 GHz
- “FR2-like”, hybrid beamforming, radiated measurements
- Up to 2k antenna elements per polarization (BS)
- Small antenna panels (UE)

US Specific:

- 12.7-13.25 GHz

More research needed through 2031

- 102.0-109.5 GHz
- 151.5-164.0 GHz
- 167.0-174.8 GHz
- 209.0-226.0 GHz
- 252.0-275.0 GHz

NI Wireless Research Program has enabled critical research since 2010

Integrated Sensing and Communications

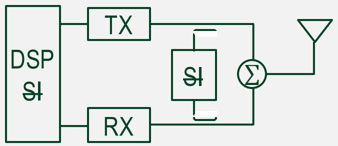
(ISAC) or Joint Communications and Sensing (JCAS)

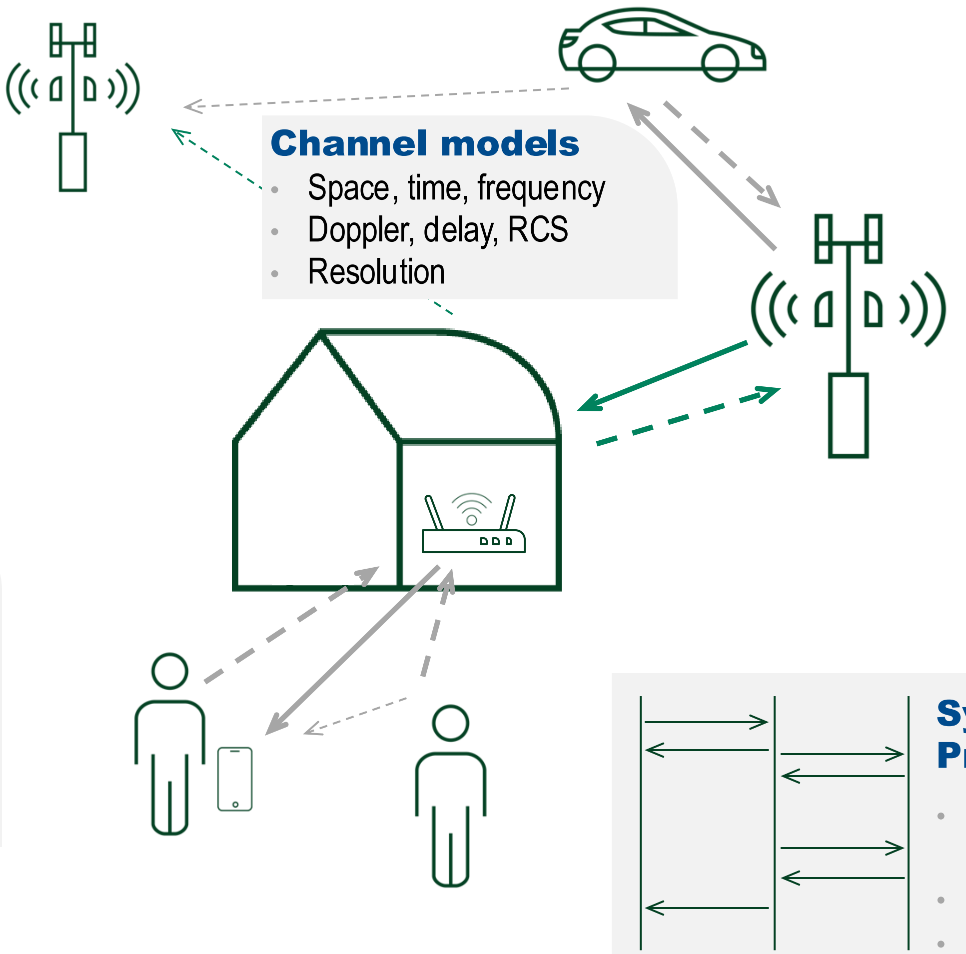
Integrated Sensing & Communication Research

Key applications
- Traffic control
- Man-machine/XR
- Vital signs
- Network twinning

Integration
- System level
- Common RF
- Common waveform

Self-interference canceller
- **Bandwidth**
- **Frequency**
- **mMIMO**
- Dynamic environments
- Processing & delay
- Circuit overhead





Channel models
- Space, time, frequency
- Doppler, delay, RCS
- Resolution

Sensing performance
Presence
Motion
Direction
Type
Accuracy
Latency

Communications performance
Throughput
Latency

System & Protocol design
- Data fusion
- Synchronization
- Cross-node scheduling
- Cross-link interference

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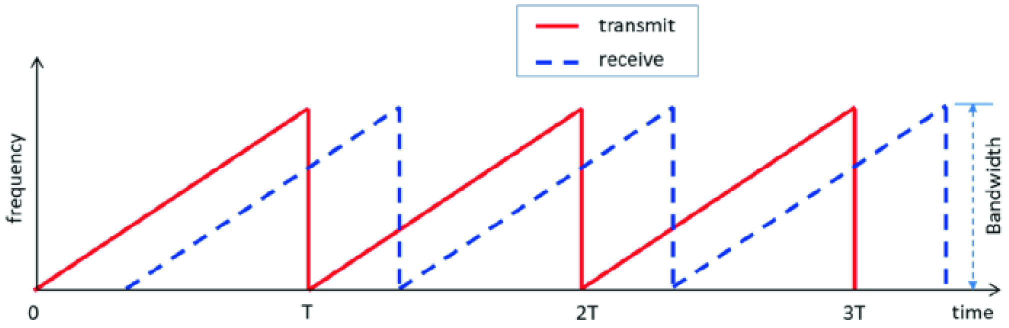
Sensing Waveform Research

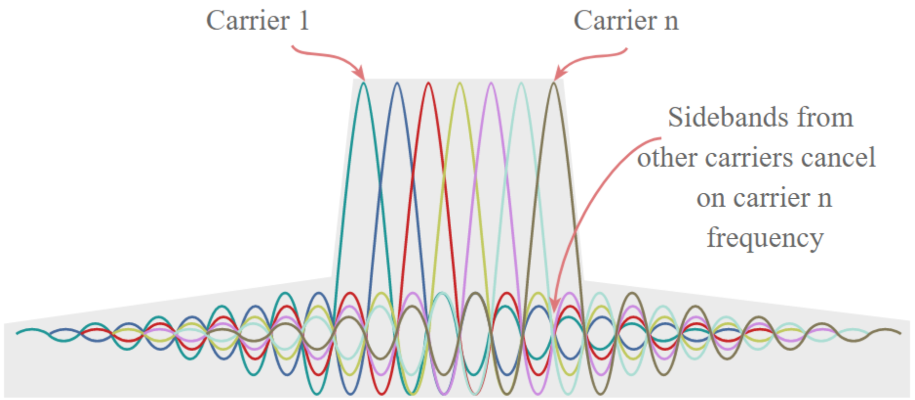
What

➢ The signal processing of radar communication integration includes integrated waveform design, joint signal transmission, and joint signal reception. The goal is to find a suitable signal waveform to complete the functions of information transmission and target detection at the same time. The NI platform acquires measured data for signal processing, model training, and inference.

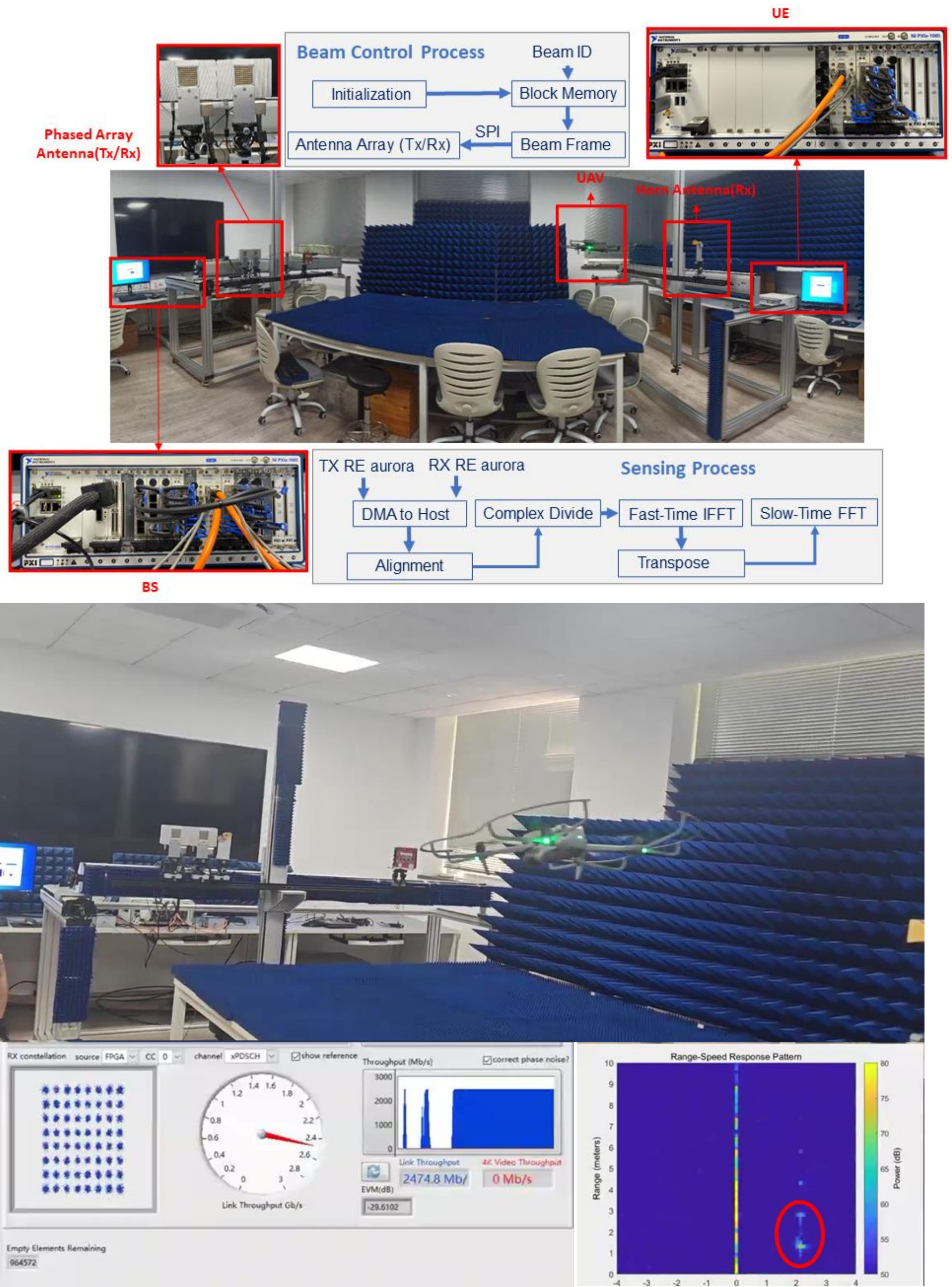
Why choose NI SDR?

- Open software-defined radio platform with support for custom waveforms
- Frequency band coverage from sub-6G to THz
- Provides a wide range of communication protocols (IP, LTE, WLAN, and 5G NR) for easy modification and redefinition.
- Support continuous collection without losing points





Above: Radar(FMCW)
Below: Communications (OFDM)

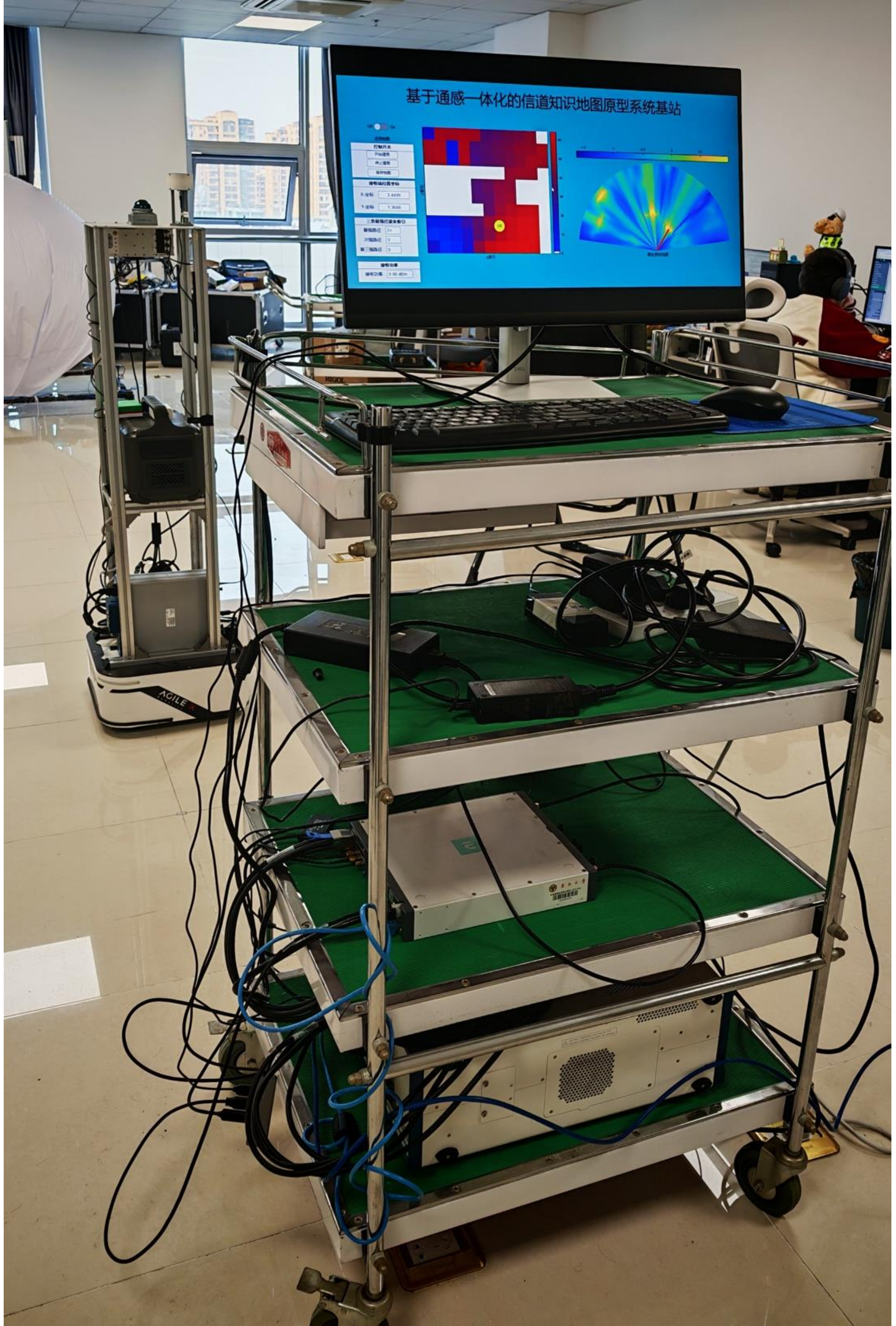


ISAC Prototyping: Zhejiang University

Built an ISAC real-time UAV tracking system using NI's mmWave Transceiver System.

- Uses OFDM communications signals to sense position and velocity
- Unique algorithms are used to extract accurate delay and doppler information from OFDM signals scattered by the target
- The system creates a comprehensive distance-Doppler 2D image of a target by combining Doppler analysis

Next Steps: Based on this system, we will design and validate more efficient integrated sensing and communication algorithms for mmWave systems to achieve optimal system performance.



ISAC Prototyping: SEU

Created an ISAC system using NI SDRs to estimate parameters based on echo signals like target distance, velocity, angle, and radar cross section.

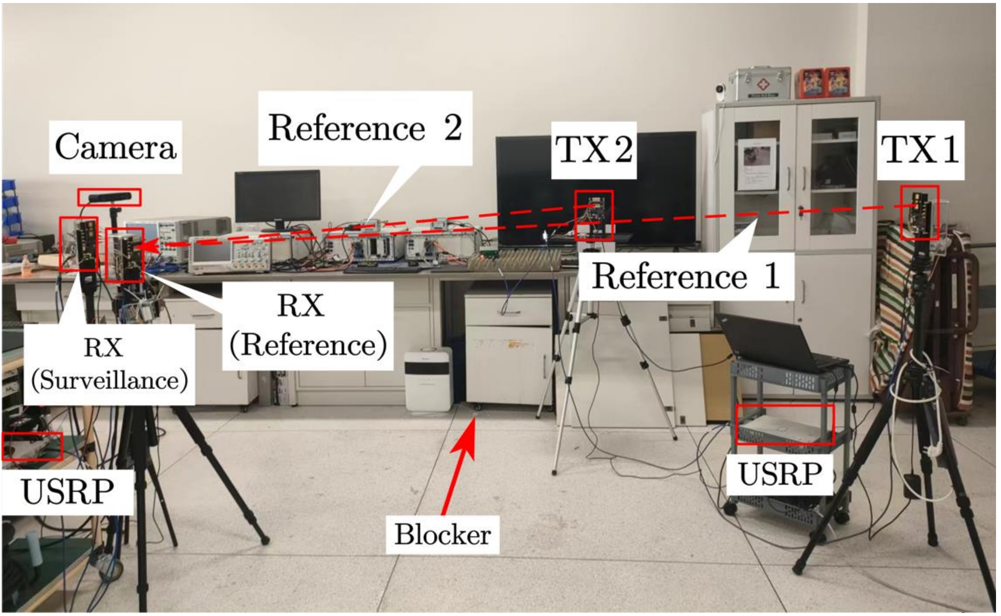
This testbed has been used to study channel knowledge maps (CKMs) and more effective approaches for localization and environment sensing data.

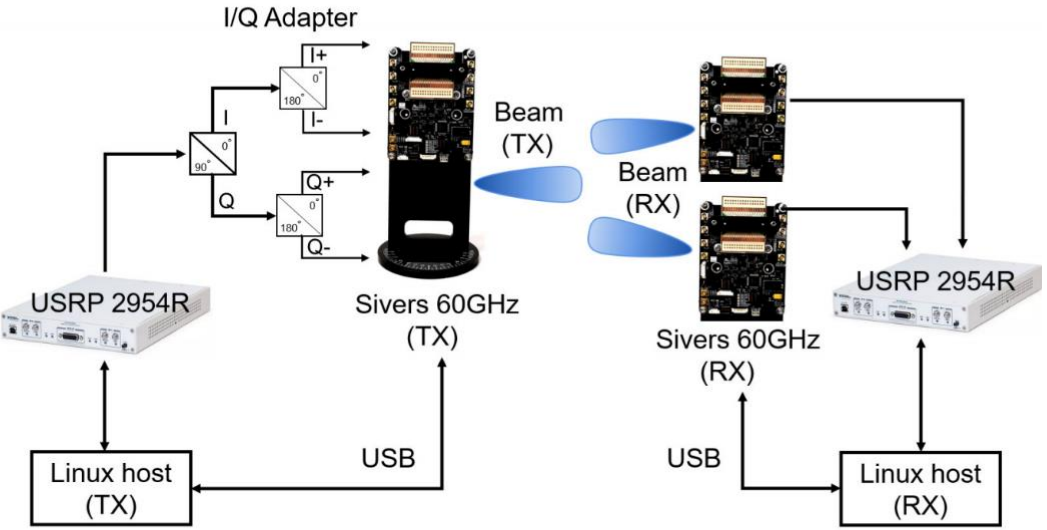
Next Steps: Build more types of CKMs and implement intelligent environment-aware wireless communication based on artificial intelligence (AI) now that this experient has shown the CKM can effectively handle environmental changes

Learn more:

https://arxiv.org/abs/2408.06164

ISAC Prototyping: SUST





Developed an ISAC testbed based on NI USRPs and custom mmWave phased arrays.

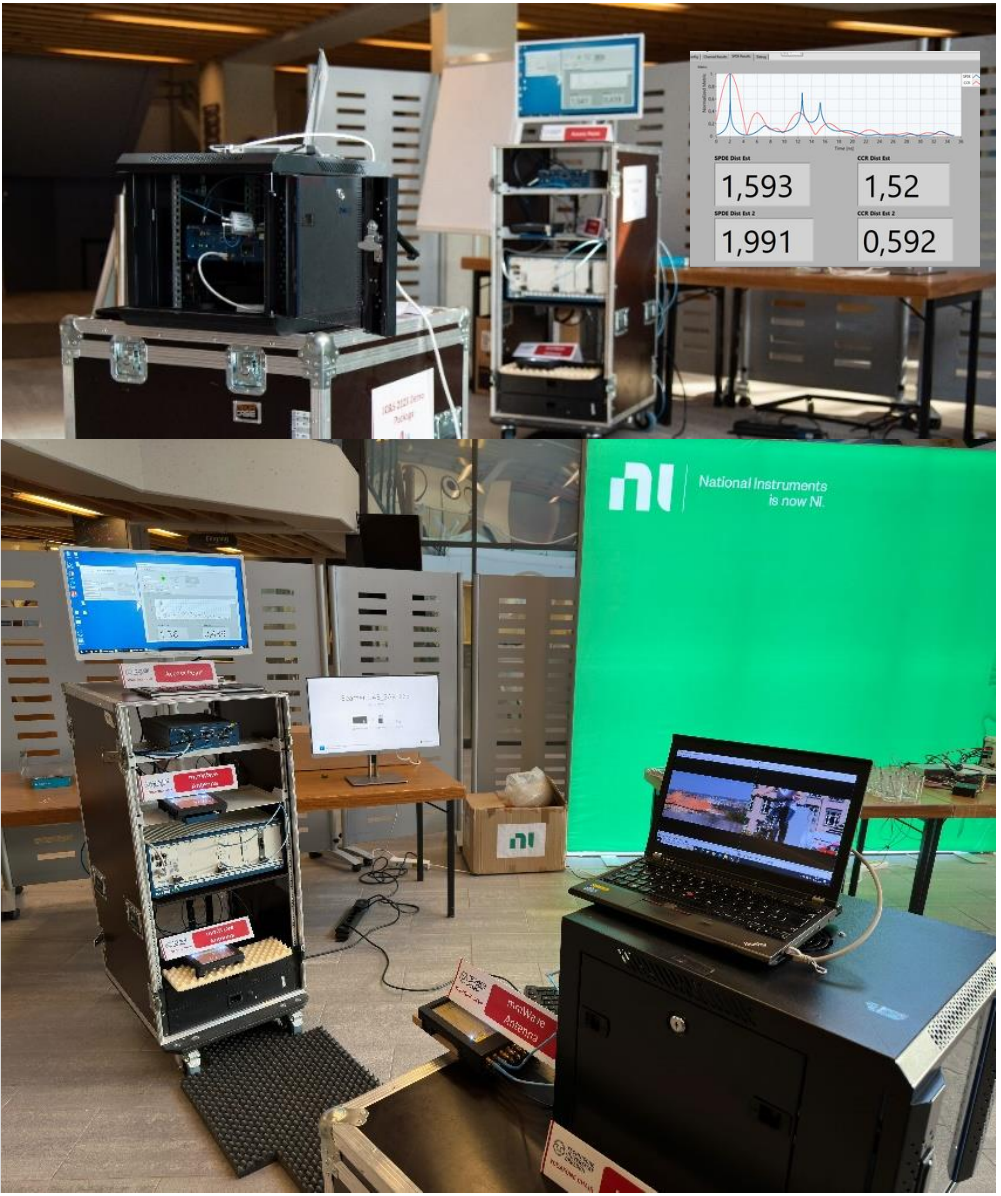
By comparing the received signals from the line-of-sight path and the non-line-of-sight path scattering off the sensing target, the bistatic Doppler frequency or bistatic range can be estimated.

Next Steps: In the future, SUST will investigate more scenarios and algorithms for sense-assisted communication, including but not limited to motion recognition, dynamic channel knowledge maps construction and more.

Learn more:

http://lasso.eee.sustech.edu.cn/mmalert/

JCAS Prototyping: TU Dresden



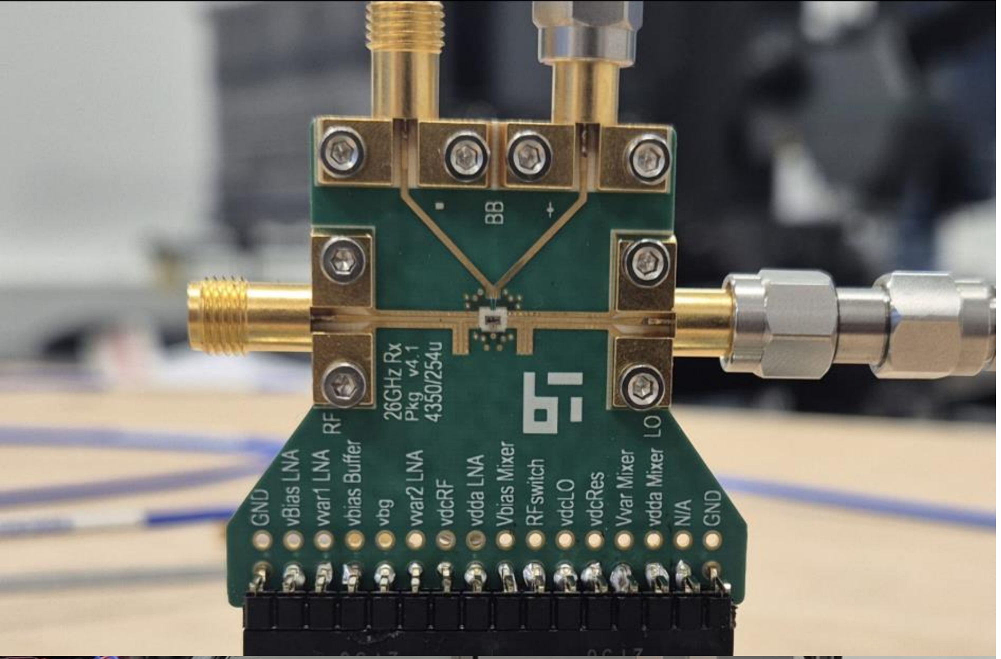
Demonstrated an algorithm that achieves high-resolution and accurate time delay estimation for monostatic ranging in an NI SDR-based testbed. It combines frequency resources distributed across the available frequency band, addressing the challenges posed by limited bandwidth.

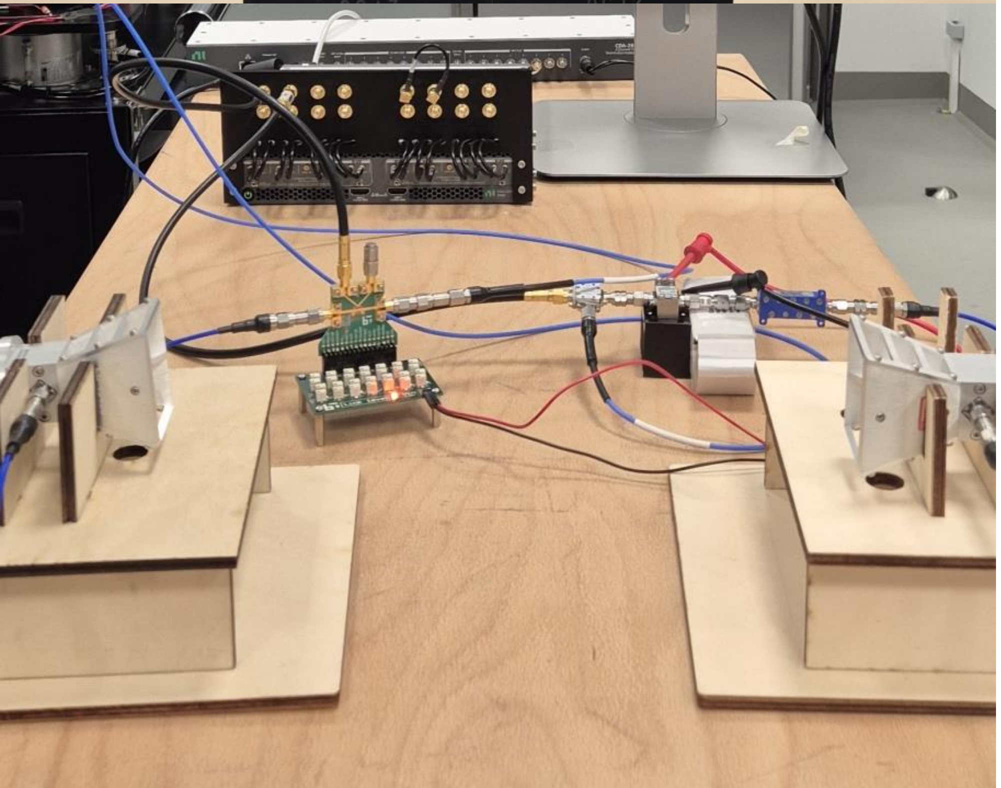
Next Steps: With a MIMO setup, angular information can also be extracted from the received signals. This addition enables precise user positioning, potentially enhancing data communication. By analyzing the echoes, the surrounding environment can be modeled for advanced sensing and environmental awareness.

“Using a software-defined radio setup, we have demonstrated the feasibility of extracting ranging information from signals designed initially for data communication in a real-world scenario.”

Zhongju Li | Vodafone Chair, TU Dresden, Dresden, Germany

JCAS Prototyping: BI





Developed an open-source software library that integrates the NI Ettus USRP X440 with the HermesPy signal processing layer.

The USRP X440 is used to generate and receive RF signals. HermesPy software is used to measure KPIs like BER, throughput, radar-range profiles, and receiver operating characteristics.

Next Steps: Future systems will support MIMO and multi- device applications with 2 GHz bandwidth. Moreover, more automated measurements will be implemented so that KPIs can be verified in a reproducible manner.

"Using our software and hardware stack, I can test my own joint communication and sensing (JCAS) RF front end in mmWave JCAS scenarios using custom waveforms with impressive signal bandwidths. This allows me to predict better performance in real-world applications"

Sandra George | RF Researcher, Barkhausen Institut

Reconfigurable Intelligent Surfaces

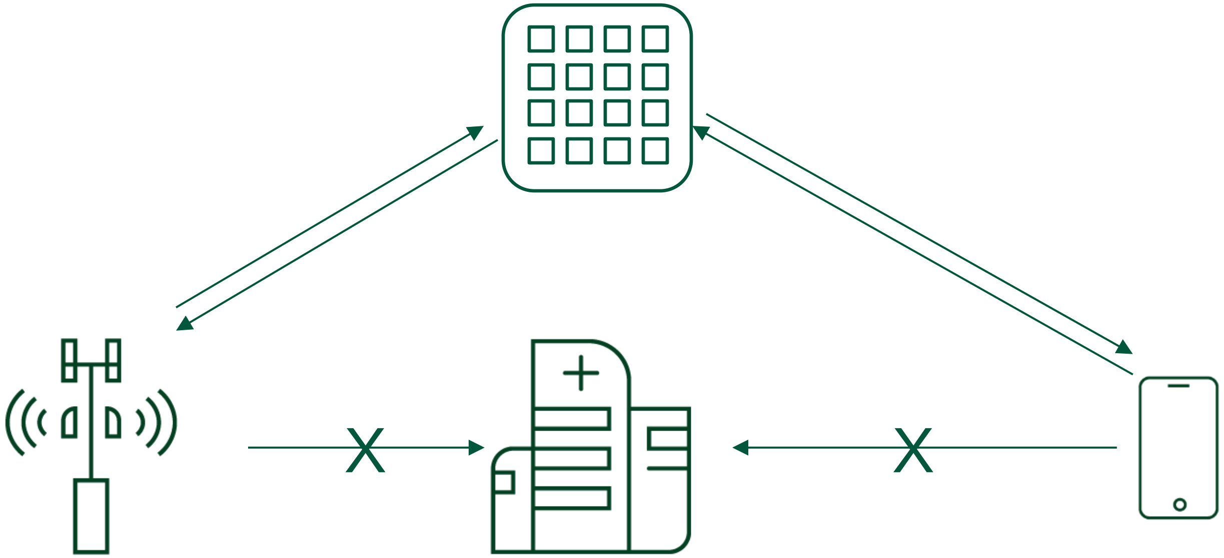
(RIS)

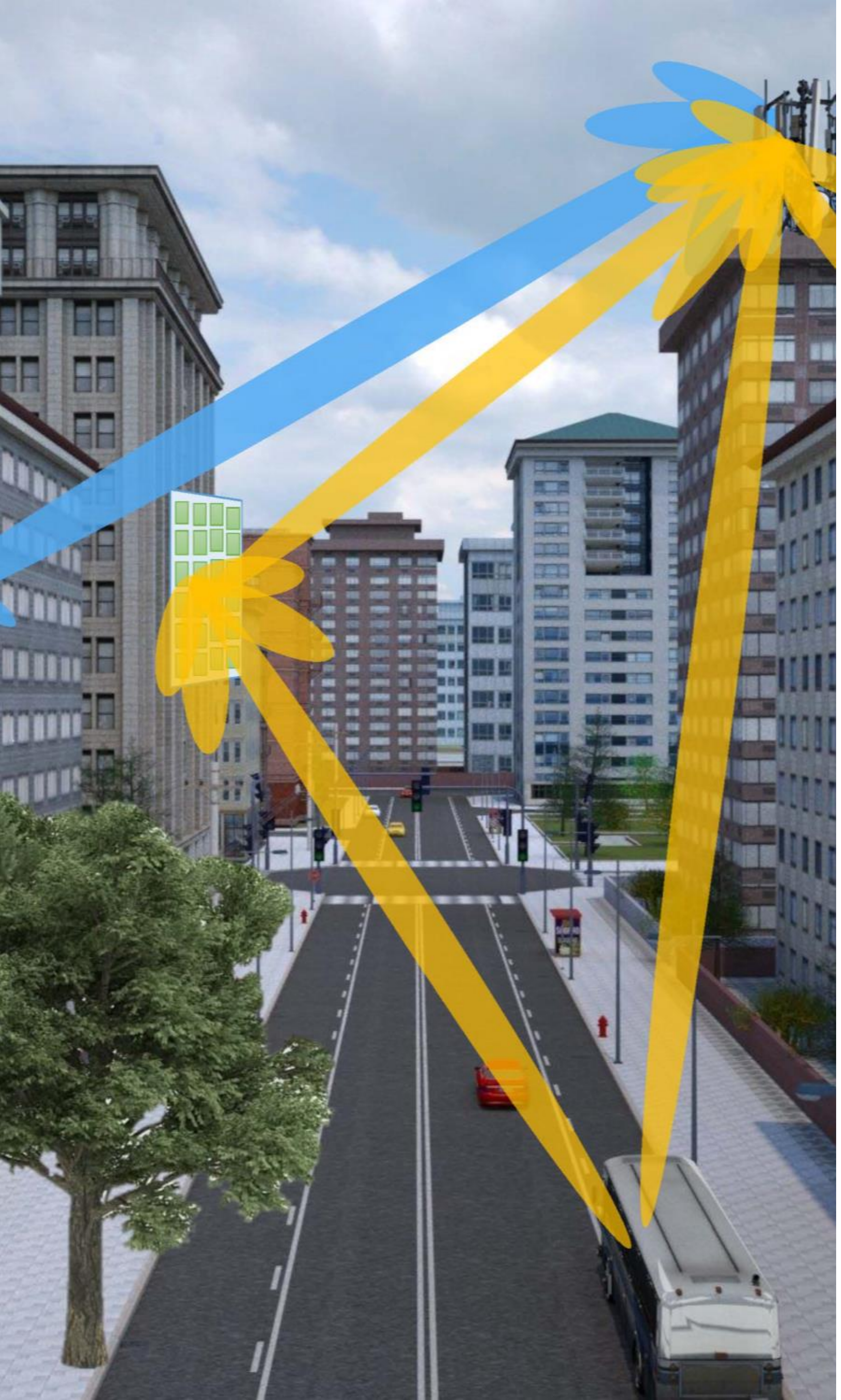
RIS Introduction

In the evolution of 6G, the prospect of using reconfigurable intelligent surfaces (RIS) to assist wireless communication systems has received a lot of attention from academia and industry. The main principle is to realize a controllable electromagnetic field through intelligent control.

A RIS can control any one or combination of the following:

- Amplitude
- Phase
- Polarization
- Frequency





RIS Applications

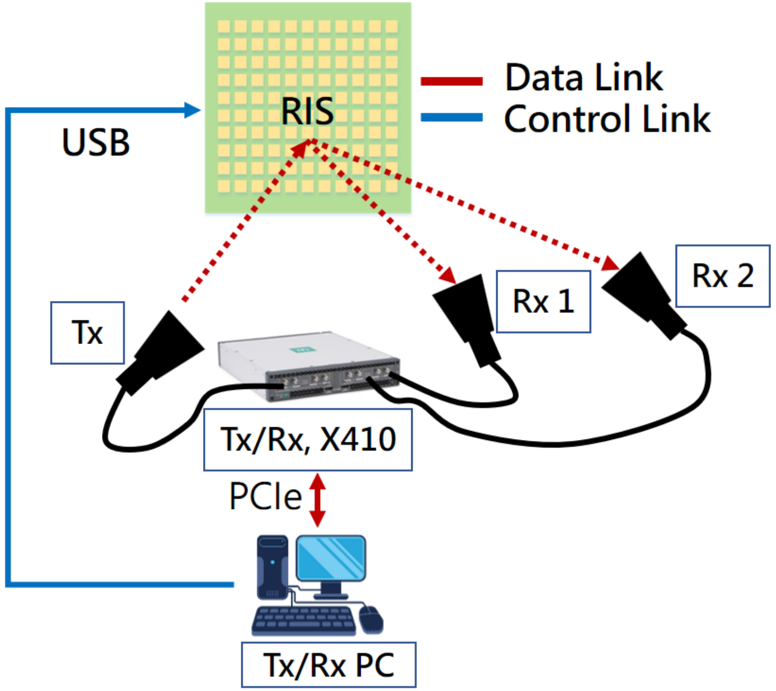
Wireless relay design: By using the unconventional characteristics of RIS metamaterials, the incident electromagnetic wave can be controlled in any phase in real time, so as to intelligently reconstruct the wireless propagation environment between transceivers and effectively improve the performance of the wireless transmission system.

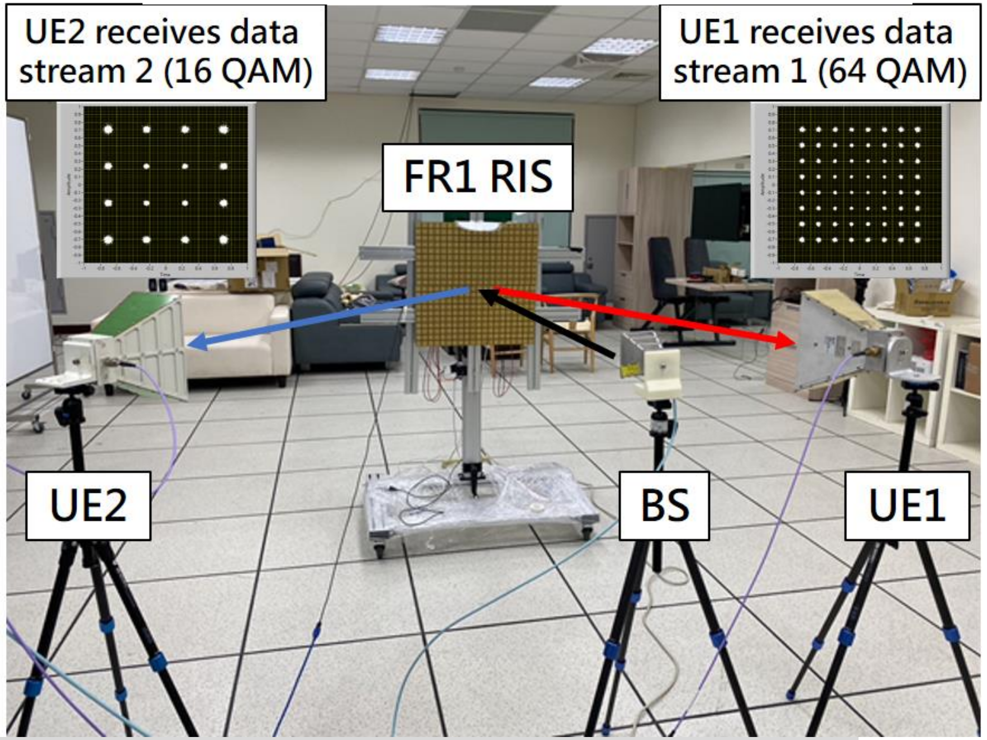
Channel coverage enhancements

Reduce base station power consumption

Beamforming

Link optimization





RIS Prototyping: NCCU

Developed an FR1 1600 element RIS-assisted dual-user OFDAM communications platform based on the USRP X410.

USRP X410s employs OFDMA data streams for two UEs using 64-QAM and 16-QAM modulation.

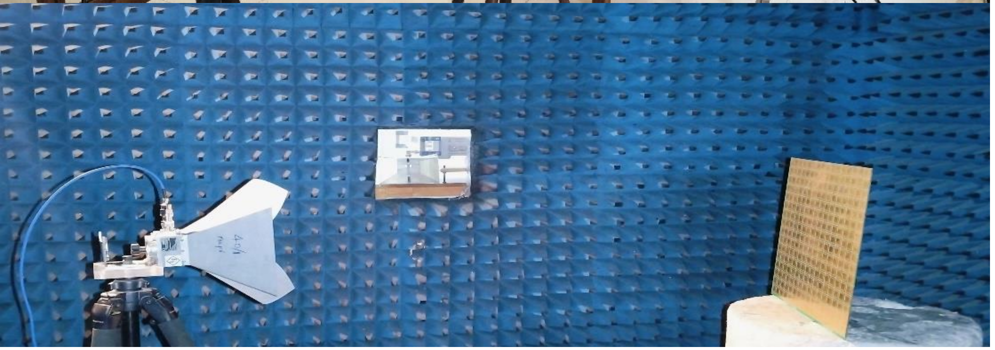
NCCU developed an algorithm for RIS-assisted beamforming that adjust the beam gain based on UE locations.

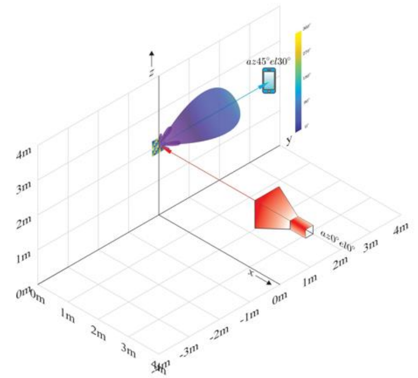
Next Steps: NCCU will focus on integrating a mmWave communication platform with a 4,096-element low-power RIS. Specifically, they will develop RIS beam-tracking techniques for multiuser communication applications.

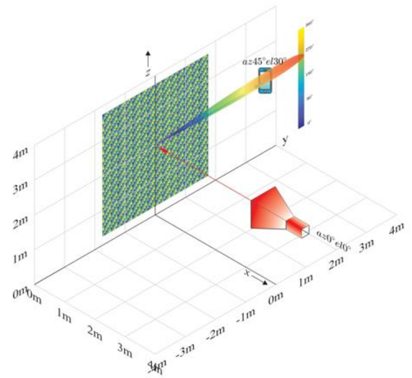
Learn More:

https://sites.google.com/a/ee.ccu.edu.tw/wireless-communication-lab/

RIS Prototyping: IIT Roorkee







Built a 256-element 1-bit RIS. Elements provide 0° and 180° phase shifts corresponding to “ON” and “OFF” states.

NI USRPs are used for RF signal processing

Next Steps: Enhance RIS efficiency by incorporating user location tracking. Future work will focus on designing a controller capable of tracking user positions.

“Reconfigurable Intelligent Surfaces (RIS) improve wireless communication by dynamically controlling electromagnetic waves, enhancing coverage, energy efficiency, spectral efficiency, and enabling robust links for future 5G and 6G networks.”

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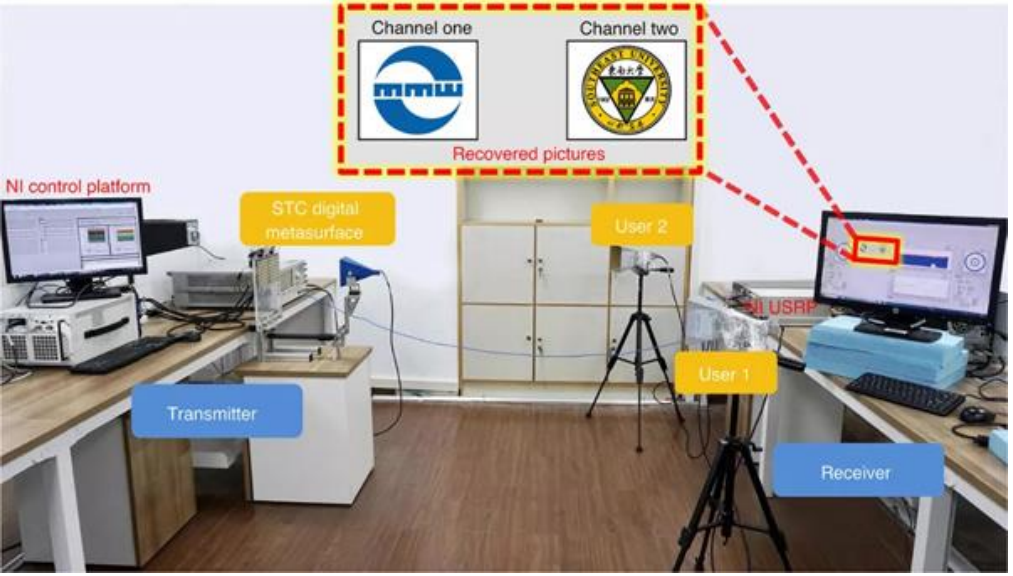
RIS Prototyping: Southeast University



Successfully built an RIS wireless communication system that supports QPSK, 8PSK (6Mbps), and 16QAM (20Mbps) using the NI SDR platform.

RF Signal Processing: NI USRP

Real-time control of RIS: NI FPGAs

At present, the research team at Southeast University has upgraded the research to the high-order modulation and mmWave band of 256 QAM. He has also successfully published in the prestigious journal National Science Review.

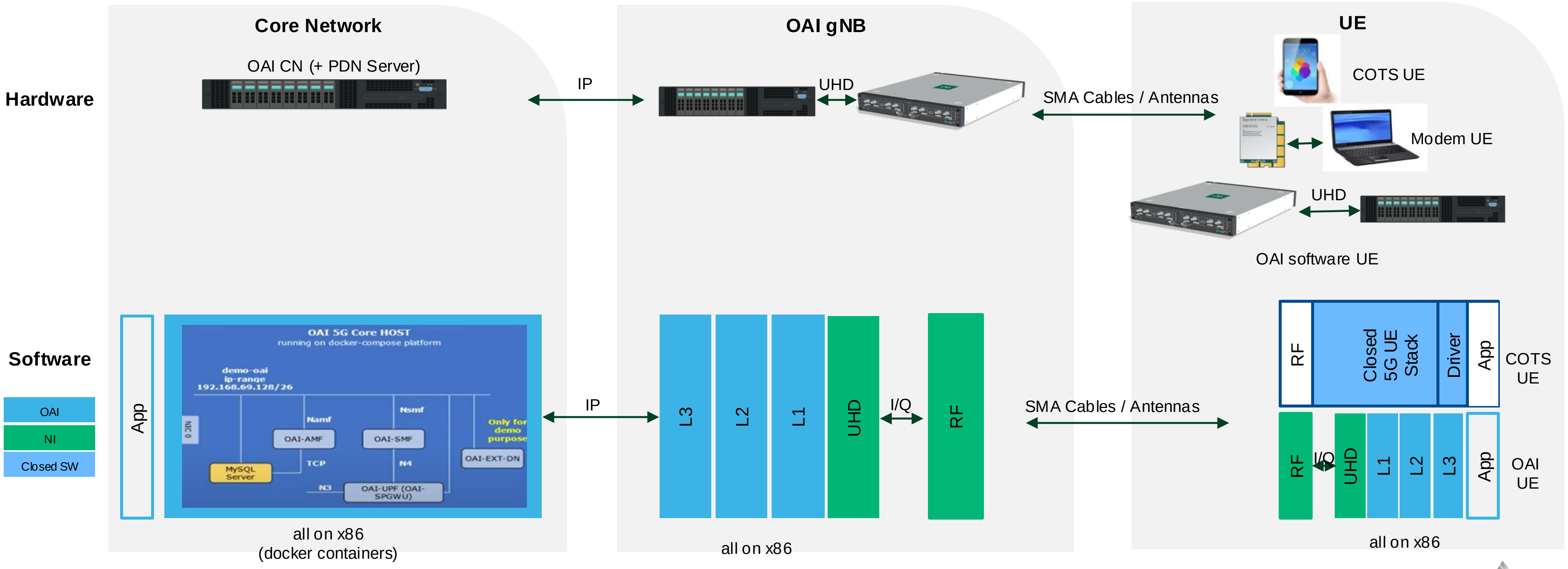
https://www.nature.com/articles/s41928-021-00554-4

Research results: "A wireless communication scheme based on space- and frequency-division multiplexing using digital meta surfaces"

OAI 5G End-to-end Reference Architecture

OAI Reference Architecture Hardware and Software

- Rich, open-source reference code for core network, gNB, and UE available based on OAI 5G-NR protocol stack
- Open architecture for real-time 5G end-to-end network to enable research and demonstration of 6G candidate technologies
- NI-validated system configuration including third-party components to ensure stable performance
- Detailed documentation, accelerating the set-up time for 5G end-to-end communication systems



Embedded, Trustworthy AI

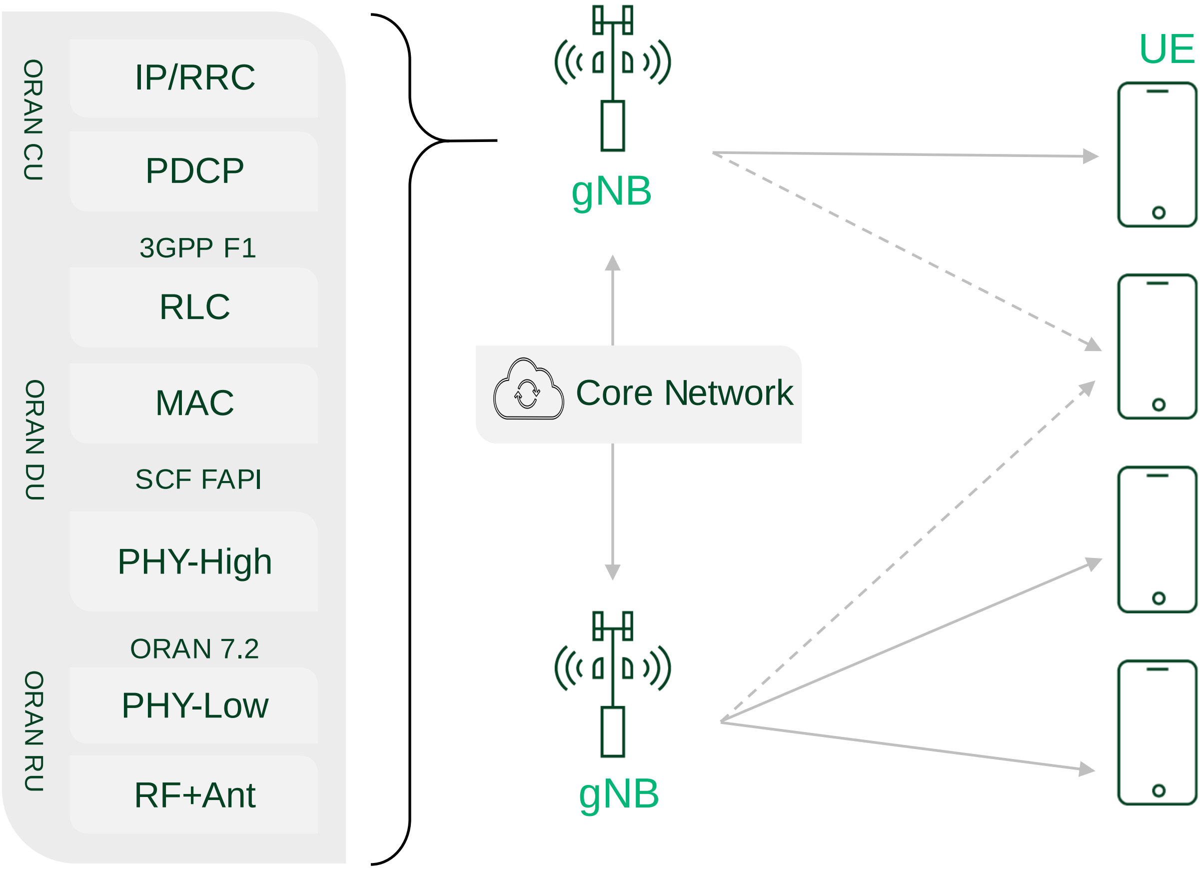
Application Areas of AI/ML in RF Wireless

Wireless / Mobile Communications

- **Network Level:** Data flow management, network parameter optimization
- **MAC:** Time/Frequency/Spatial resource scheduling (spectrum sharing), (mmWave) Beam acquisition / selection & tracking
- **PHY:** Channel estimation & equalization, symbol detection, channel en/decoding
- **RF:** Spectrum sensing, Digital pre-distortion

Other Applications

- RF Fingerprinting / Security
- …



Three Challenges of AI/ML in Wireless Comms

No widely re-usable reference data sets available

No common tool sets, very heterogeneous data & metadata formats, missing or incomplete scenario descriptions

Often very manual process to generate data sets with comprehensive metadata (scenario description)

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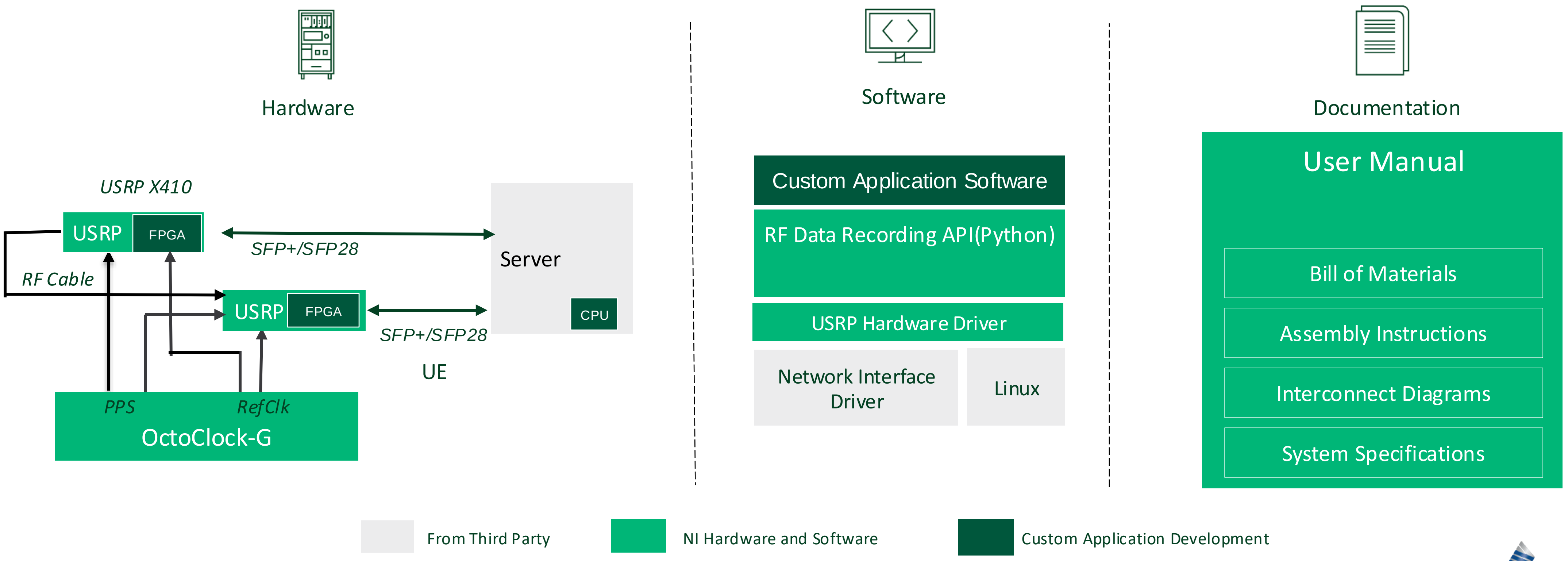
AI/ML Reference Architecture with NI USRP

Bridging the gap between theoretical and practical issues around 5G system deployment and implementation for enabling engineers and researchers to rapidly develop and test novel use-cases



NI RF Data Recording API Application Note

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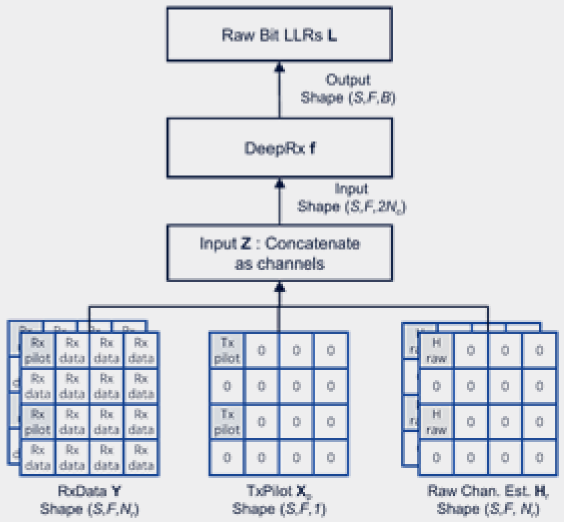
Neural Receiver Example

Used publicly available neural receiver model for OFDM-based wireless communication systems (DeepRx)

Example to study new validation and testing methodologies on embedded AI in 6G wireless

Initial step: Implemented, trained and validated neural receiver model in link level simulation chain

DeepRx Neural Receiver Model



Source: Honkala et al.: "DeepRx: Fully Convolutional Deep Learning Receiver"

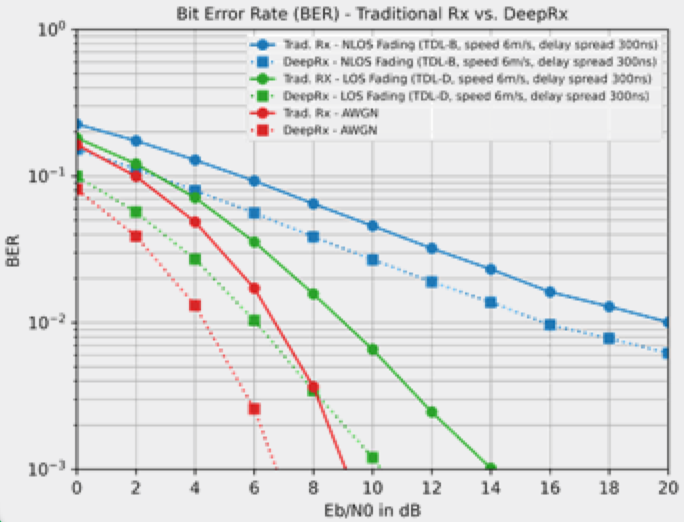
Classical Receiver

Channel Estimation → Channel Equalization → Symbol Detection / Demapping

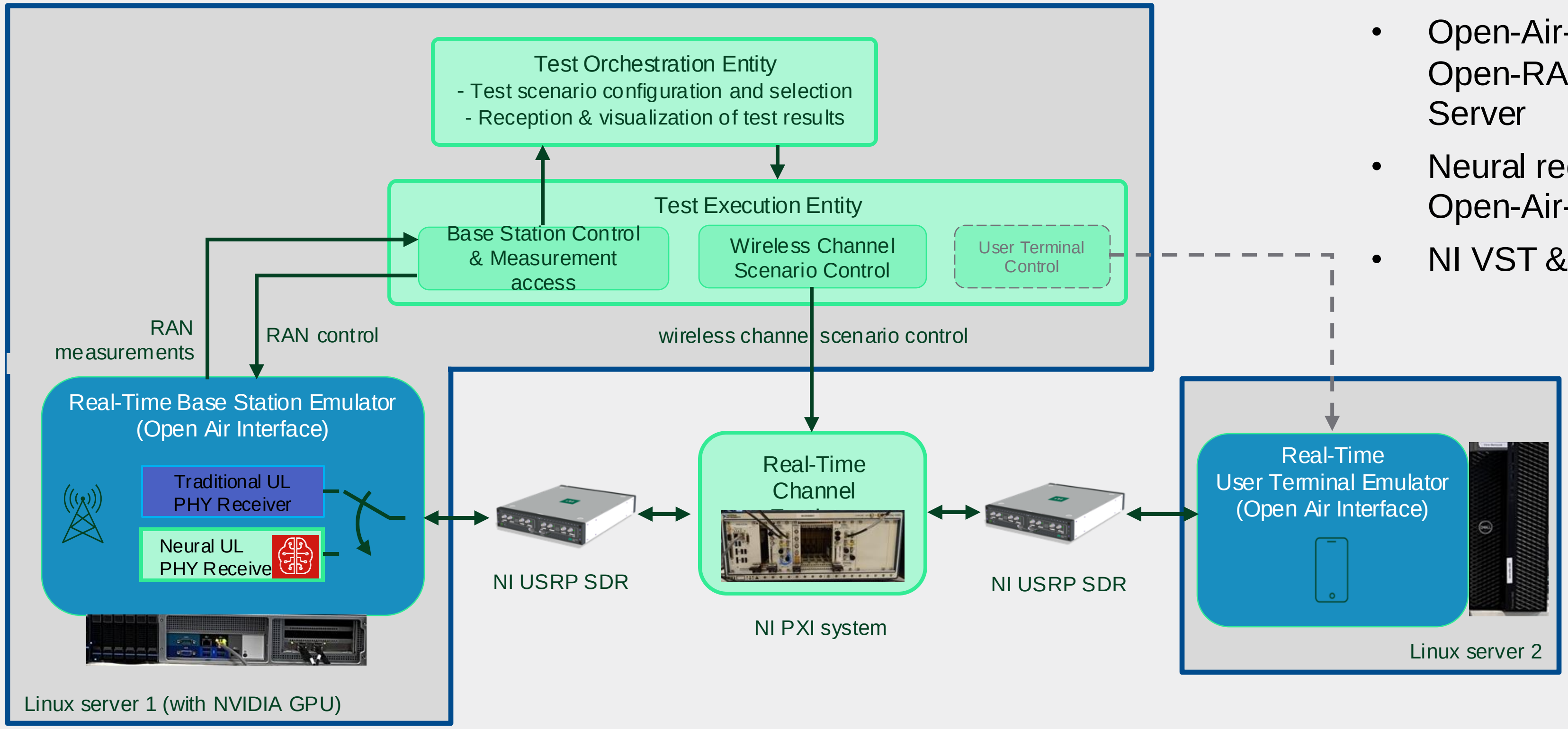
Neural receiver (DeepRx Example)

Compare & Benchmark Results

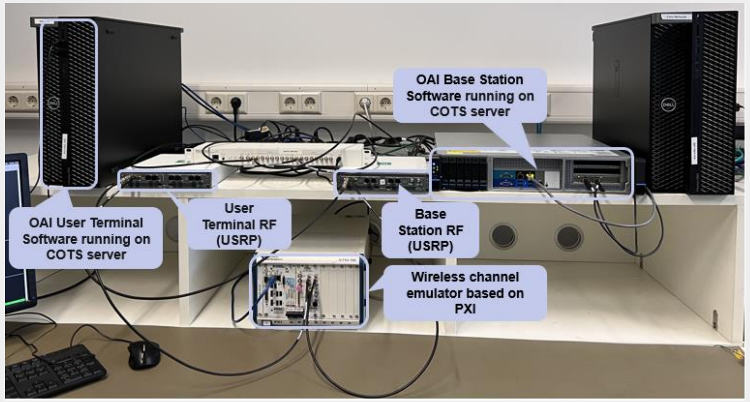
Benchmarking in Simulation Chain



Neural Receiver Real-Time Benchmarking Setup



- Open-Air-Interface as system level emulation IP using Open-RAN architecture and running on standard CPU/ Server
- Neural receiver running on Nvidia GPU and integrated into Open-Air-Interface through Tensorflow RT C-API
- NI VST & PXI based channel emulator



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Initial Neural Receiver Benchmarking Results

Validation scenario:

Single 5G NR link between 1x gNB and 1x UE

Switch between gNB uplink traditional 5G NR receiver vs neural receiver

Increase signal-to-noise ratio (SNR) for fading channel

Monitor uplink block error rate (BLER)

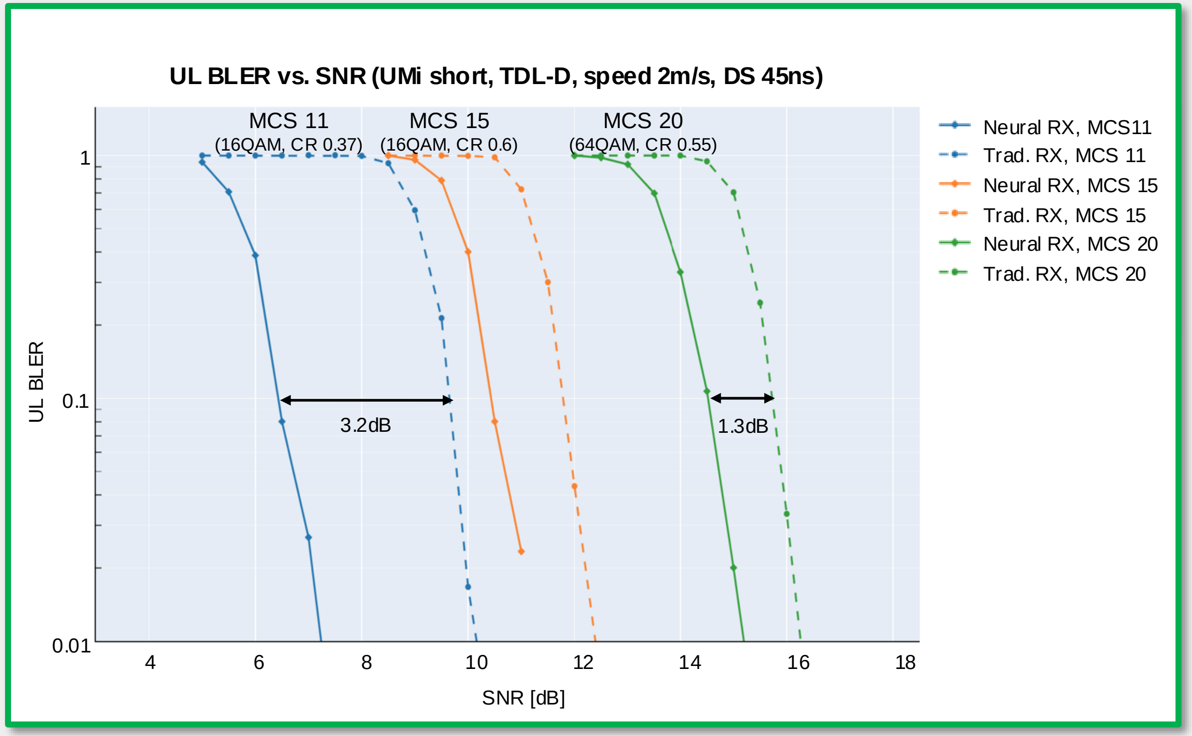
Test different Modulation & Coding schemes (MCS)

gNB and UE configuration:

Uplink / Downlink TDD

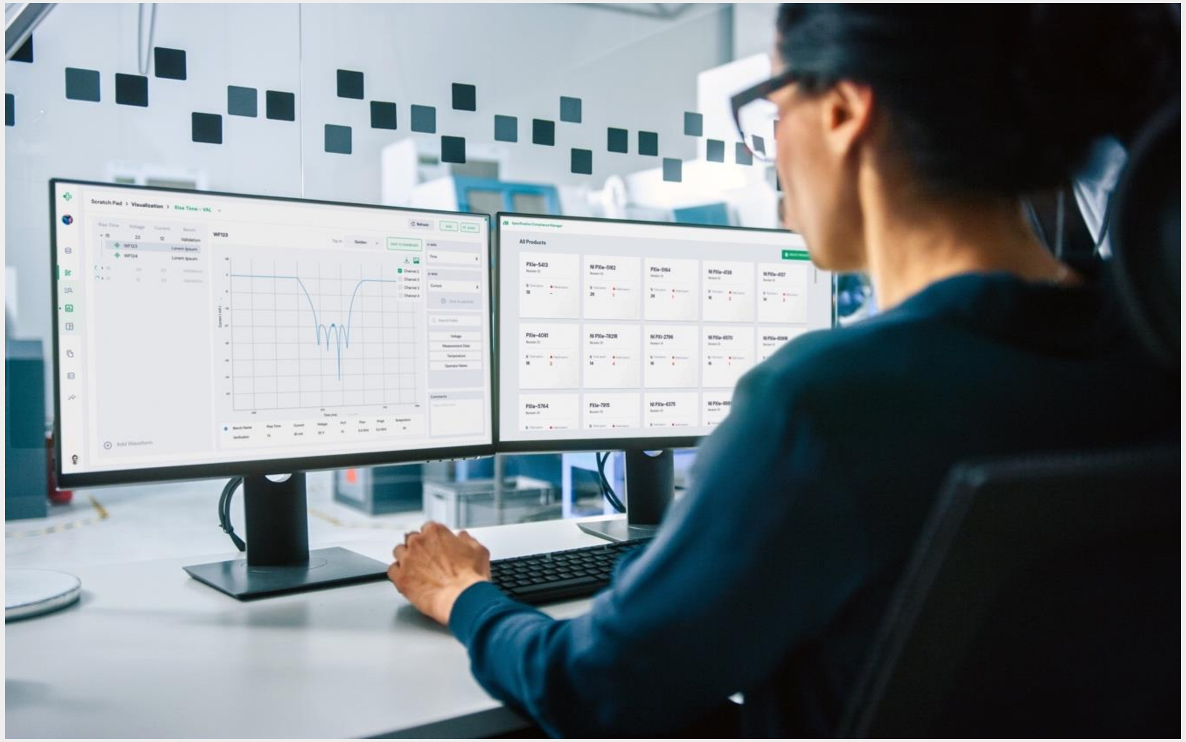
Bandwidth mode: 40 MHz / Subcarrier Spacing: 30 kHz

Used uplink bandwidth: 6 PRB = 2.16 MHz



Initial Key Learnings & Takeaways

- Due to strict timing requirements in cellular wireless communications **complexity reduction of AI models** is needed to meet timing constraints (in our case >10x)
- Low complexity AI models are **more difficult to train** for a broad variety of wireless scenarios because of reduced generalization capabilities
- Broad testing of embedded AI/ML models is important to **detect and iteratively improve for unexpected failure cases** using synchronized data recording



NI is now part of Emerson.