6G series workshop from Hexa-X-II

Radio Design and Spectrum Access Requirements and Key Enablers for 6G Evolution

Ahmad Nimr [TU Dresden]
(WP4 co-lead, with Nurul Mahmood [University of Oulu])

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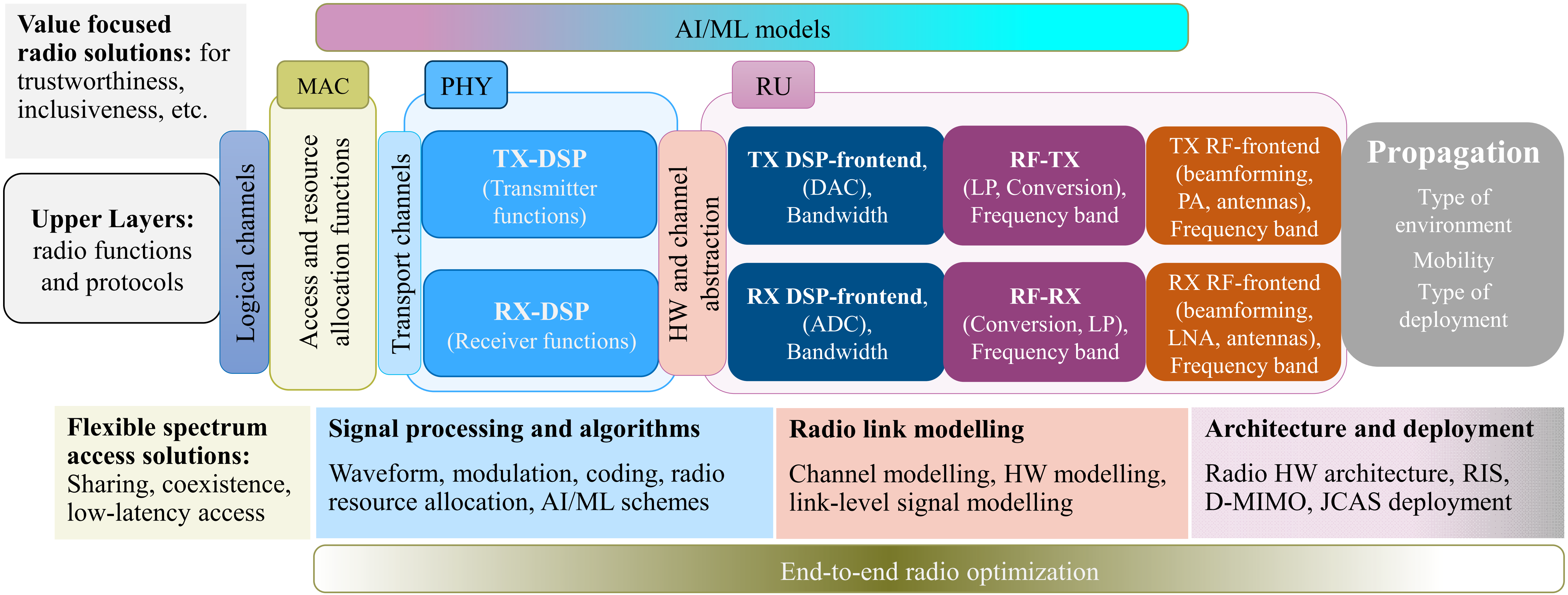
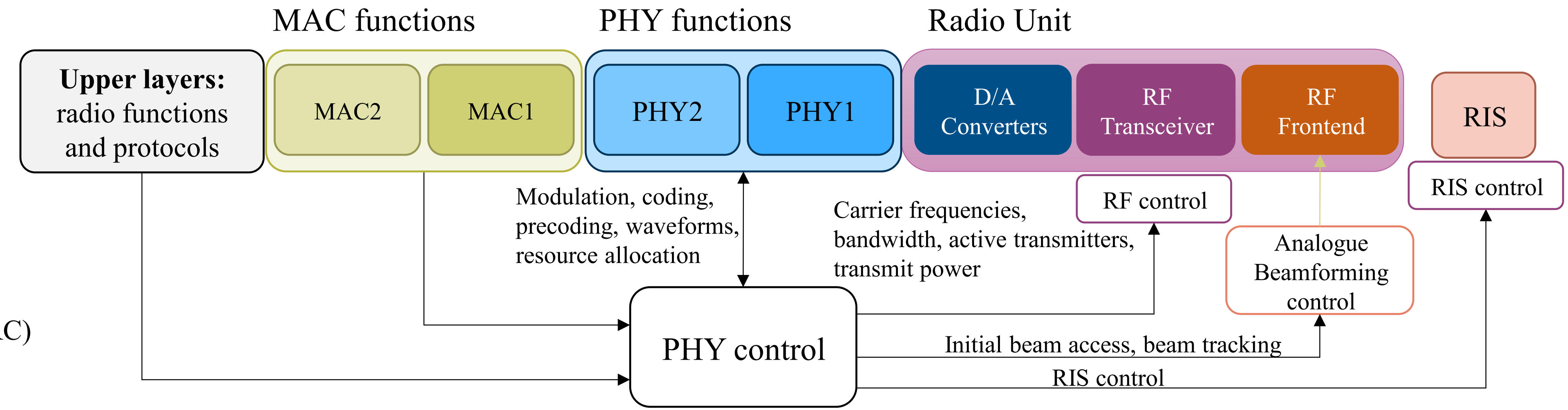
Sustainable, trustworthy and inclusive holistic radio design framework

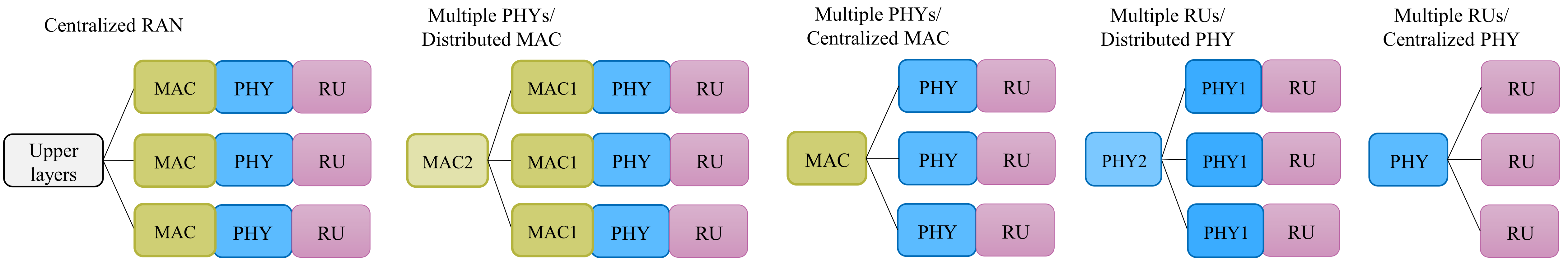
Holistic radio design considers the entire radio system as a whole, and the interdependencies between different elements.



Flexible radio architecture and deployment



Radio link control (RLC)
Packet data convergence protocol (PDCP)
Radio resource control (RRC)



Dual connectivity at PDCP

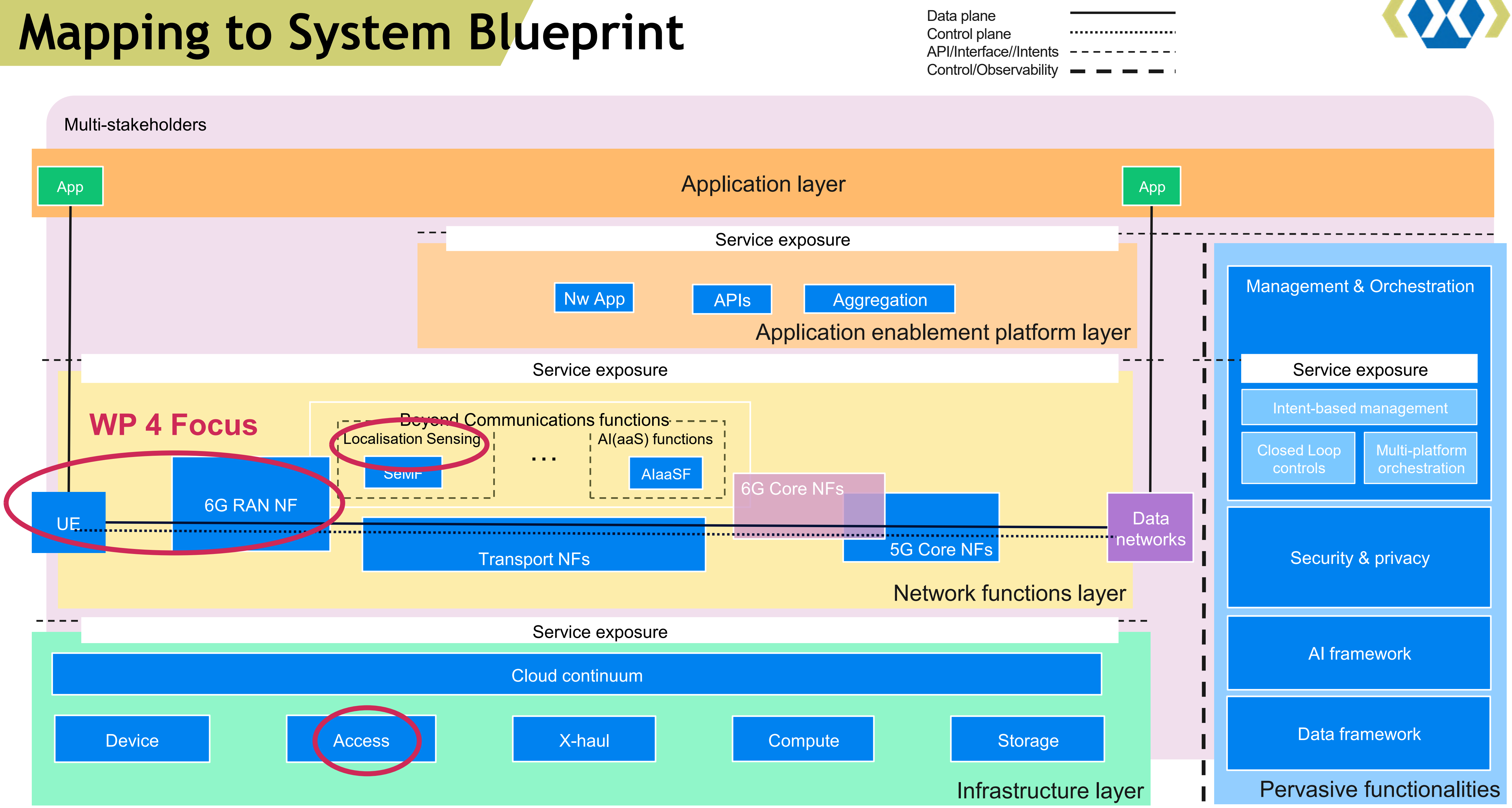
Carrier aggregation in different ranges, e.g. (FR1, FR2)

Carrier aggregation

D-MIMO, distributed PHY processing

D-MIMO, centralized PHY processing

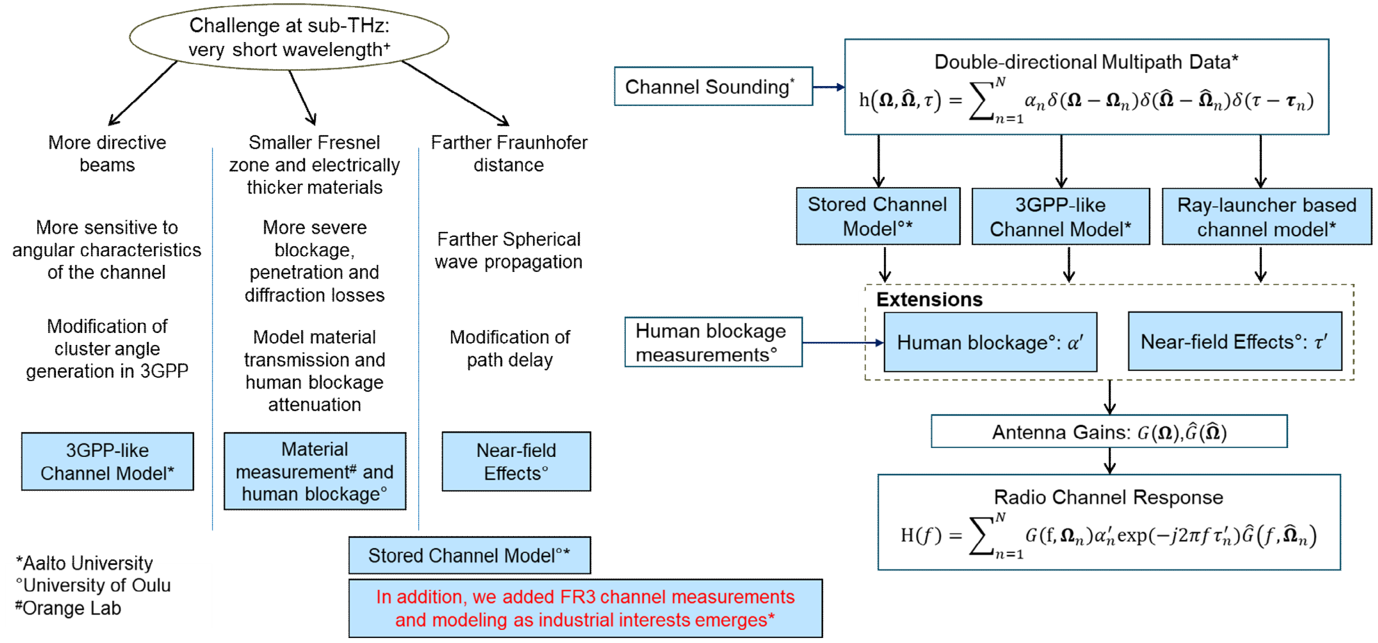
Mapping to System Blueprint



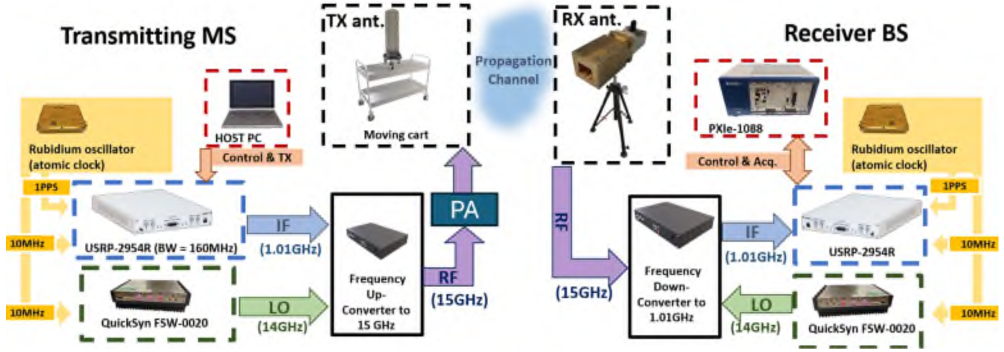
Channel Modelling

- Channel modelling at (sub)-THz frequencies
  - Impact of rough and coated surfaces on reflection coefficients from 1 GHz to 250 GHz
  - Simplified model for molecular absorption loss
  - Sub-THz dual-band channel characterization for IIoT
  - Channel model components for near-field condition
  - 3GPP-like channel model
  - Calibration of ray-launcher for radio coverage study
  - Coverage analysis at THz frequencies
- FR-3 channel sounding: dynamic wideband measurements in UMa and UMi scenarios
- JCAS channel models
- Implication of sub-THz link budget on EMF compliance

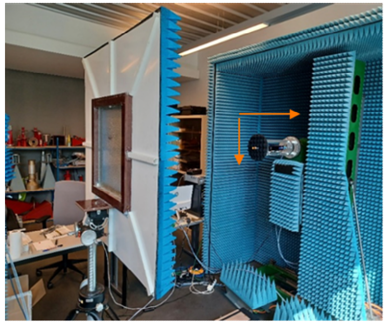
Chanel modelling methodology

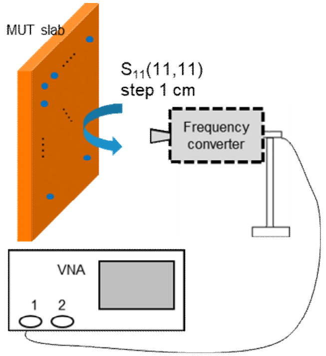


FR-3 Channel Sounding

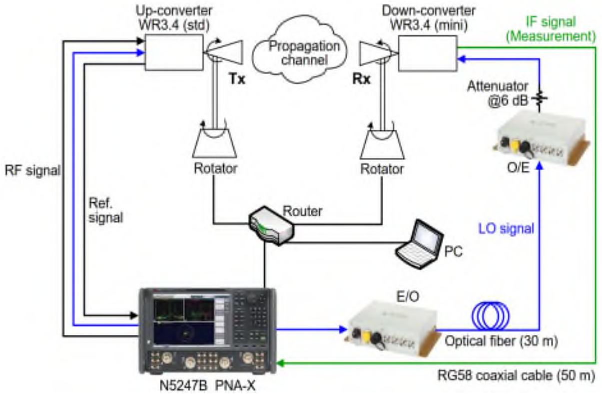


Material interaction setup





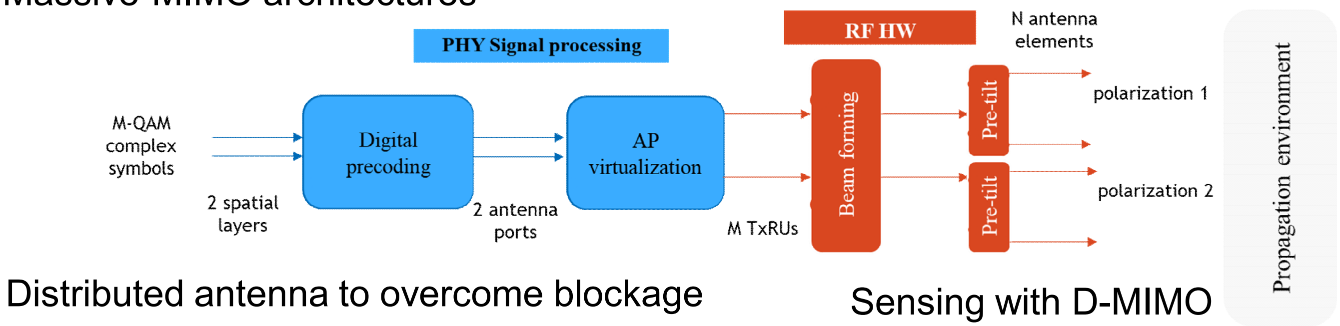
Channel sounding setup



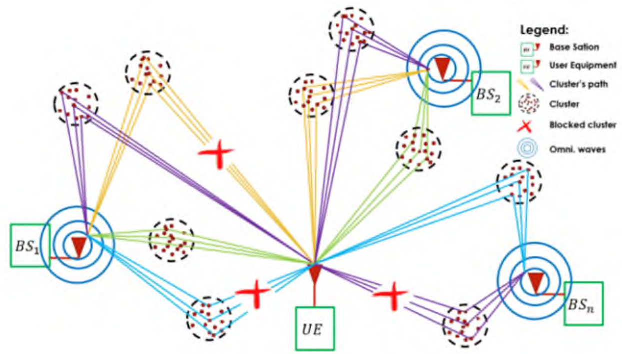
MIMO Transmission

- Massive MIMO architecture
  - Energy efficient beamforming architecture and deployment for sub-THz
  - Hybrid analogue-digital architectures
  - Digital architecture with 1-bit DAC/ADC
- MU-MIMO optimization
- D-MIMO architectures
  - D-MIMO for JCAS
  - Flexible position MIMO and D-MIMO with rotary ULAs
  - D-MIMO with analogue fronthaul
- D-MIMO transmission schemes
  - Coherent joint transmission
  - Non-coherent space-time coded transmission
  - Distributed OTA cooperative beamforming design

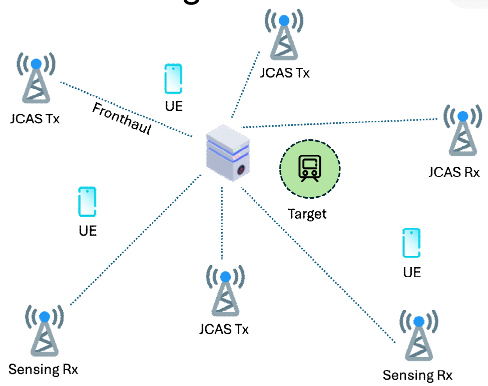
Massive-MIMO architectures



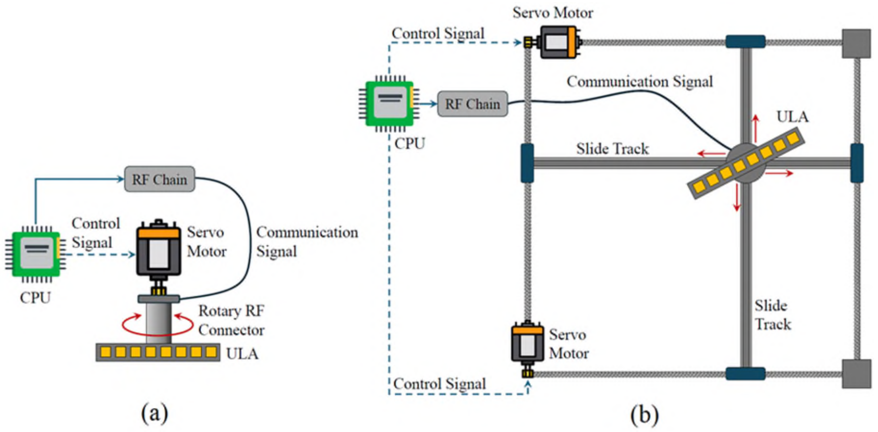
Distributed antenna to overcome blockage

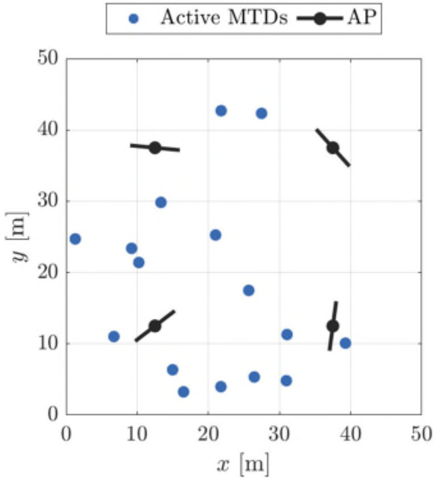


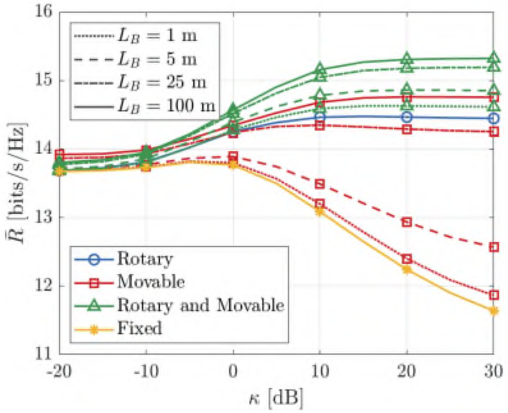
Sensing with D-MIMO

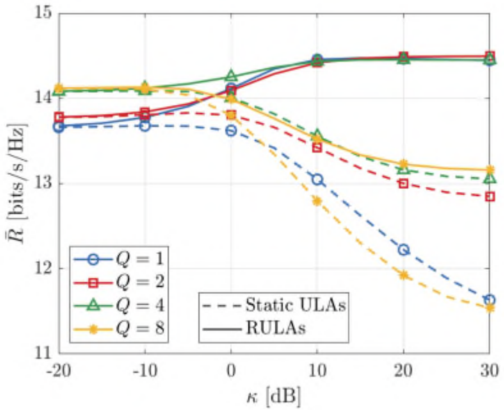


Arrays with different movement capabilities





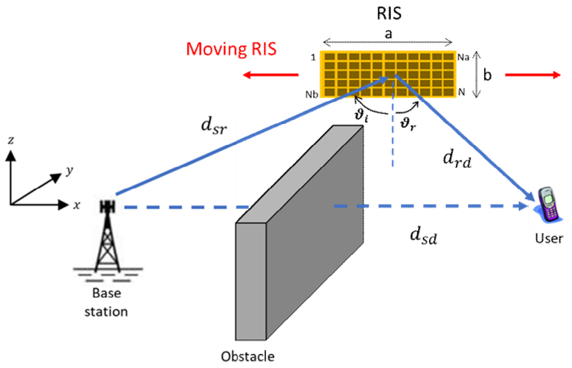


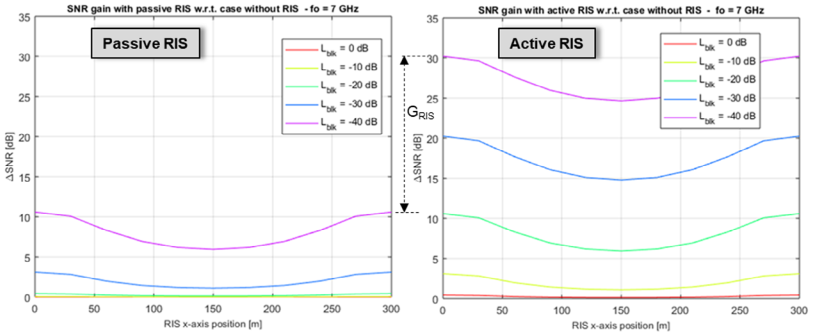


RIS-Assisted Transmission

- RIS-assisted architecture
  - D-MIMO assisted with RIS
  - RIS assisted integrated access and backhaul
- RIS optimization
  - Control procedures for non-radiative RIS
  - Reflection modulation via RIS with jointly active and passive beamforming
- Signal level analysis for RIS in a simplified scenario

RIS signal level analysis

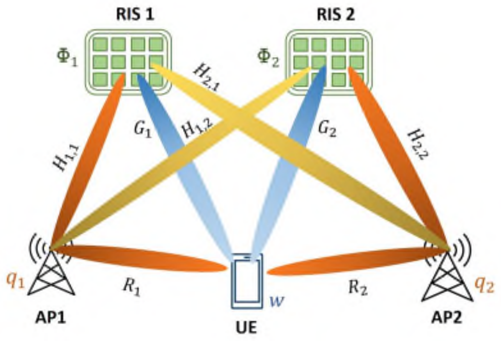


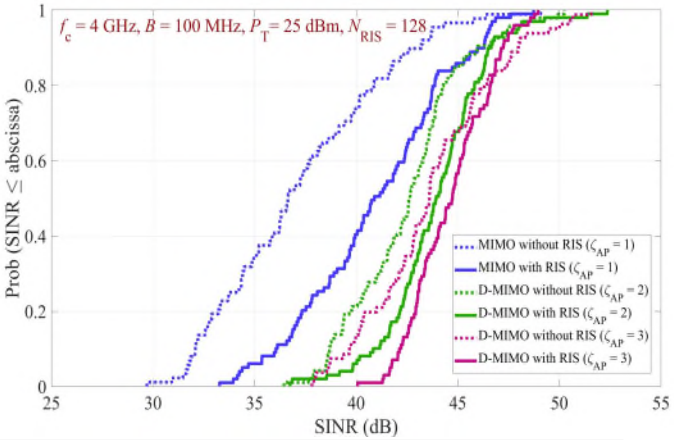


SNR gain at the receiver with respect to a system without RIS (f_0=7 GHz, RIS 16×16, G_{RIS}=20 dB)

- Optimal placement of the RIS is near to the transmitter or the receiver
- Passive RIS provides a significant coverage enhancement under high blockage
- Active RIS improve coverage with medium blockage

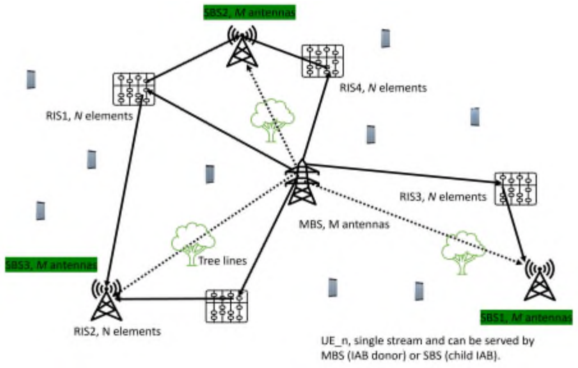
D-MIMO assisted with RIS

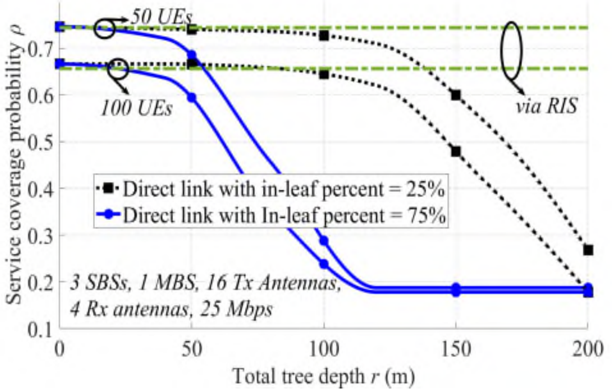




- RIS-assisted D-MIMO system with a smaller AP cluster-size and larger number of RIS elements outperforms a conventional D-MIMO system with a larger AP cluster-size

RIS assisted integrated access and backhaul



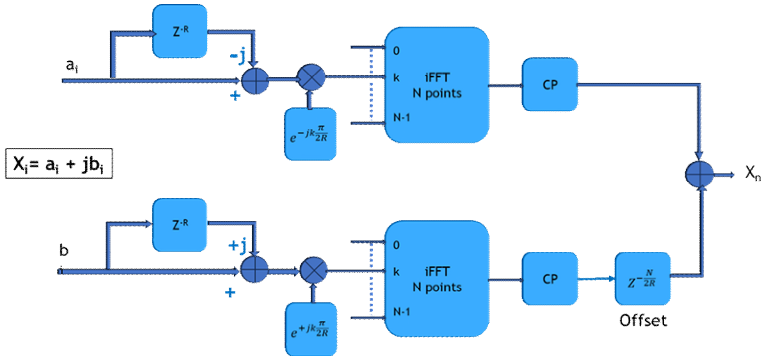


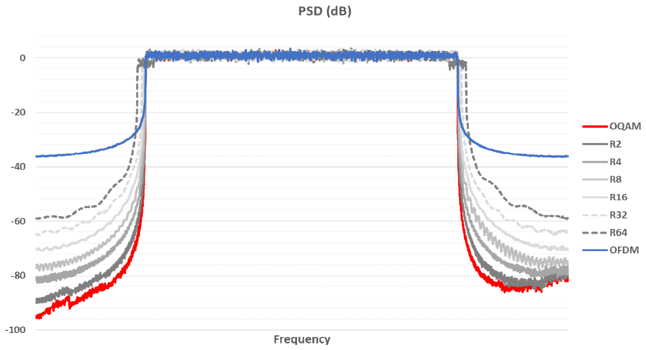
- The service coverage probability remains resilient for tree foliage when backhaul link is connected via RIS

Waveform and Modulation

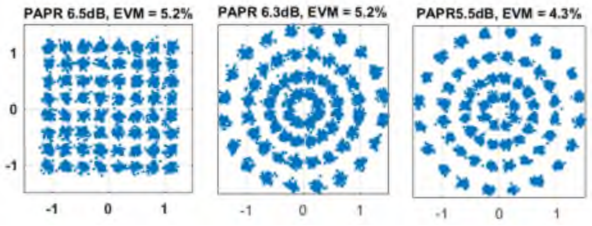
- Sub-THz waveform and constellation candidates
  - Evolution of NR numerology and waveforms towards sub-THz
  - Polar constellations
  - Hardware-friendly waveforms
  - Energy-efficiency of 1-bit quantized zero-crossing modulation
- Waveform and modulation enhancements
  - Adaptive multi-carrier modulation (AMCM)
  - New LDPC code parity matrix design

Adaptive multi-carrier modulation: control of PSD vs complexity of equalization

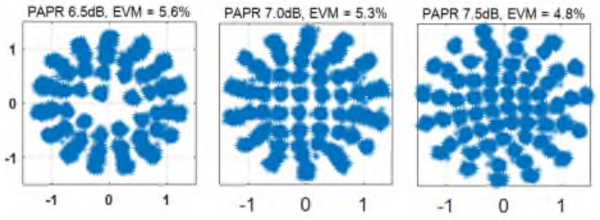




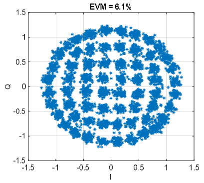
Conventional constellation

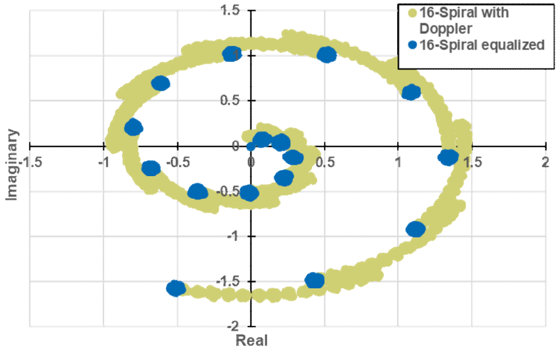


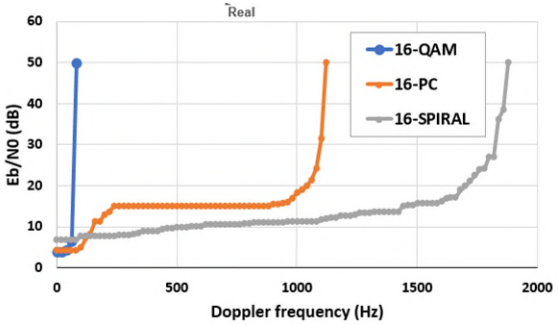
Learned constellation for various PAPR



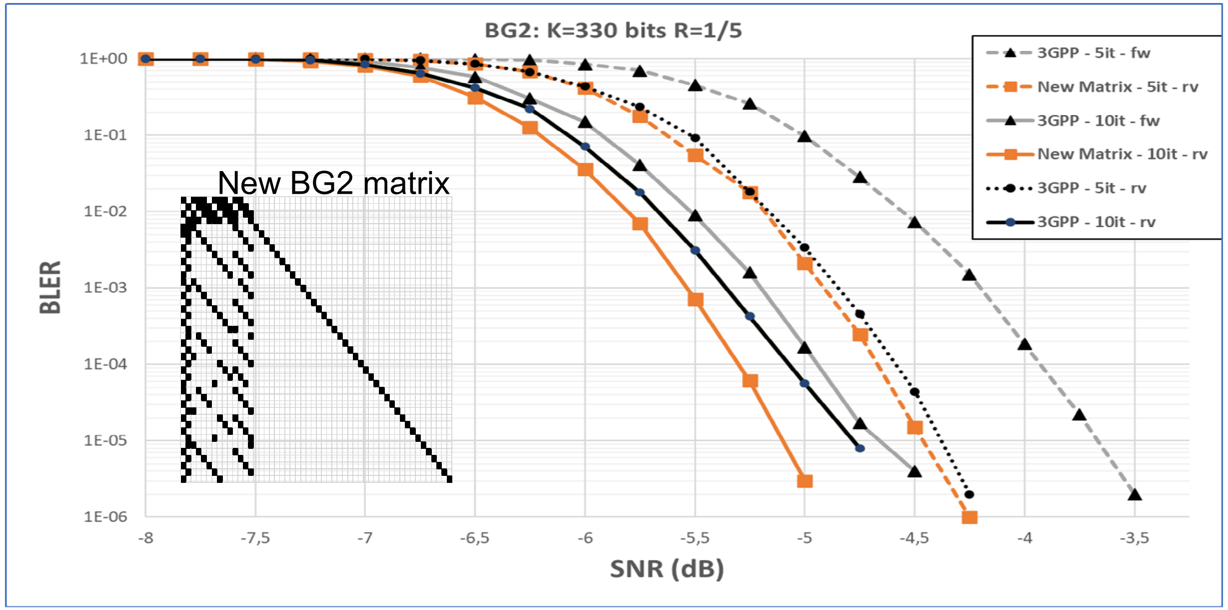
Learned constellation for optimized PAPR







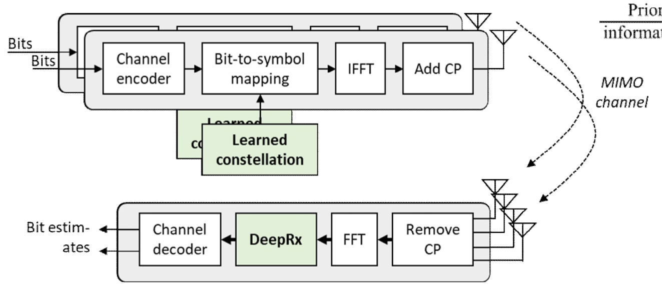
Optimized LDPC code parity matrix



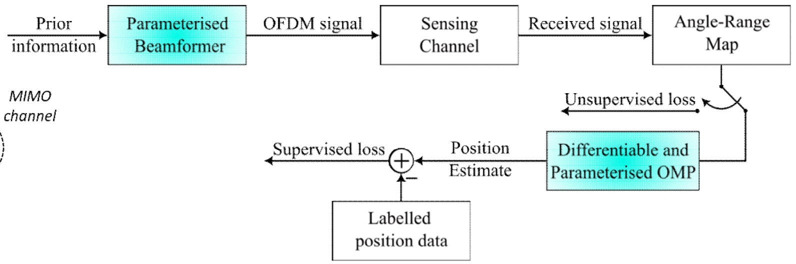
Intelligent Radio Interface Enablers

- Learning for waveform, modulation, and coding
  - MIMO waveform for communications
  - waveform and precoding for JCAS
  - AI for LDPC matrix structure optimization
- AI-based CSI acquisition
  - ML-based channel state feedback compression in a multi-vendor scenario
  - Intelligent CSI compression
  - CSI prediction
- AI-based MIMO transmission
  - Antenna muting
  - User pairing for MU-MIMO
  - Pilot assignment for D-MIMO
  - Power control for D-MIMO
- AI solutions for hardware impairments
  - AI-based PA-nonlinearity compensation
  - Generative AI for hardware impaired communication

MIMO Waveform for Communications

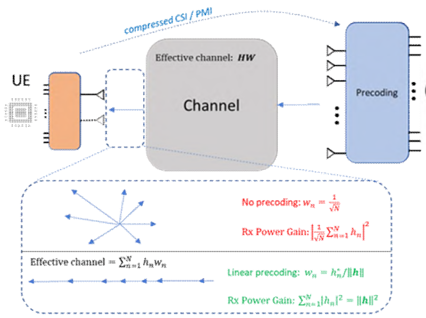


Waveform and precoding for JCAS

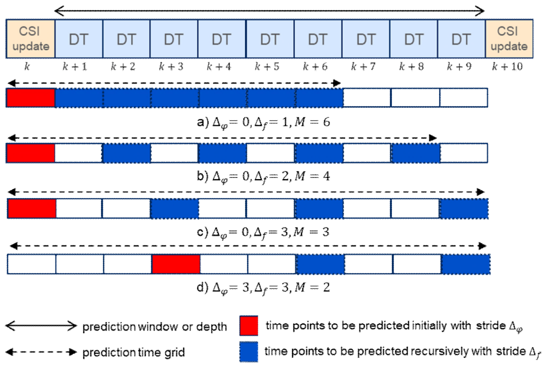


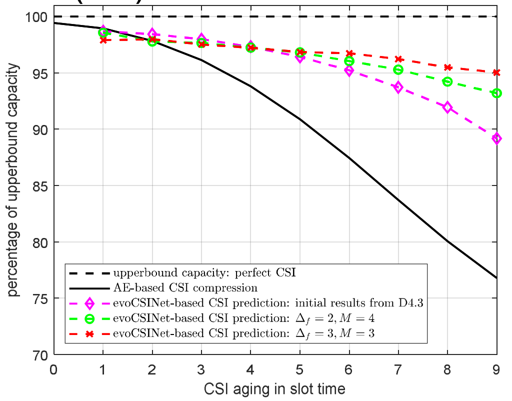
CSI feedback

CSI compression

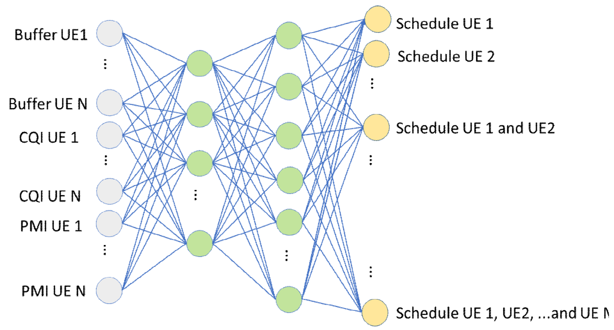


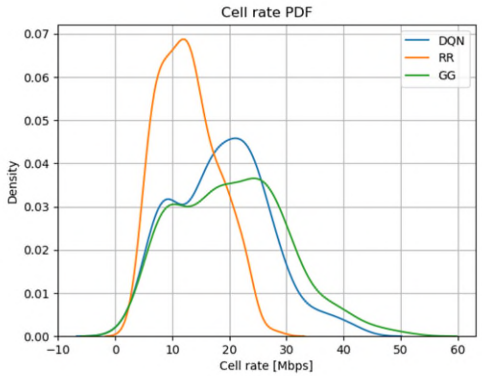
CSI prediction in FDD using auto encoder (AE)





User pairing for MU-MIMO: Deep Q-L

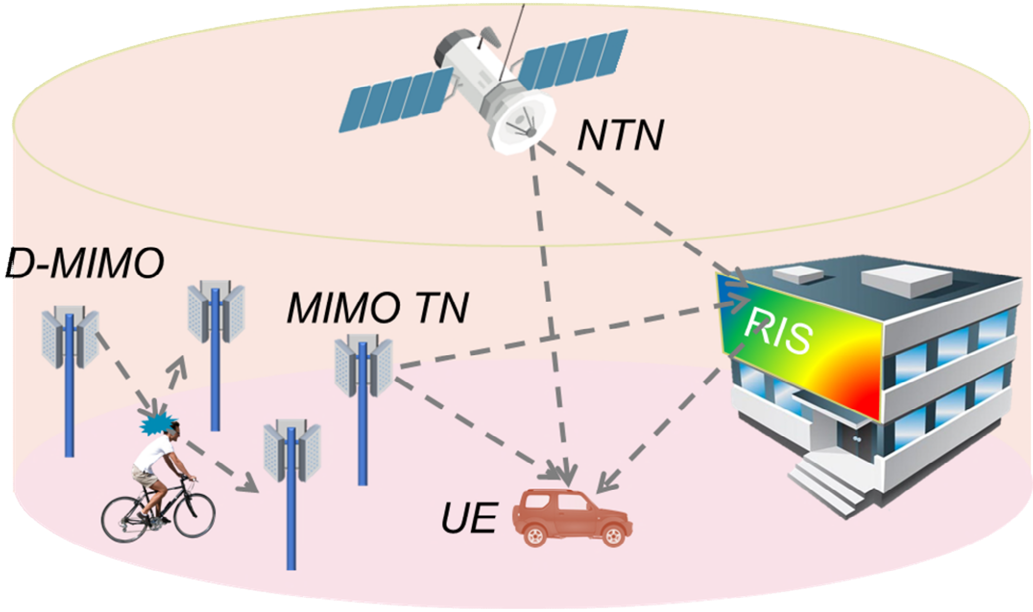




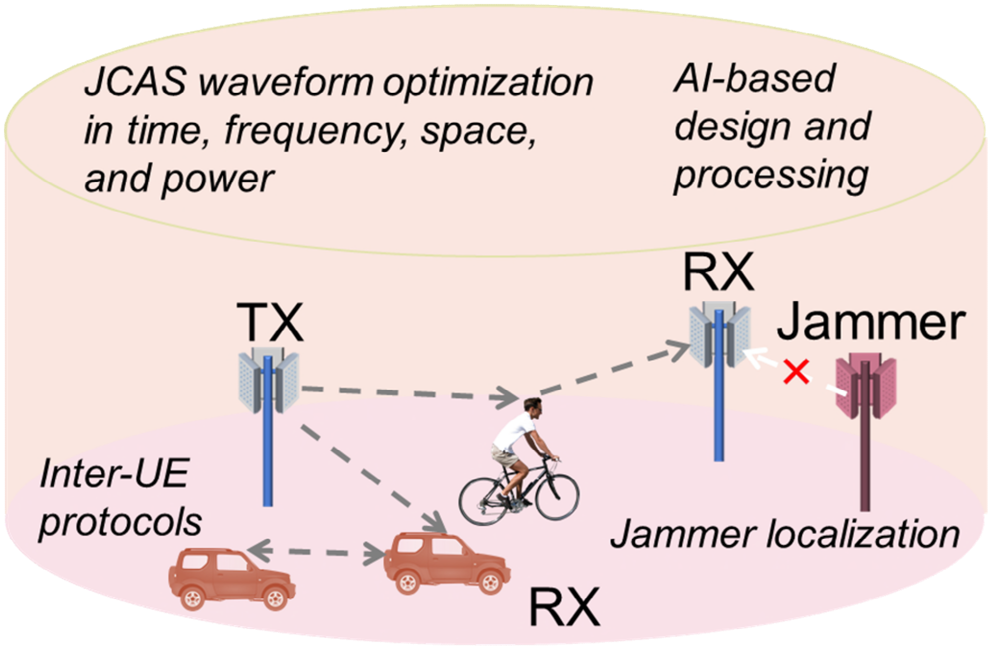
Joint Communications and Sensing

- JCAS deployments
  - NTN and RIS-aided localization
  - Multi-static sensing
- JCAS resource optimization
  - Optimization of OFDM-based bistatic sensing
  - Resource allocation and protocols for inter-UE sensing
- Holistic view of JCAS Radio

JCAS uses deployment enablers



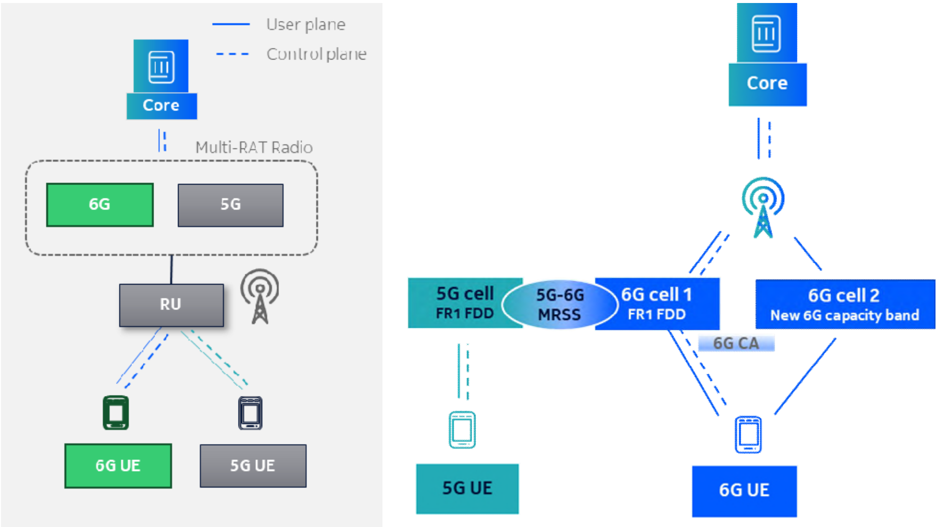
JCAS uses waveform and signal processing enablers



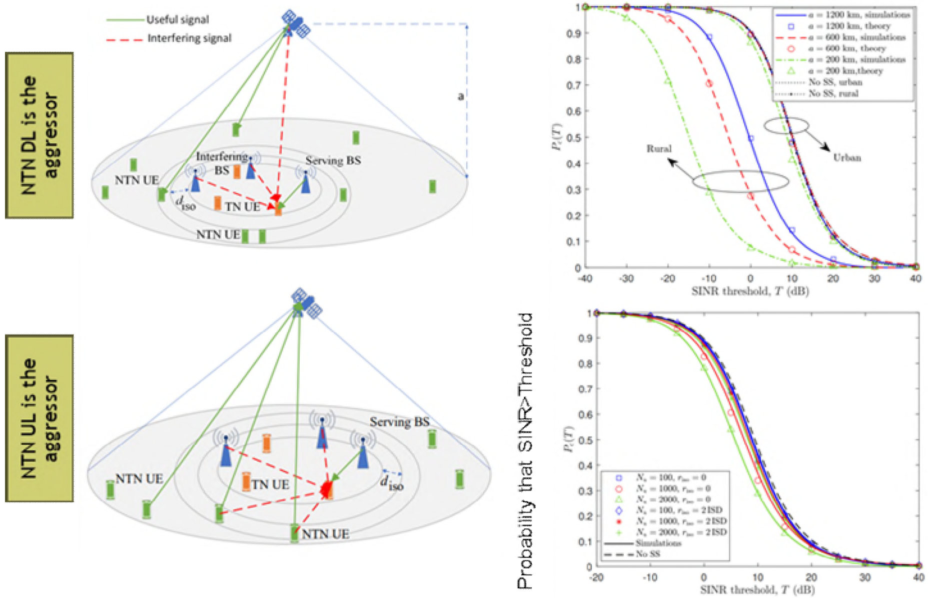
Flexible Spectrum Access

- Spectrum sharing and coexistence (satellite services)
  - Assumptions and models to determine sharing possibilities with FSS ES
  - Spectrum sharing between 6G and FSS UL
  - TN-NTN spectrum sharing in S-band using stochastic geometry
- Multi-RAT spectrum sharing (MRSS)
- Inclusive radio interface via TN/NTN enhancements
  - NTN handover methods
  - TN/NTN radio interference mitigation
  - Inclusive radio interface via high altitude platforms (HAPS)

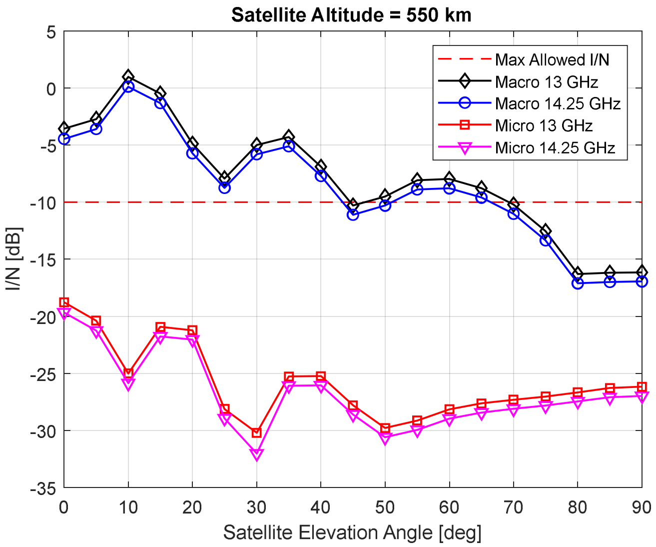
Multi-RAT Spectrum Sharing (MRSS)



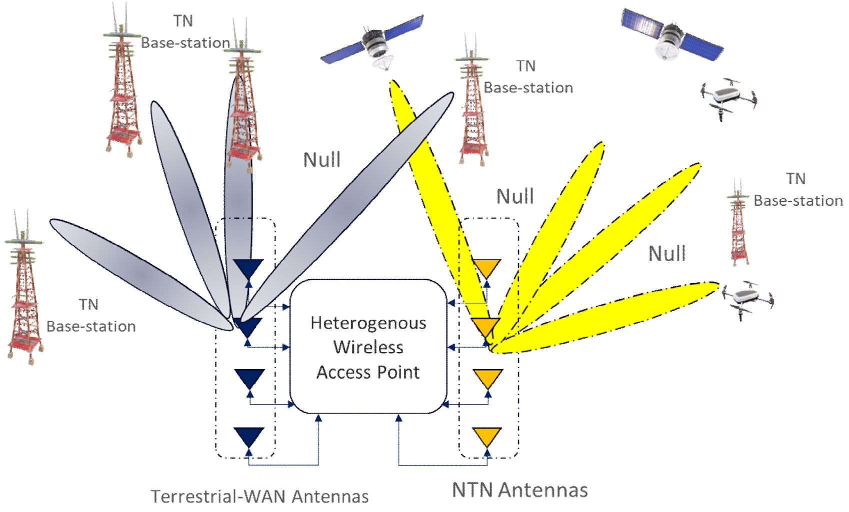
TN-NTN Spectrum Sharing in S-Band



Spectrum sharing between 6G and fixed satellite service (FSS) UL



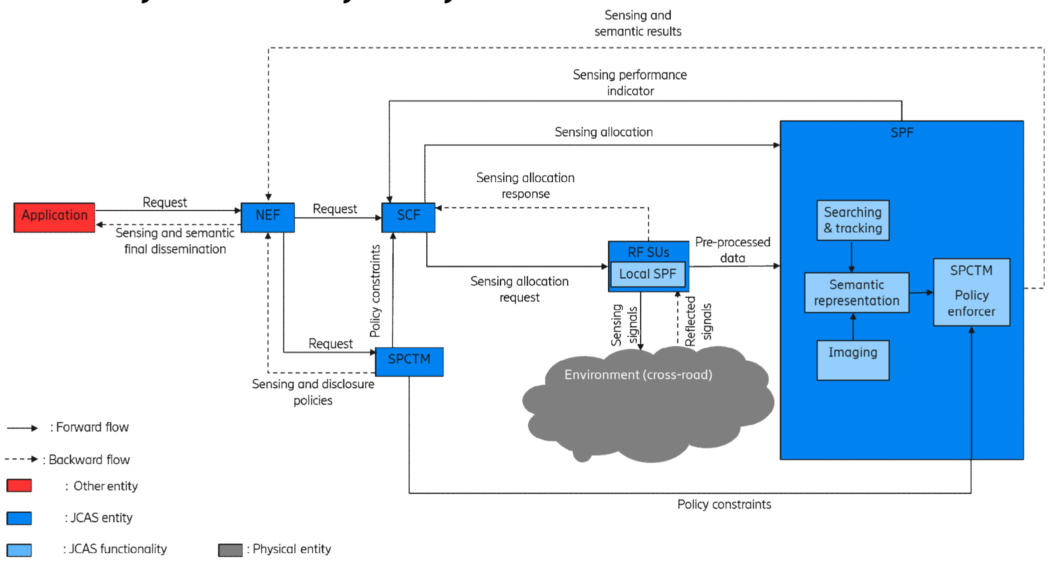
TN/NTN Radio Interference Mitigation



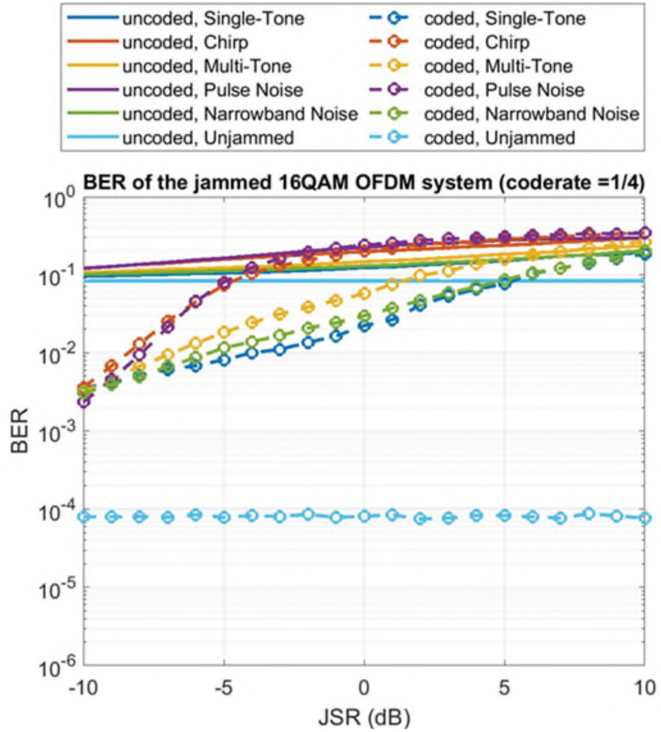
Trustworthiness

- Jamming analysis
  - Impact of jamming as a foundation towards resilience
  - Indoor jammer localisation
- Security and privacy analysis of JCAS
  - Security and privacy analysis of a general cellular JCAS system
  - Security and privacy analysis of a cell. JCAS system deployed for cross-road monitoring
- Resilient-by-design framework for 6G

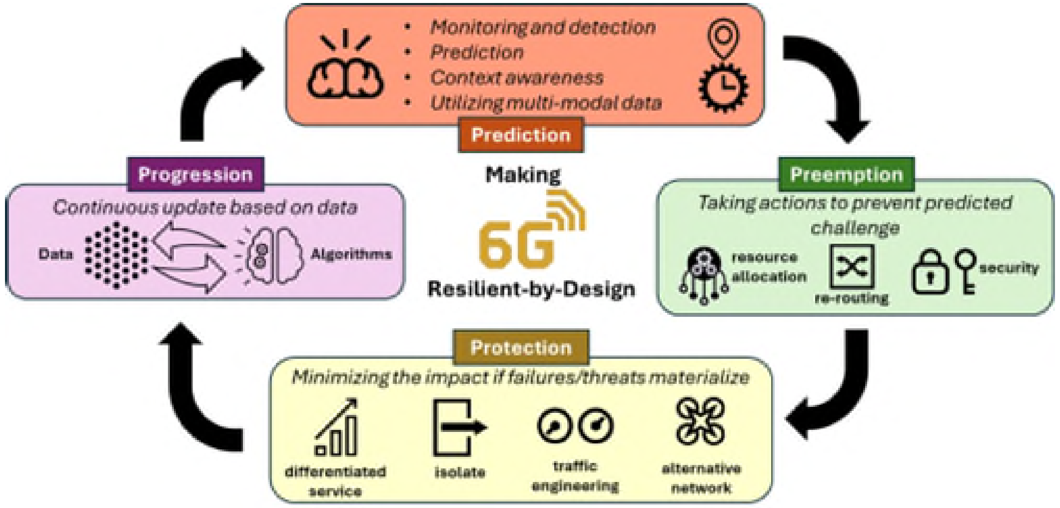
Security and Privacy Analysis of a Cellular JCAS



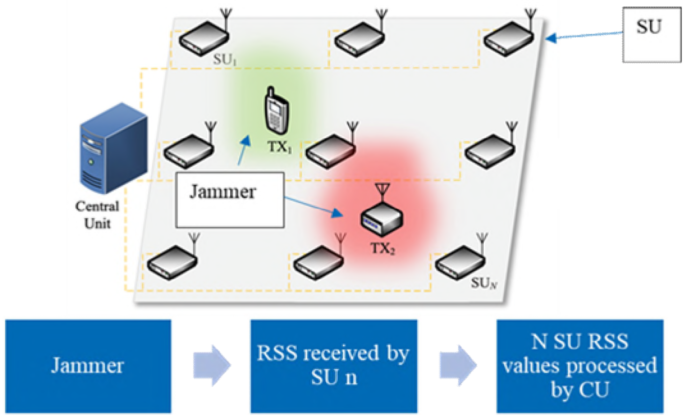
Impact of different type of Jamming signals



Resilience framework



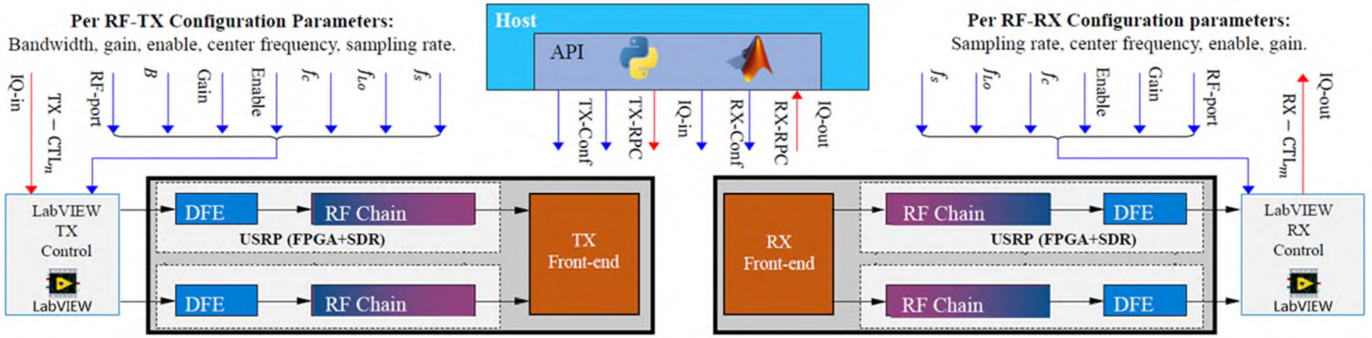
Jammer localization



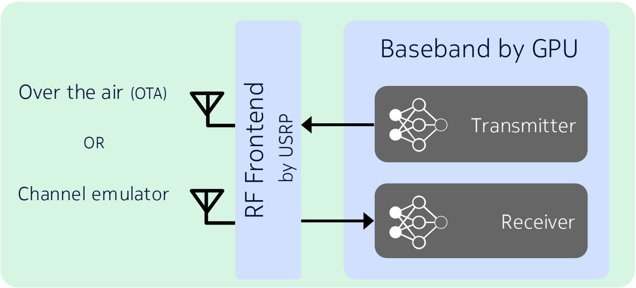
Proof-of-Concepts and Simulators

- Link modelling of 6G physical layer
- Flexible modulation and transceiver design
- AI-native air interface
- Bistatic joint communication and sensing
- Power consumption of JCAS
- EMF assessment for D-MIMO
- Channel measurements and data models

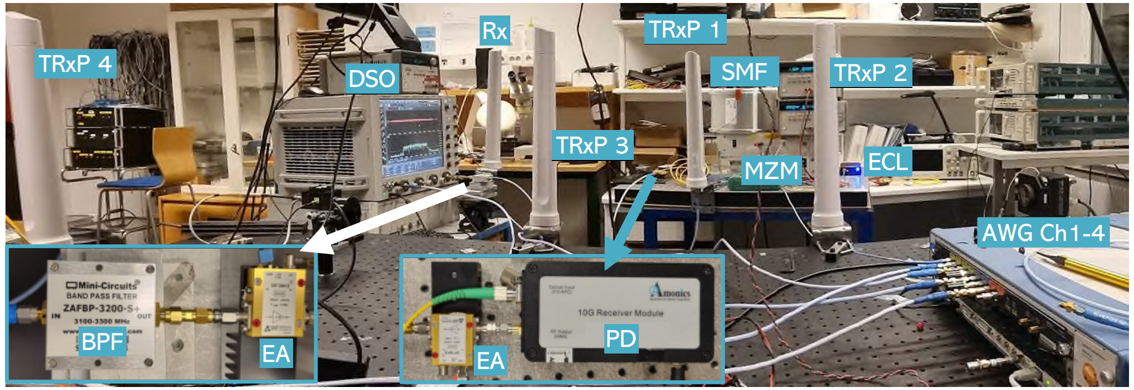
Flexible transceiver platform



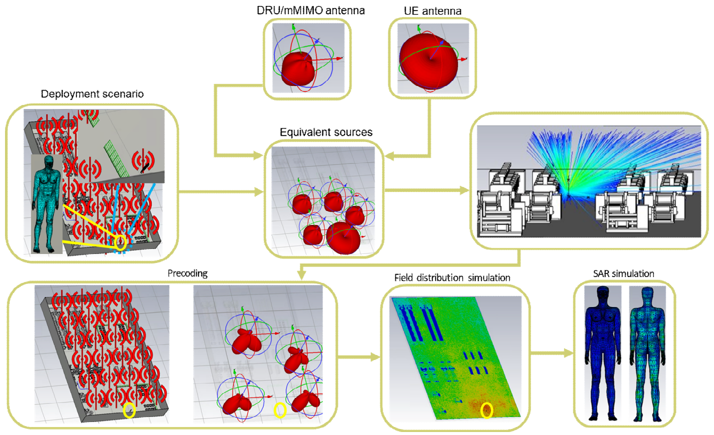
AI-native air interface

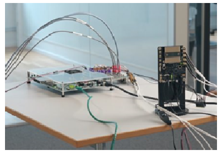


Distributed-MIMO testbed

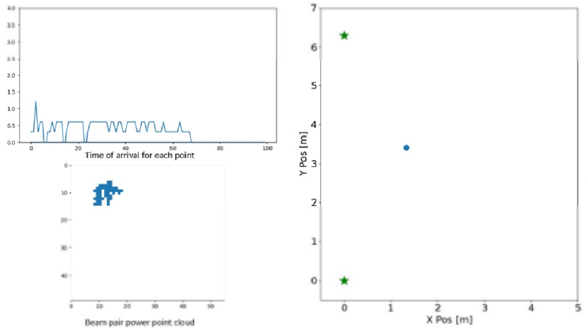


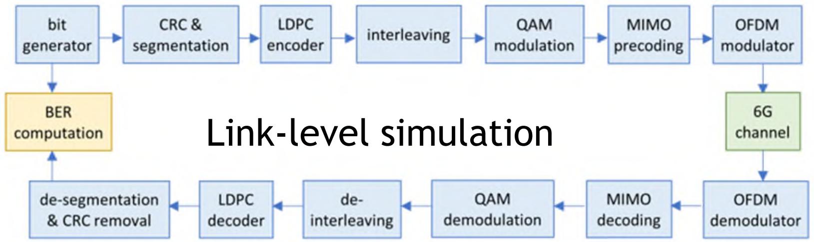
EMF Assessment for D-MIMO





Bistatic JCAS





Link-level simulation

More details

D4.2 - Radio design and spectrum access requirements and key enablers for 6G evolution

Available on Hexa-X-II website

HEXA-X-II

A holistic flagship towards the 6G network platform and system, to inspire digital transformation, for the world to act together in meeting needs in society and ecosystems with novel 6G services

Deliverable D4.2

Radio design and spectrum access requirements and key enablers for 6G evolution

Co-funded by the European Union

6GSNS

Hexa-X-II project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095759.

Date of delivery:	31/10/2023	Version:	1.0
Project reference:	101095759	Call:	HORIZON-JU-SNS-2022
Start date of project:	01/01/2023	Duration:	30 months

D4.3 - Early results of 6G Radio Key Enablers

Available on Hexa-X-II website

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Deliverable D4.3

Early results of 6G Radio Key Enablers

Co-funded by the European Union

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Date of delivery:	30/04/2024	Version:	1.0
Project reference:	101095759	Call:	HORIZON-JU-SNS-2022
Start date of project:	01/01/2023	Duration:	30 months

D4.5 - Final Results of 6G Radio Key Enablers

Upcoming in March 2025

HEXA-X-II

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Deliverable D4.5

Final Results of 6G Radio Key Enablers

Co-funded by the European Union

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Date of delivery:	XX/02/2025	Version:	0.1
Project reference:	101095759	Call:	HORIZON-JU-SNS-2022
Start date of project:	01/01/2023	Duration:	30 months

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