6G series workshop from Hexa-X-II

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

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Hexa-X-II

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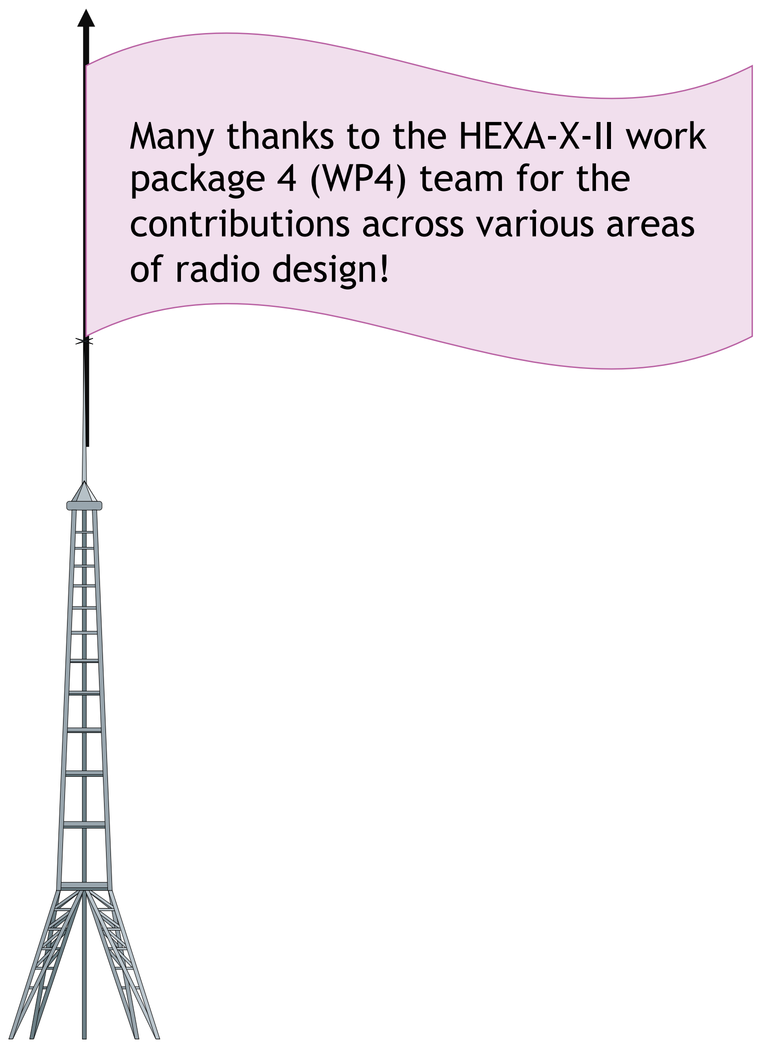
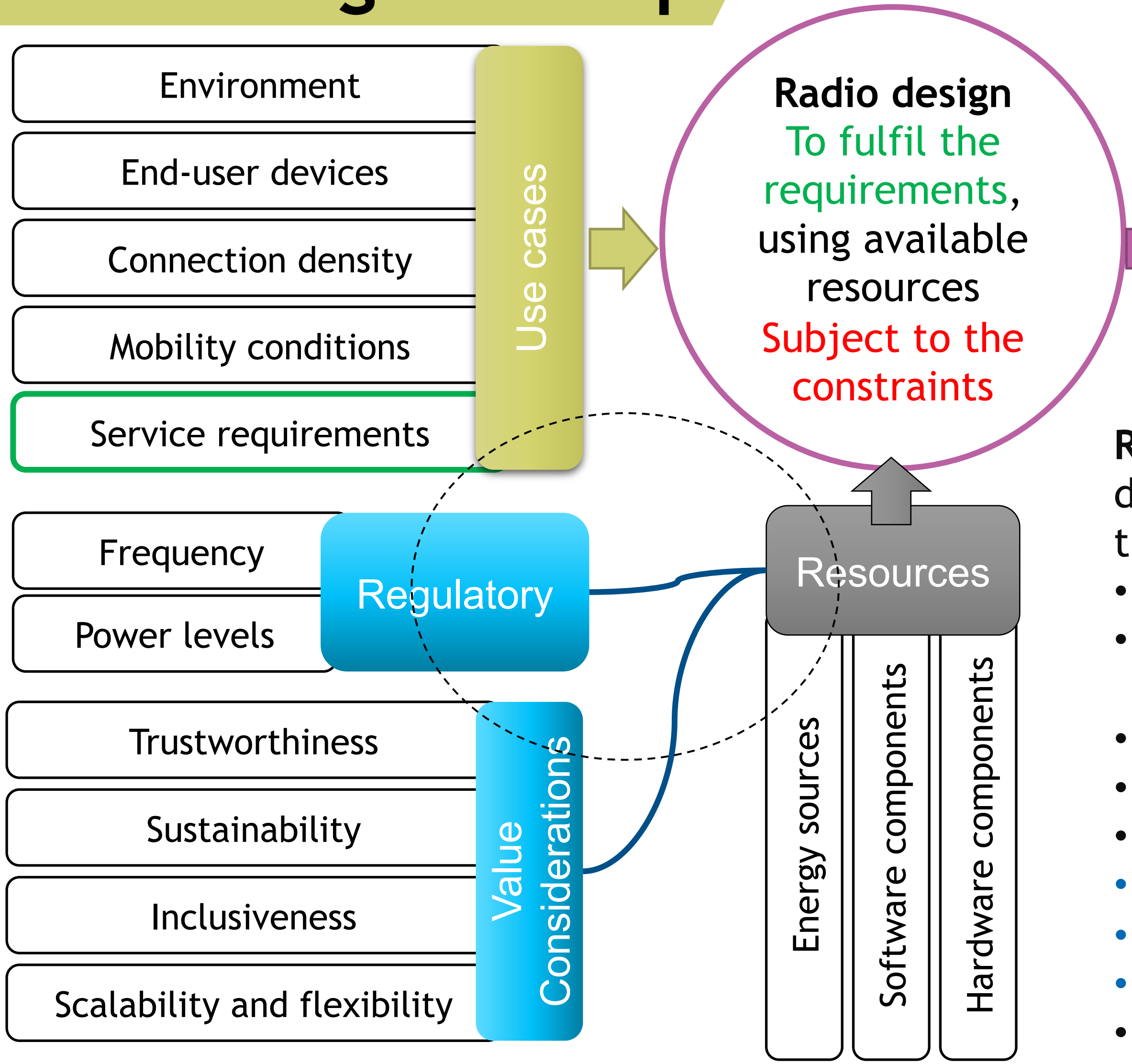
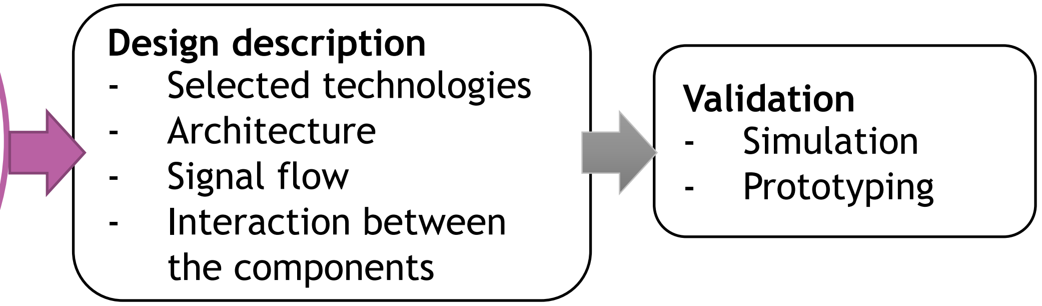
Outline

- Radio design concept
- Overview of HEXA-X-II WP4
- Radio scenarios
  - Selected use cases
  - Deployment scenarios
  - Performance metrics
- Overview of holistic design framework and enablers
  - Architectural enabler
  - Signal processing
  - Flexible spectrum access solutions
  - KVIs focused solutions
  - Simulation and modelling tools
- Proof of concepts



Radio design concept





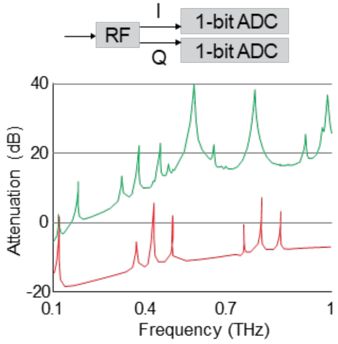
Radio design enablers: technologies and tools that allow the development and implementation of radio systems to achieve the goals and overcome the constraints

- New spectrum allocation (e.g. sub-THz)
- Technologies that improve the resource usage for multiple functionalities (e.g. Joint communication and sensing)
- Advanced computational tools (e.g. AI/ML)
- Mechanisms for efficient spectrum sharing
- Technologies to mitigate the impact of environment (e.g. RIS)
- Simulation and modelling tools
- Solutions for enhancing trustworthiness
- Prototyping platforms
- Energy efficient techniques
- Novel material and HW components
- …

Note: the list of constraints is not exhaustive.

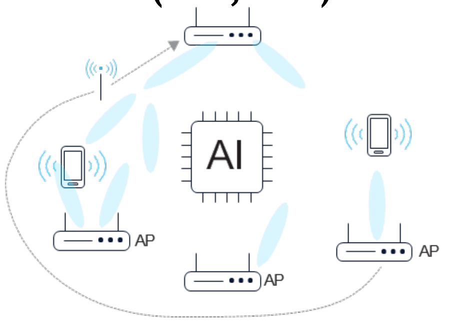
WP4: Radio evolution and innovation

Towards THz communications



- Channel modelling
- Waveforms and modulations
- Massive MIMO
- Distributed MIMO
- Link-level simulator

Intelligent radio air-interface design (FR1, FR2)

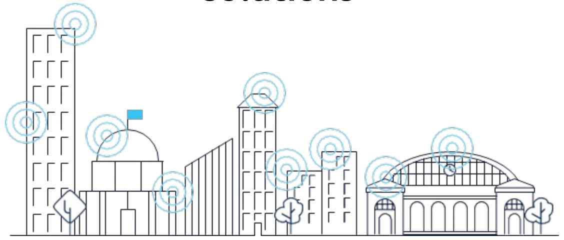


- AI solutions for HW impairment compensation, resource allocation, channel prediction, beamforming, ..
- Modulation and coding
- D-MIMO transmission
- RIS-assisted transmission

Joint communications and sensing

- Sensing architectures
- Waveforms optimization
- Resource allocation and protocols
- Security, resilience and cross-functional benefits

Flexible spectrum access solutions



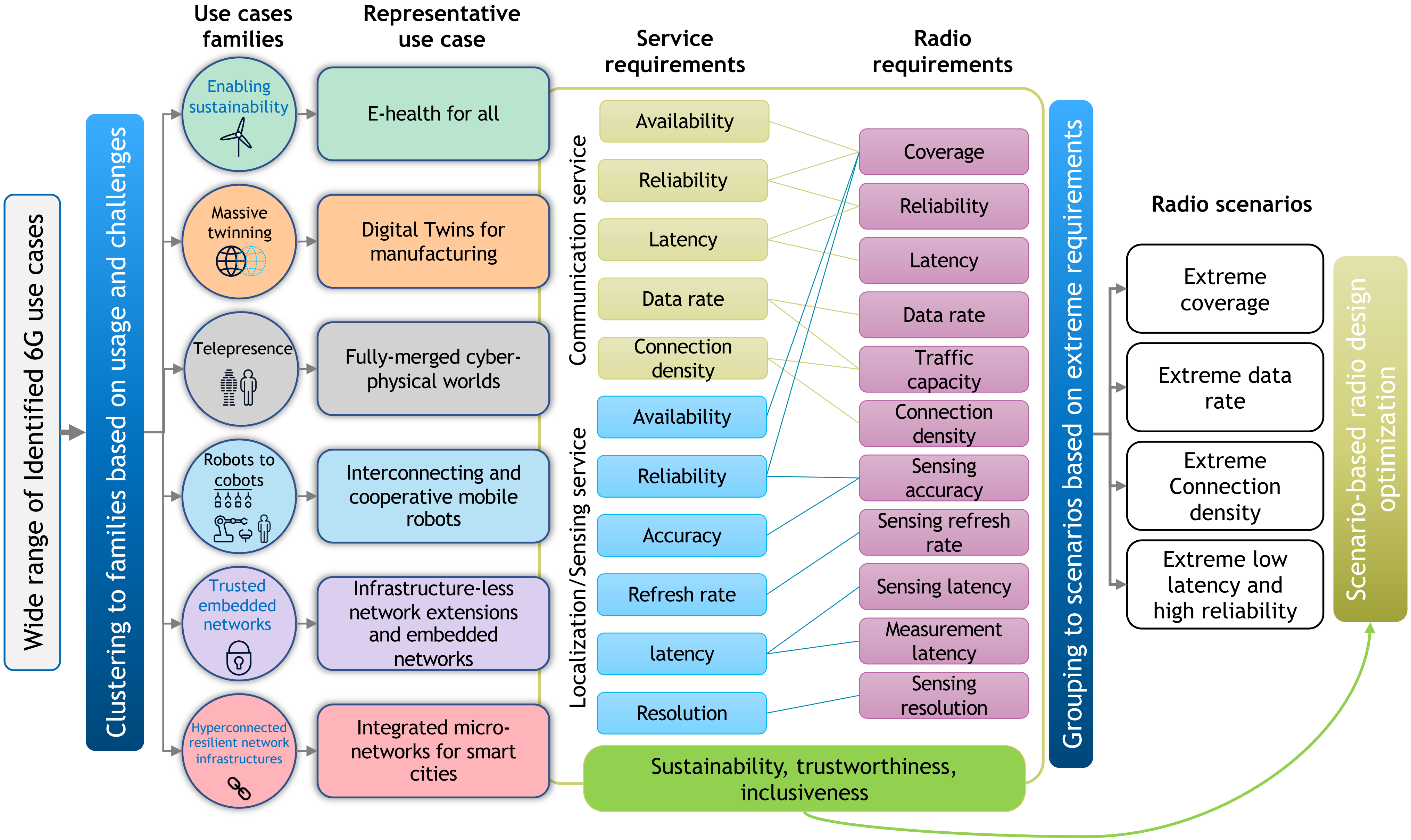
- Spectrum sharing and coexistence
- Multi-rat spectrum sharing
- Low-latency random access
- Risk-informed random access

Sustainable, trustworthy and inclusive holistic radio design

- Flexible design
- Inclusive interface
- Sustainable solutions
- Trustworthy solutions

Selected use cases and defined radio scenarios

- The defined radio scenarios are characterized by extreme use cases requirements
- The corresponding radio design should consider value considerations



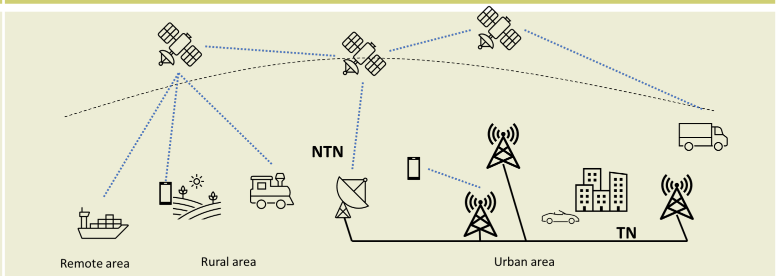
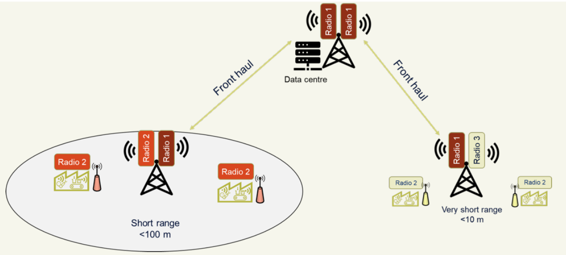
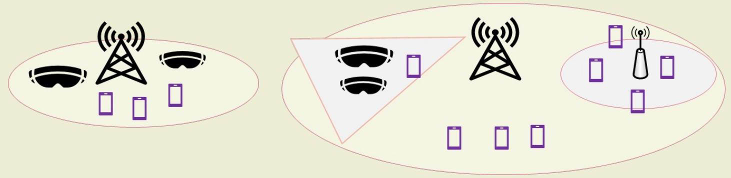
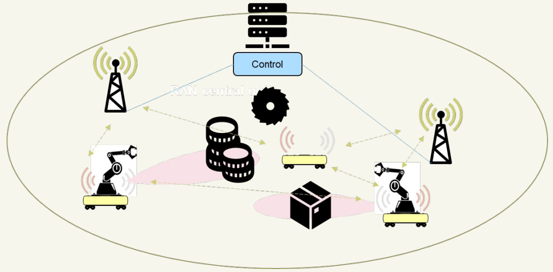
6G Radio scenarios KPIs

- Derived by analysing the service requirements of representative use cases and mapping to radio requirements

Radio scenario	Use cases	ITU usage scenarios	Data rate	Reliability	Latency	Connection density	Coverage	Sensing-related capabilities
Extreme coverage	E-health for all	Ubiquitous connectivity	Low Medium < 1 Gbit/s	Variable	Variable	Variable	Ultra-wide Extreme-wide Availability (99.99%-99.999999%)	Variable
Extreme data rate	Digital twins for manufacturing	Artificial intelligence and communication Immersive communication	Ultra-high Extreme-high (10-100 Gbit/s)	Variable	Variable	Low Medium $<10^4$ device/km^2	Local	Variable
Extreme connection density	Fully merged cyber-physical worlds and merged reality game/work Immersive smart cities & integrated micro-networks for smart cities	Immersive communication Massive communication	Medium High < 10 Gbit/s	Variable	Variable	Ultra-high Extreme-high (10^6-10^8) device/km^2	Variable	Variable
Extreme low latency and high reliability	Interacting and cooperative mobile robots Infrastructure-less network extensions and embedded networks	Hyper reliable and low-latency communication Integrated sensing and communication	Low < 10 Mbit/s	Ultra-high Extreme-high (99.999%-99.99999%)	Ultra-low Extreme-low (0.1-10) ms	Variable	Local	Ultra-high Positioning accuracy (0.1-1) cm

6G Radio scenarios parameters

- Sub-scenarios can be defined by different combinations of scenario parameters

Radio scenario	Use case	Environment	Deployment option	Radio devices	Mobility	Frequency	Example
Extreme coverage	E-health for all	Mobile indoor Public indoor Outdoor (urban, suburban, rural)	Long range Short range Fixed/temporary Mobile infrastructure TN/NTN integration	Enhanced 5G (mMTC, eMBB) devices Energy neutral devices	Static Low, Medium High Very-high Ultra-high	Sub-GHz Sub-6 GHz 7-15 GHz Satellite frequency ranges	
Extreme data rate	Digital twins for manufacturing	Controlled and semi-controlled indoor and outdoor	Small cell D2D Sensor network with a gate way Embedded network	Access points for backhaul Gateway for sensors Local devices (sensors, actuators)	Static Low mobility Controlled mobility	mmWave or sub-THz Mixed and unlicensed for local connections	
Extreme connection density	Fully merged cyber-physical worlds	Urban indoor/outdoor with high density of users High-rise	High density of cells Macro cell Micro cell	Reliable high data rate with bounded latency devices	Static Low Medium	mmWave 7-15 GHz high bandwidth	
Extreme low latency and high reliability	Interacting and cooperative mobile robots	Indoor Embedded network	Small cell On premises infrastructure Sensor network	High reliability & low latency devices	Static Low mobility Controlled mobility	Private frequency Sub-GHz Sub-6 GHz 7-15 GHz mmWave, sub-THz for sensing	

6G Radio performance metrics

- Performance requirements related to services

Air interface communication requirements	Performance metrics
Data rate	Peak data rate, throughout, capacity, spectral efficacy, sum rate, average rate, packet rate.
Coverage	Range (spatial separation distance), beamwidth, signal-to-noise ratio (SNR), coverage probability, outage probability.
Air interface latency	The time needed to transmit and receive L2 packet successfully.
Air interface reliability	Bit error rate (BER), frame error rate (FER), block error rate (BLER), symbol error rate (SER), normalized mean square error (NMSE).
Radio sensing requirements	**Performance metrics**
Location/sensing accuracy	Error norm value (distance between true and estimated value) corresponding to a certain percentile of the location error norm.
Sensing latency	The time between initialization of sensing/localisation procedure and acquiring localisation/sensing estimate.
Orientation accuracy	The orientation error norm value corresponding to a certain percentile (e.g., 90%, 99%) of the orientation error norm.
Location coverage	The area or volume or fraction of a space in which the localization error is below a certain limit.
Sensing resolution	The smallest difference in a dimension (e.g., range, angle, Doppler) between objects to have measurably different values.
Sensing detection probability	The probability that a target is detected given that it is present .

- General performance requirements

Implementation and operation	Performance metrics
Energy efficiency	Ratio of output power to the total consumed power, energy consumption to achieve certain performance goal (such as energy required to transfer a bit).
Complexity	Amount of hardware resources, computational complexity of algorithms.
Cost	Cost of design, implementation, deployment, and operation.

- Design value requirements

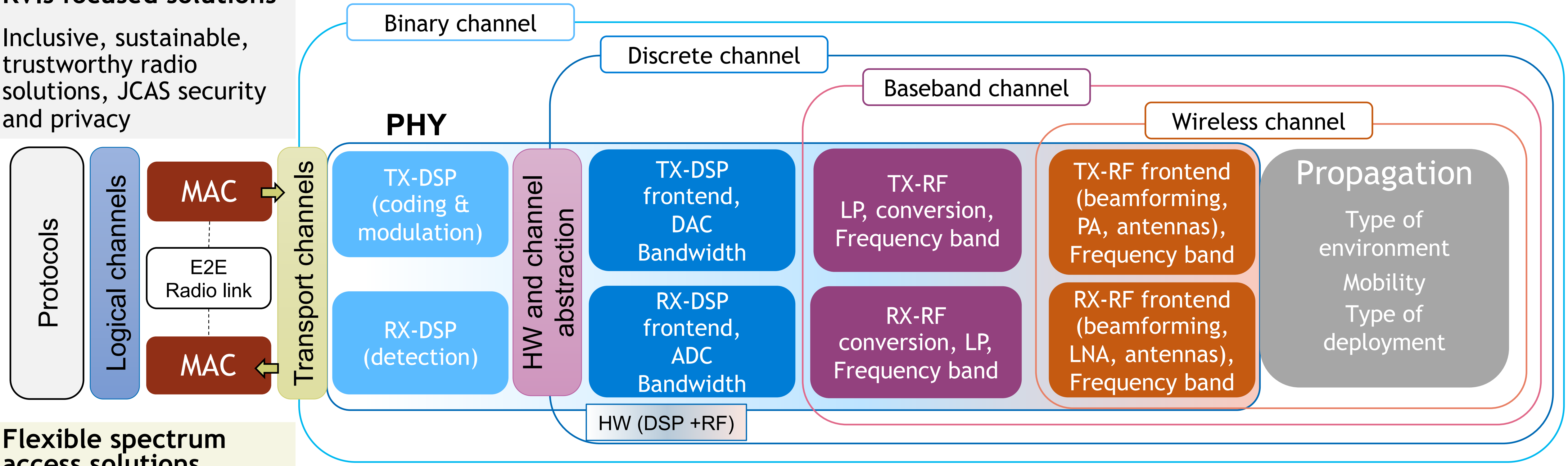
Value requirements	Performance metrics
Inclusiveness	Coverage, global standard, proper number of manageable interfaces, affordable devices.
Trustworthiness	Reliability, security, resilience, integrity.
Sustainability	Values and needs of the end-users, energy consumption, life cycle assessment (LCA) of material, electromagnetic field (EMF) exposure.

Holistic radio design framework

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

KVIs focused solutions

Inclusive, sustainable, trustworthy radio solutions, JCAS security and privacy



Flexible spectrum access solutions

Sharing, coexistence, low-latency random access

Signal processing and algorithms

Waveform, modulation, coding, radio resource allocation

Radio link modelling

Channel modelling, HW modelling, Link-level signal modelling

Architecture and deployment

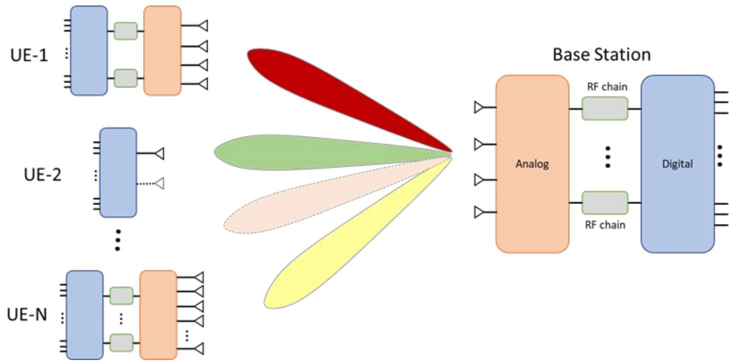
Radio HW architecture, D-MIMO, RIS, JCAS deployment

End-to-end design optimization

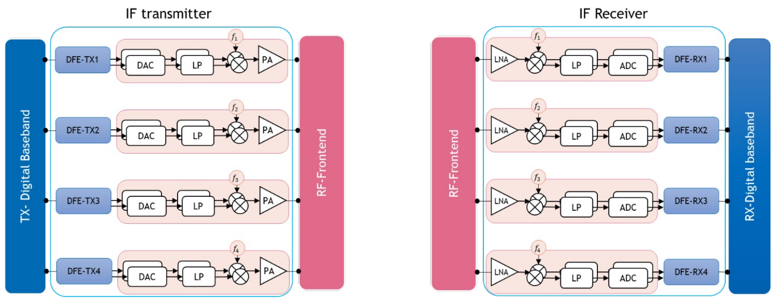
Architecture and deployment

Topics
Distributed MIMO and RIS-assisted transmission • Distributed massive MIMO for machine type communication • RIS-assisted IAB • RIS control procedure, interface and integration • D-MIMO assisted with RIS • Decentralized transmission • One-bit ADC for multi-cell setup
Massive MIMO schemes and architectures • Hybrid analogue-digital architectures • Fully digital architectures with low-resolution ADCs/DACs
Flexible transceiver architecture • Multiband, reconfigurability of bandwidth, carrier frequency, RF frontend
Joint communications and sensing • NTN-assisted localization • Integrated communication and monostatic sensing • Integrated monostatic and bistatic sensing • Multi-static sensing

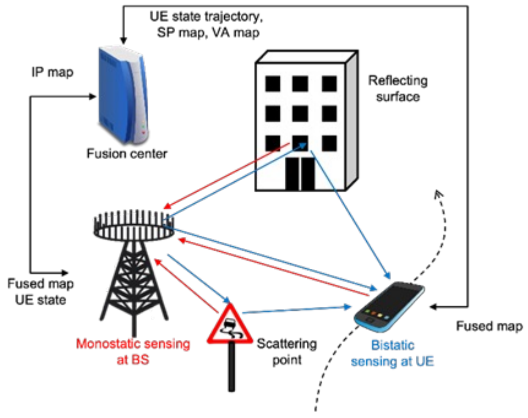
Massive MIMO schemes and architectures



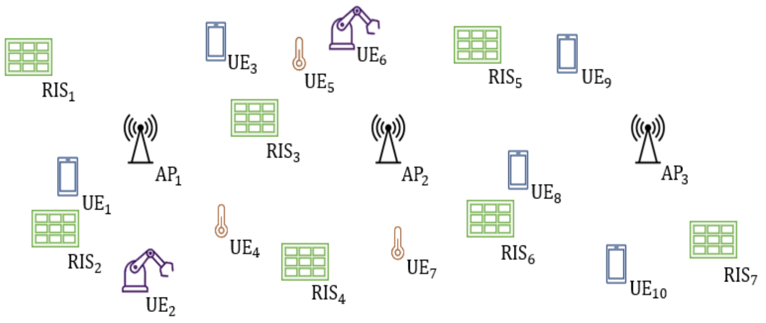
Flexible transceiver architecture



Joint communications and sensing



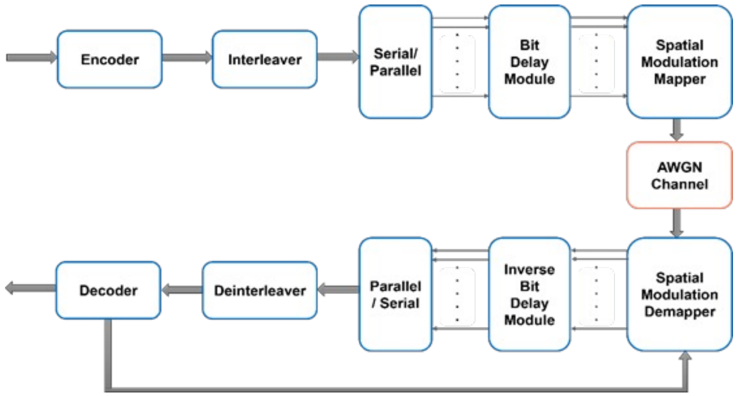
Distributed MIMO and RIS-assisted transmission



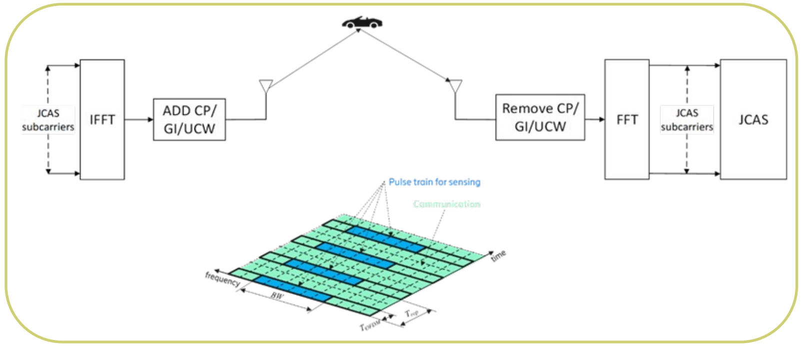
Signal processing and algorithms (model/AI-based)

Topics
Waveforms, modulations, and coding • OFDM-based waveforms at sub-THz frequencies • Zero-crossing modulation (ZXM) with one-bit quantization • Polar constellations • AI/ML learned waveforms • Learn RIS-reflecting modulation (RM) • Optimized codding
Signal processing for MIMO schemes • Multi-antenna location-dependent coded caching • Coherent joint transmission • Non-coherent joint transmission • Channel estimation for RIS • CSI prediction • CSI compression • ML-based joint user-AP allocation/selection
Signal processing for joint communications and sensing • Flexible baseband transceiver for JCAS • Waveform learning for JCAS • Optimization of OFDM-based bistatic sensing • Resource allocation

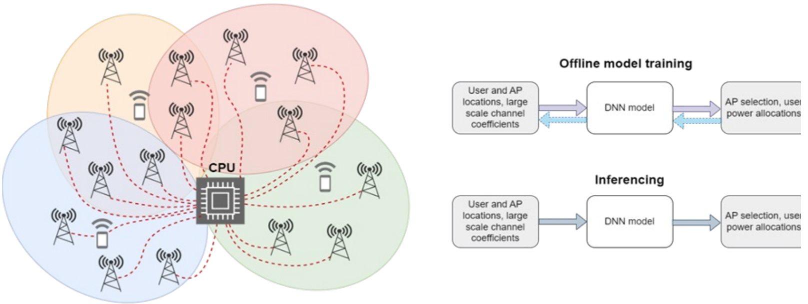
Optimization of modulation and coding



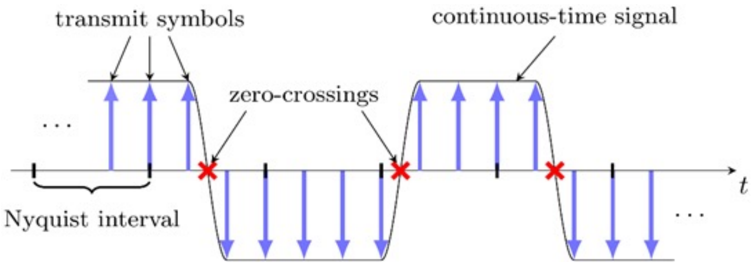
Resource allocation for JCAS



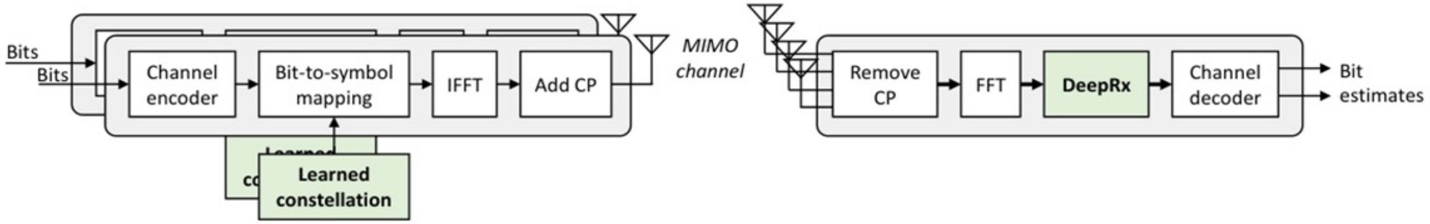
ML-based joint user-AP allocation/selection



ZXM modulation



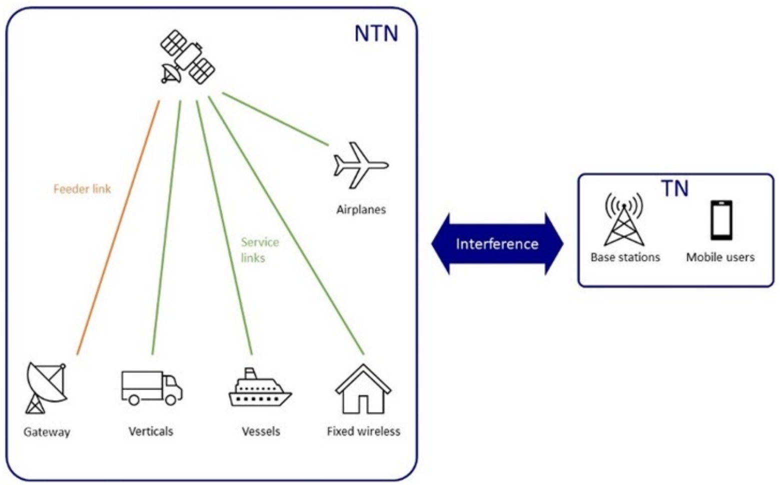
Constellation learning



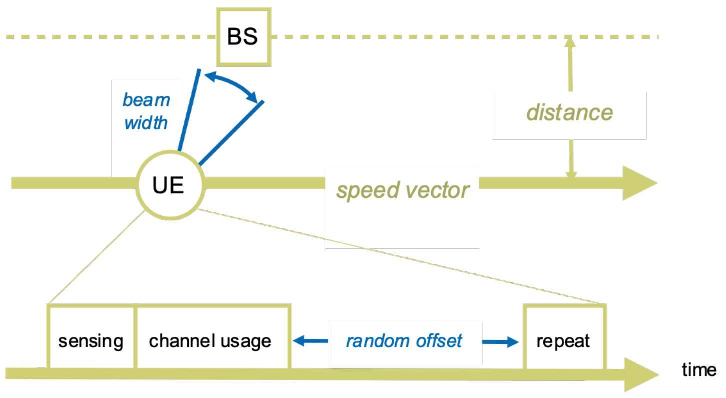
Flexible spectrum access solutions

Topics
Spectrum sharing, coexistence • Assumptions and models to determine sharing possibilities • TN-NTN spectrum coexistence and sharing • Multi-RAT spectrum sharing • TN/NTN enhancement
Low-latency random access • sub-THz access methods • Risk-informed random access
Proactive resource management • Improve resource utilization and optimization of transmission parameters

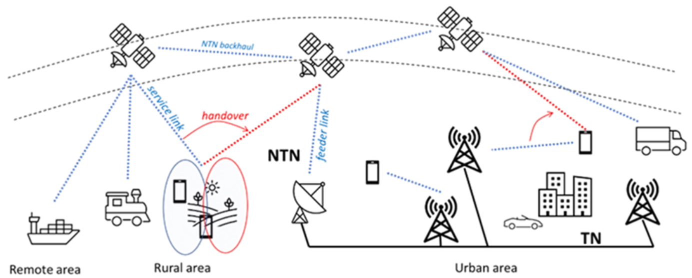
TN-NTN coexistence scenarios



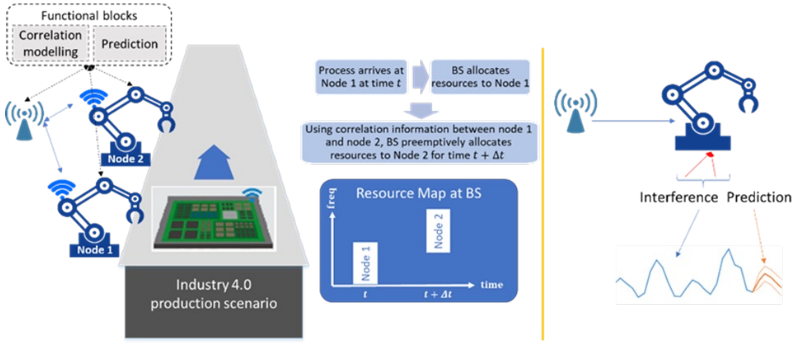
Low-Latency Random-Access



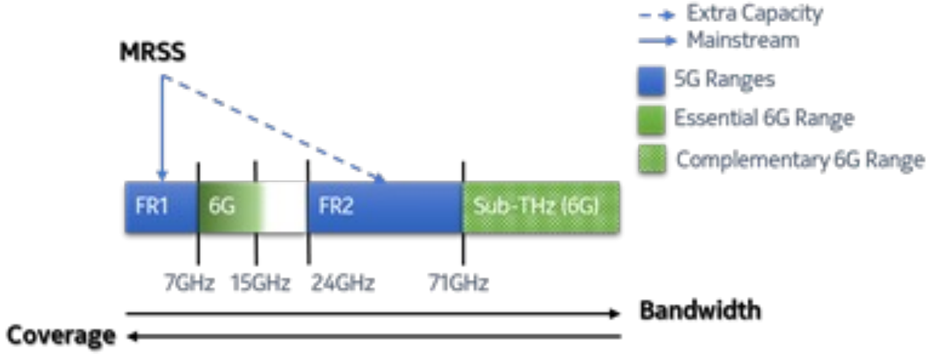
TN/NTN enhancement



Proactive resource management



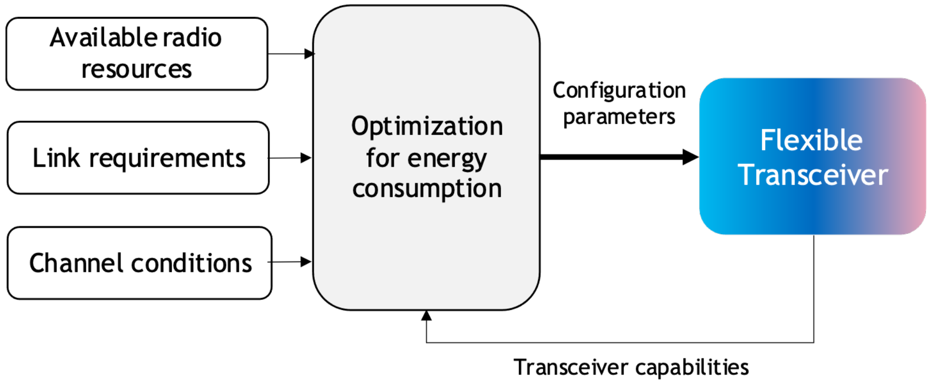
Spectrum sharing and coexistence



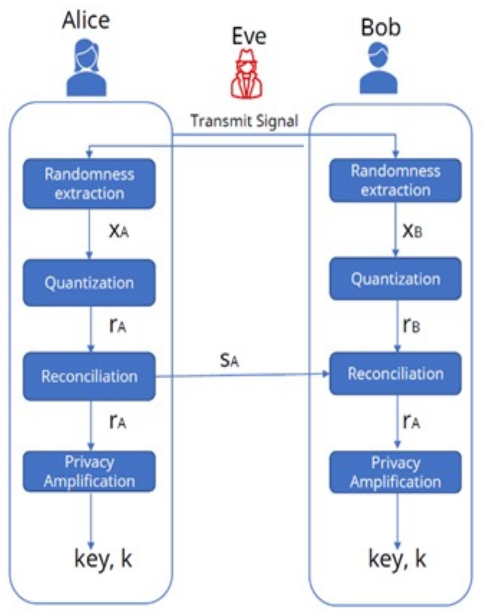
KVIs focused solutions: sustainability, security, resilience

Topics
Sustainability • Flexible transceiver reconfiguration for energy efficiency
Security • Physical layer security: secrete key generation • JCAS security and privacy
Resilience • Jammer localization • Jamming resilience schemes:

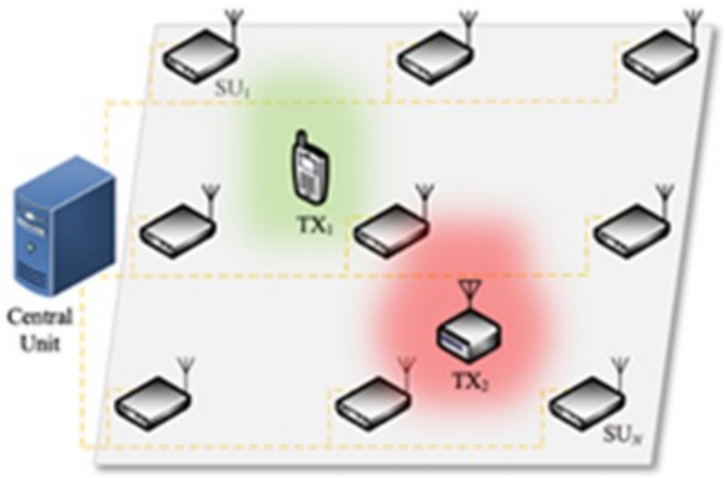
Transceiver reconfiguration for energy efficiency



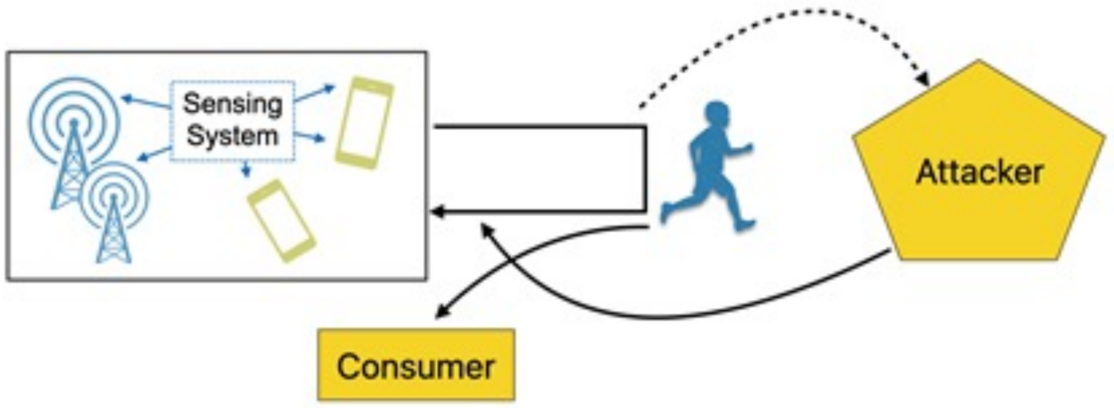
Secret key generation



Jammer localization



JCAS security



Link modelling and simulation tools

Topics

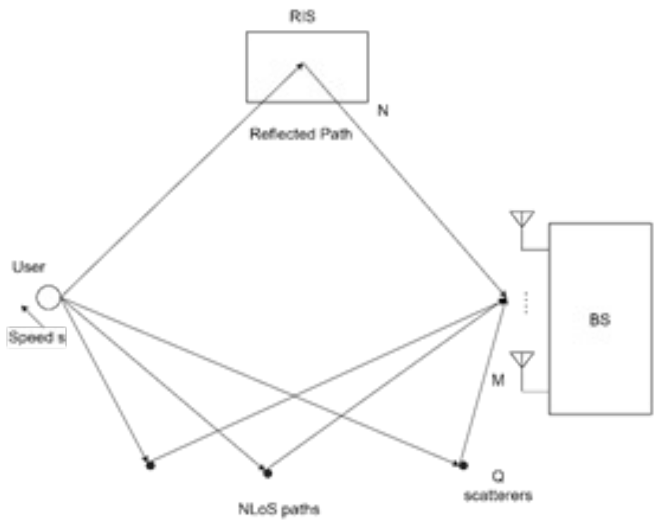
Channel modelling

- Sub-THz channel parameters for 3GPP channel model
- Sub-THz channel model component for near-field condition
- Coverage analysis at THz frequencies
- JCAS channel modelling

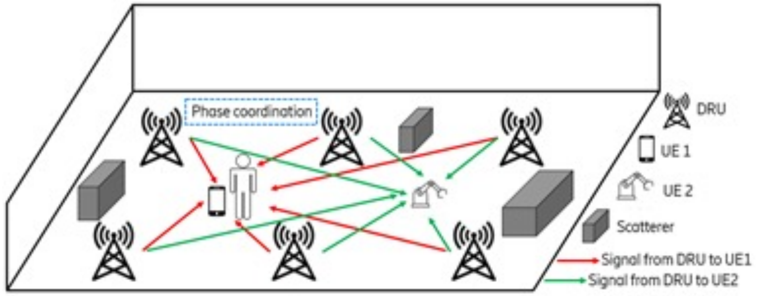
Simulation tools

- RIS modeless
- Link-level model for 6G PHY
- Electromagnetic filed (EMF) assessment in D-MIMO

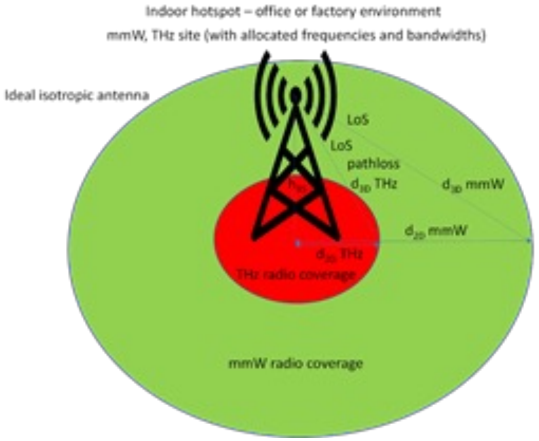
Signal level analysis for RIS



EMF simulation environment



Coverage analysis



Link-level simulator

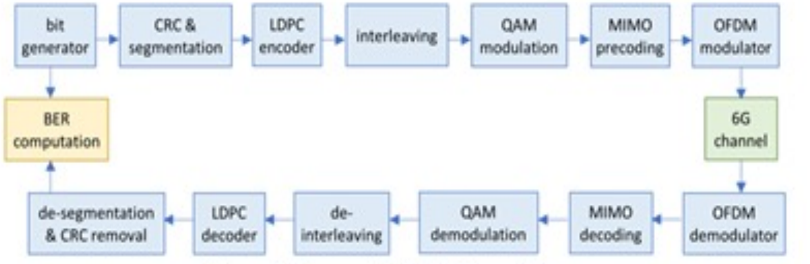
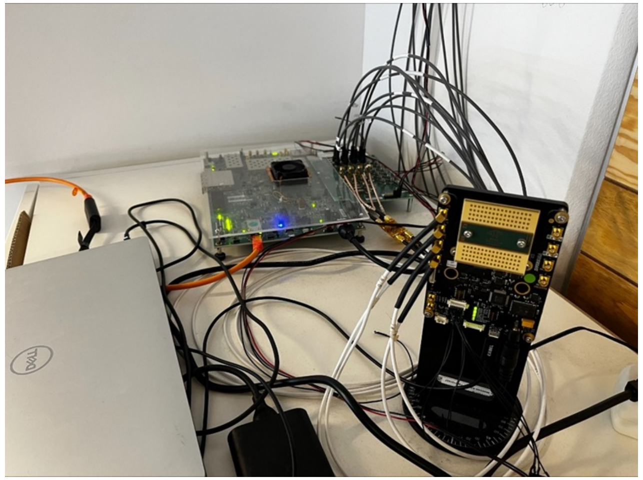


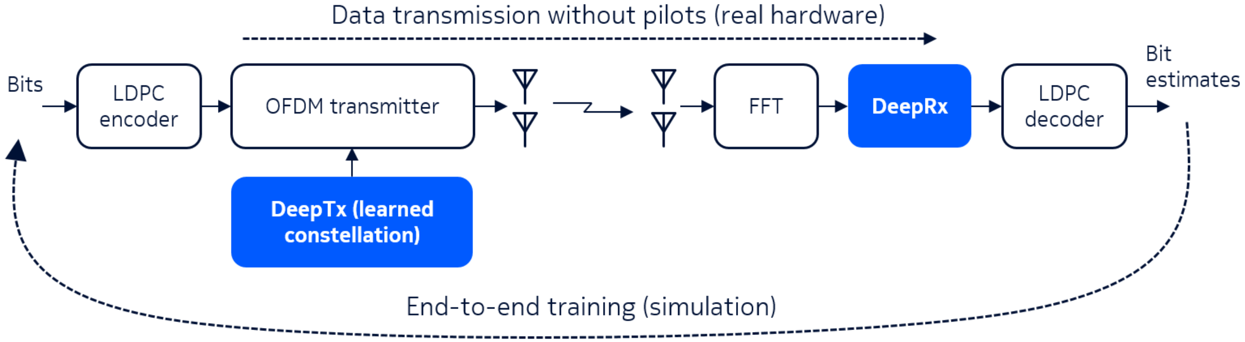
Figure 4-3 Diagram of the 6G PHY layer simulator.

Proof of Concepts

JCAS demonstrator: to show the possibility of using the same hardware for both communication and sensing

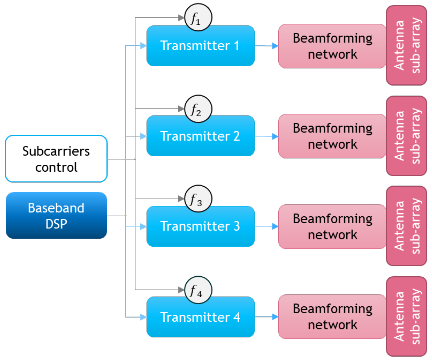


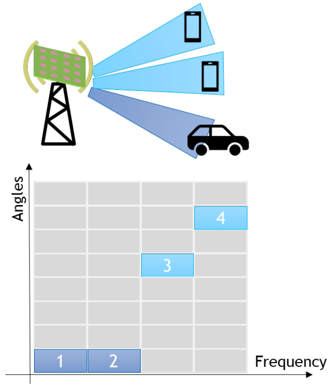
AI-native air interface: to demonstrate higher throughput with a partially learned air interface



Radio propagation measurements: to collect data for radio channel modelling

SDR-based flexible transceiver: integration of multiband IF transceiver with high frequency frontend





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.

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Start date of project:	01/01/2023	Duration:	30 months

D4.3 - Early results of 6G radio key enablers

Available in May 2024

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Deliverable D4.3

Early results of 6G Radio Key Enablers

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