Hexa-X-II | WP4 | D4.2

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





Hexa-X-II

hexa-x-ii.eu

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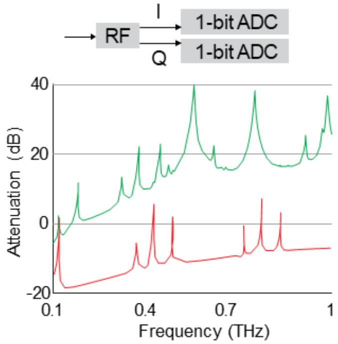
Outline

- Objectives
- Overview of value-based holistic radio design
  - Radio design KPIs and KVIs
  - Representative use cases and radio scenarios
- 6G radio design enablers
  - Radio design enablers for flexible, inclusive, sustainable and trustworthy radio
  - Radio link modelling
  - Waveforms and modulations
  - Intelligent radio air interface
  - MIMO transmissions
  - Flexible spectrum access solutions
  - Joint communications and sensing
- Proof of concepts

Objectives

Analyse of 6G radio design and spectrum access requirement and identify key 6G radio enablers

Towards THz communications

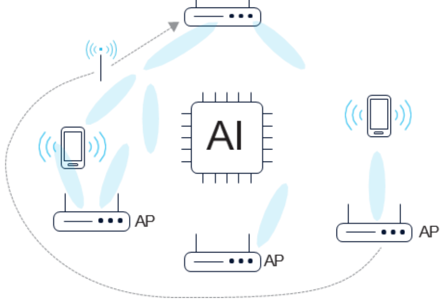


WPO 4.2: Provide a suitable channel model and develop novel broadband air-interface techniques to enable energy-efficient operations in the (sub-)THz bands, including new energy-efficient waveforms and modulations, and advanced massive MIMO techniques.

Joint communications and sensing

WPO 4.3: Provide solutions that enable flexible, cross-functional joint communication and sensing over a unified radio infrastructure, including new architectures, signals, methods, and protocols.

Intelligent radio air-interface design (FR1, FR2)



WPO 4.4: Design intelligent radio air interface to improve one or a combination of KPIs including spectral efficiency, energy efficiency, coverage, or lower cost at FR1 and FR2 spectrum.

Flexible spectrum access solutions

WPO 4.5: Develop spectrum sharing and medium access mechanisms for enabling an efficient transition to 6G (coexistence) and low-latency service access.

WPO 4.1: Develop an inclusive, trustworthy, and flexible radio design tailored to meet given 6G KPIs and KVI requirements through analysis and integration of HW architectures, transmission schemes and security solutions.

Sustainable, trustworthy and inclusive holistic radio design

KVI: key value indicator
KPI: key performance indicator

Overview of value-based holistic radio design

Holistic radio design components

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

Radio device capabilities
- Radio hardware
- Transmission schemes and signal processing algorithms
- Access schemes

Deployment scenario
- Type of deployment
- Frequency band
- Radio devices

Use case specifications:
- Type of environment
- Mobility
- Connection density
- Type of devices
- Service requirement

Optimization for improving KVIs while fulfilling performance KPIs.

Optimization of transmission schemes

Transmission schemes
Radio device (DSP): impact of DSP capabilities

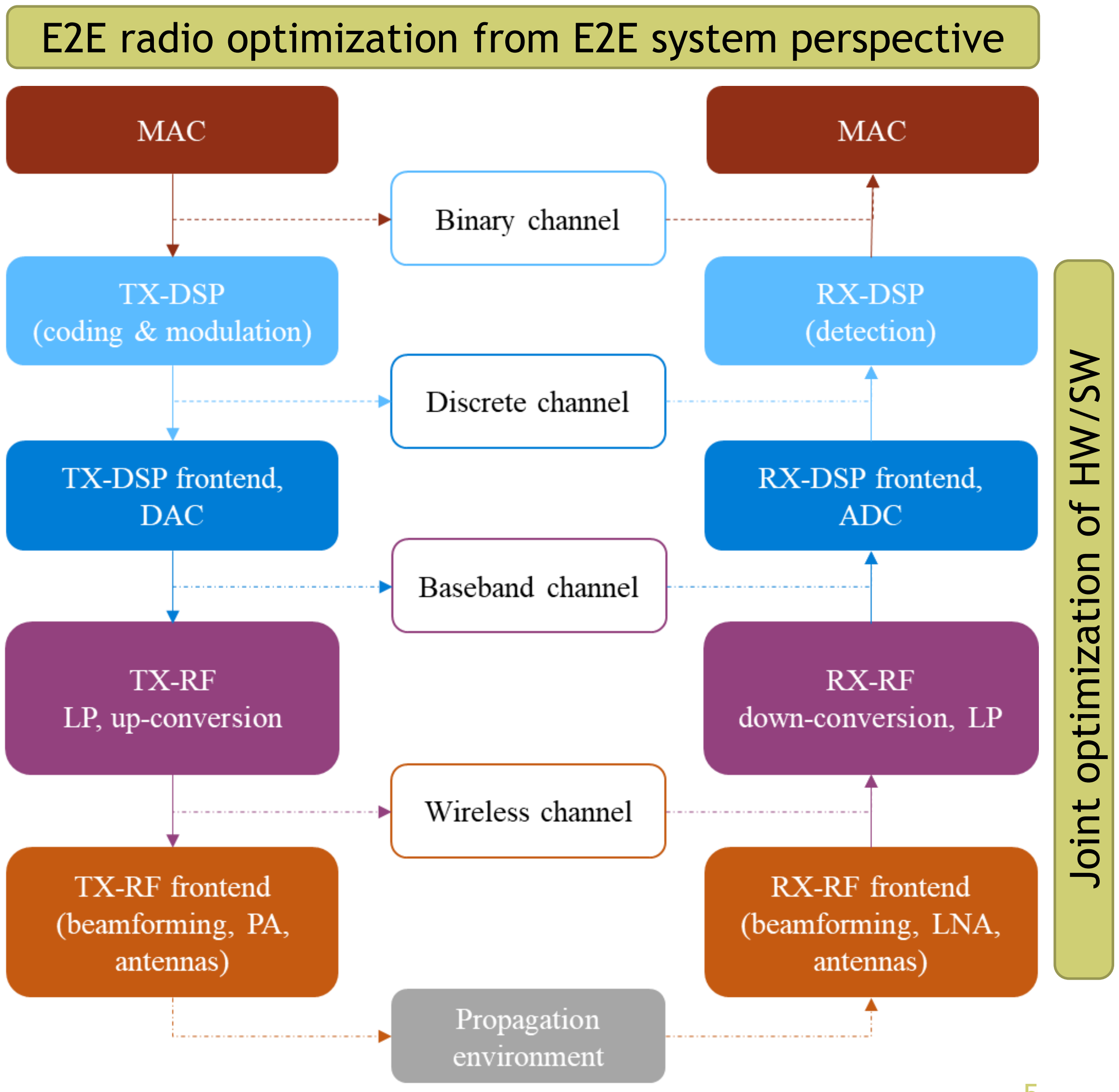
Radio device (DSP-Frontend, DAC, ADC): impact of DAC/ADC resolution

Radio device (RF converters, LPs): impact of phase noise

Optimization of frequency range and deployment

Frequency band and bandwidth
Radio device RF-frontend (antenna and beamforming, PA, LNA): impact of noise figure, PA non-linearity

Type of environment
Mobility
Type of deployment



6G Radio design requirements

- 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 .

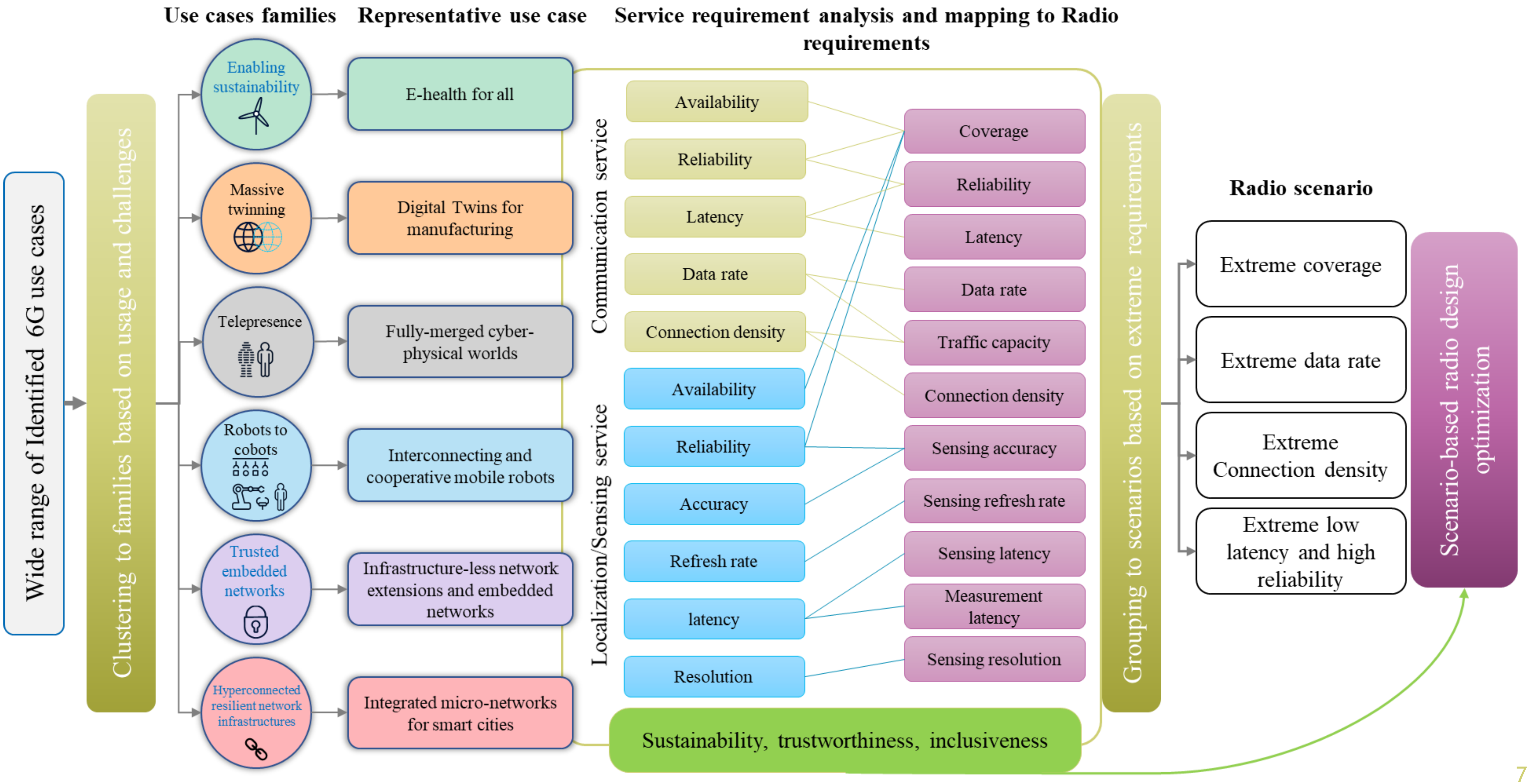
- General performance requirements

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.

Selected use cases and defined radio scenarios



Radio scenarios parameters and KPIs

- Sub-scenario can be defined by different combinations of scenario parameters
- Radio options can be provided by a range of requirements (e.g., extreme data rate for different coverage)

Radio scenario	Environment type	Deployment option	Radio devices	Mobility	Frequency	Data rate	Reliability	Latency	Connection density	Coverage	Sensing-related capabilities
Extreme coverage	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	Low Medium	Variable	Variable	Variable	Ultra-wide Extreme-wide	Variable
Extreme data rate	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	Static Low mobility Controlled mobility	mmWave or sub-THz Mixed and unlicensed for local connections	Ultra-high Extreme-high	Variable	Variable	Low Medium	Local	Variable
Extreme connection density	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	Medium High	Variable	Variable	Ultra-high Extreme-high	Variable	Variable
Extreme low latency and high reliability	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	Low	Ultra-high Extreme-high	Ultra-low Extreme-low	Variable	Local	Ultra-high

Radio design enablers for flexible, inclusive, sustainable and trustworthy radio

Summary

- Radio design enablers that contribute to achieving the KVIs of 6G system → WPO 4.1

Enablers	Topics	Scope

Flexible radio design	• Gearbox PHY
	  • Flexible hardware architecture
	  • Flexible transmission schemes
	• Proactive resource management
		• Provide multiple radio/PHY options to meet the diverse requirements of use cases (data rate, latency, reliability) to
		  • Improve energy efficiency
		  • Improve resource utilization
		  • Improve coverage

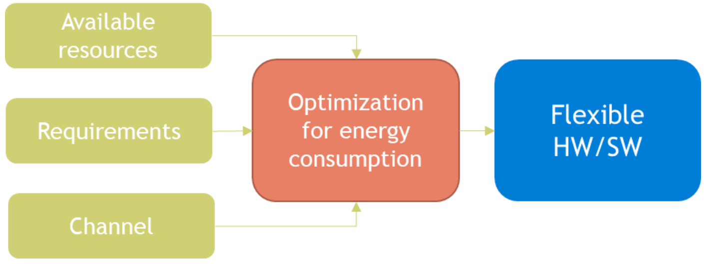
Inclusive radio interface	• TN/NTN enhancements
	• Integration with HAPS
		• Integrating terrestrial networks with non-terrestrial networks
		  • Connectivity to remote and rural areas
		  • Connection diversity for critical applications in urban areas
		  • 6G network for sustainability

Sustainable radio solutions	• Optimization framework for gearbox PHY switching
	• E2E optimization framework for energy efficiency
		• Optimization and selection of radio configurations
		  • Reduce overall energy consumption and achieve environmental sustainability
		  • Reduce the energy consumption and meet EMF exposure requirements

Trustworthy radio solutions	• PHY security • Jamming resilience schemes	• Physical layer based secret key generation (SKG) • Resilience against jamming attacks and resilience against unexpected failures

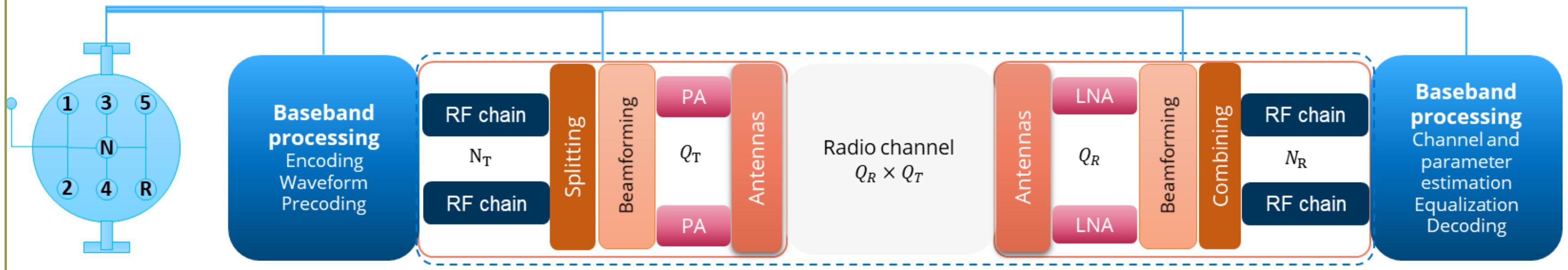
Flexible radio design and sustainability solutions

Gearbox PHY switching optimization



Selection of optimized radio option

Gearbox PHY: HW/SW flexible architecture



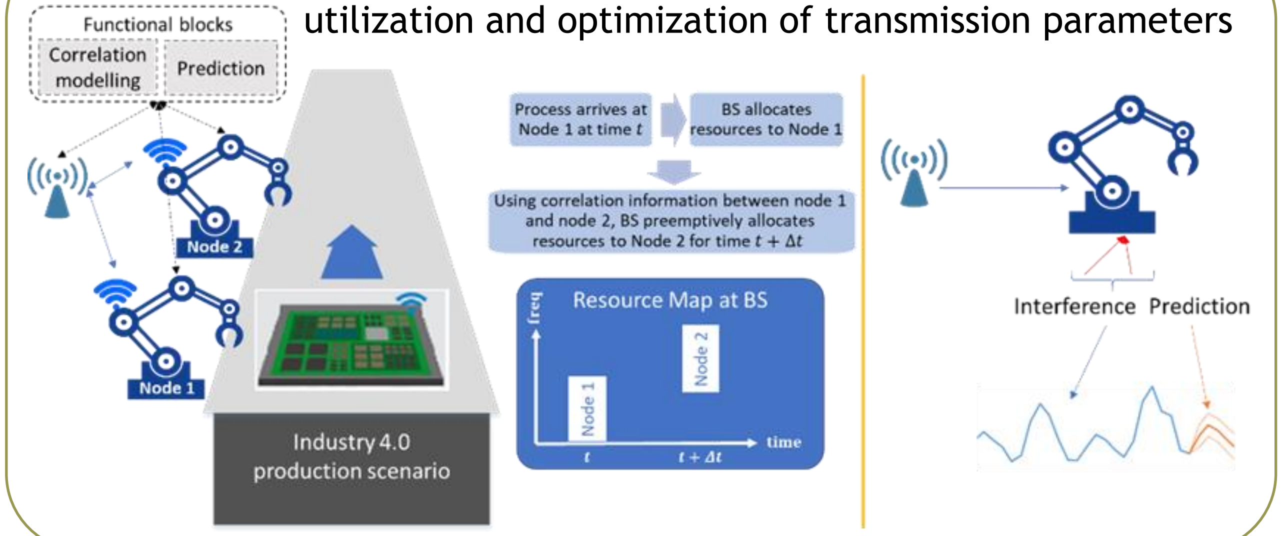
Flexible transmission schemes

Flexible hardware architecture

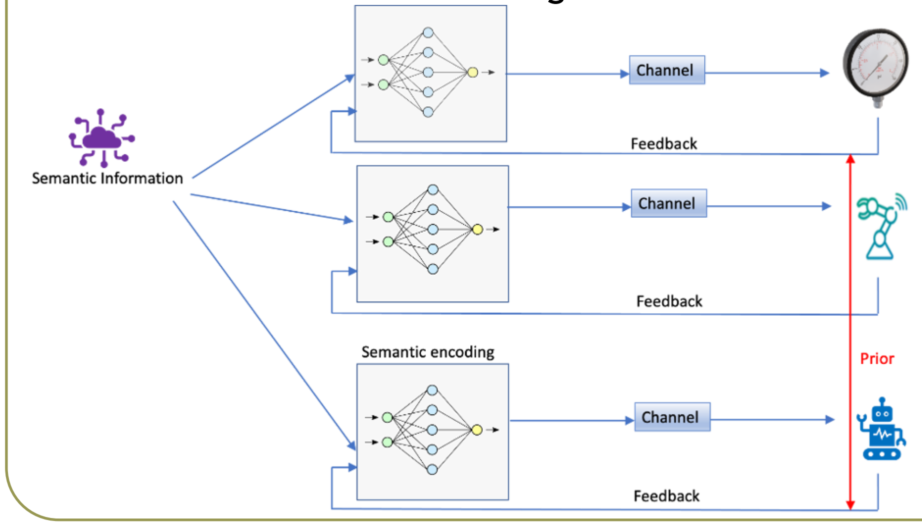
Flexible receiver algorithms

Sustainability solution for optimized operation of flexible radio

Proactive resource management: improve resource utilization and optimization of transmission parameters



Task-oriented semantic encoding: joint optimization of source and channel coding



Optimization for fulfilling communication requirements with minimum energy consumption

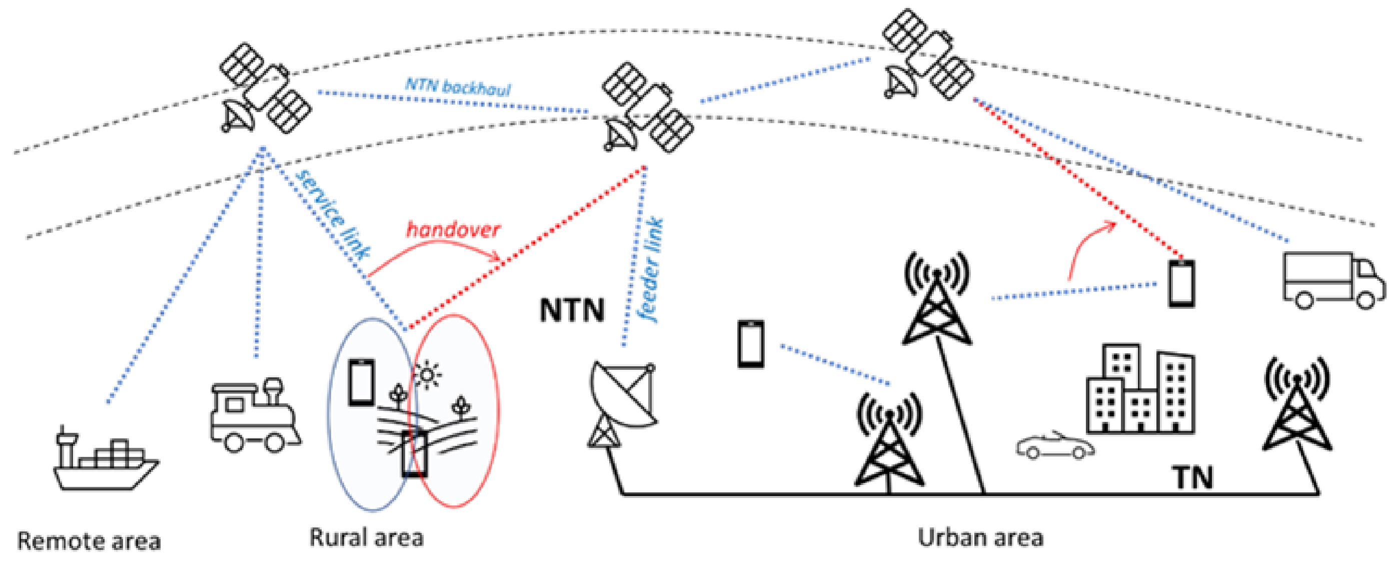
KPIs: trade-off between HW complexity and flexibility

Sustainability: optimization to reduce energy consumption

Inclusive radio interface

TN: terrestrial network
NTN: non-terrestrial network
HAPS: high altitude platform station

TN/NTN enhancement: including HAPS



- Air interface enhancement solutions in-line with 3GPP standardization
- Enhancements on mobility and service continuity procedures (e.g., handover, cell reselection)
- Convergence of multiple different technologies such that they can seamlessly coexist and provide un-interrupted service with acceptable costs and complexity

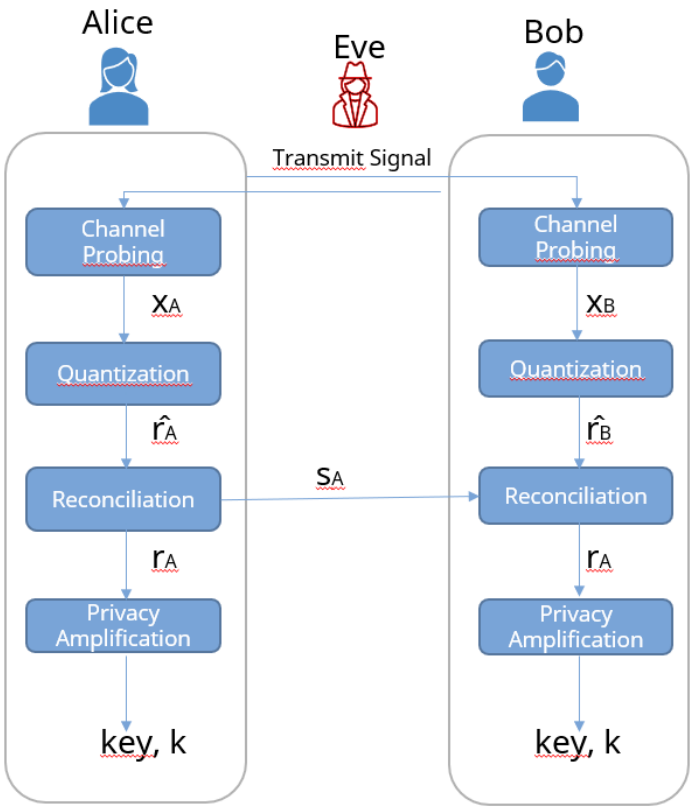
- Improvement of coverage area
- Reduction of signalling overhead

KPIs: trade-off between complexity and flexibility

Inclusiveness: Improving access and reliability in rural and/or remote areas

Trustworthy radio solutions

PHY Security: secret key generation using channel state information



KPIs: information leakage

Trustworthiness: Security through PHY-based secret key generation

Jamming resilience schemes: to recover to the original state after a disruptive incident

- Detection of adverse events, like jamming and informing the application to switch to a safe state.
- The network may explore alternative routes, radio resources, or access points.
- Flexible PHY offers transmission modes that are harder to jam, such as spread spectrum techniques.
- Future steps:
  - Define threat scenarios.
  - Develop and evaluate schemes against these scenarios.
  - At the PHY level, emphasize creating jam-resistant transmission modes.

BER in jammed scenarios, availability metrics

KPIs: jamming classification accuracy

Trustworthiness: resilient schemes provide robustness against jamming attacks and unexpected failures

Radio link modelling

Summary

- Channel modelling and link-level modelling and simulation tools→ WPO 4.2

Enablers	Topics	Scope

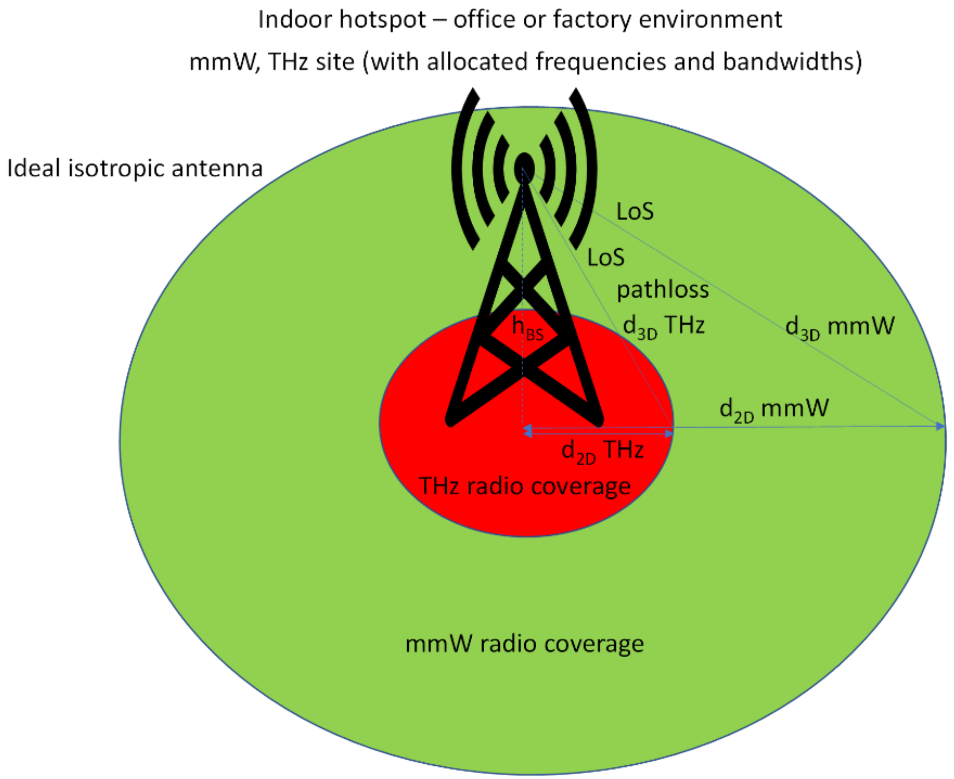
Channel modelling	• Channel models at Sub-THz frequencies
	• Coverage analysis at THz frequencies
		• Study of signal behaviour at sub-THz frequencies in different scenarios and sites
		  • Channel models for fading, blockages and other propagation mechanisms for the (100-300 GHz) range
		  • Guidelines for modelling frameworks (e.g., stochastic and deterministic models)
		• Study of coverage
		  • Radio coverage at THz frequencies (300 GHz–3 THz)
		  • Compare coverage achievable at THz frequencies with that at sub-THz frequencies using theoretical analysis

Link-level signal modelling	• Link modelling of 6G physical layer
	• Hardware modelling of RIS
		• Provide a comprehensive analysis of the potential and main limitations of communications in the sub-THz band
		  • Develop a link-level simulation tool for 6G PHY that includes propagation model in the sub-THz frequency band
		• RIS modelling to be incorporated in link-level simulation tool
		  • Simulate model radiation patterns of RIS and compare simulated results to measurements in the FR2 frequency band

Channel modelling

Channel models at Sub-THz frequencies (100-300 GHz):
measurement campaign

Coverage analysis at THz frequencies (300 GHz-3 THz):
theoretical analysis

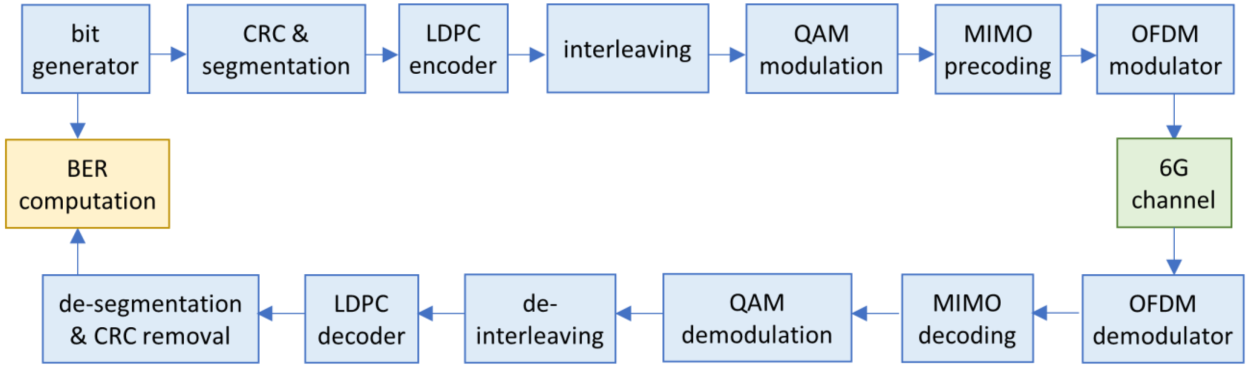


KPIs: Coverage, SNR, achievable range

Inclusiveness: new frequency ranges with increased bandwidth enable new services

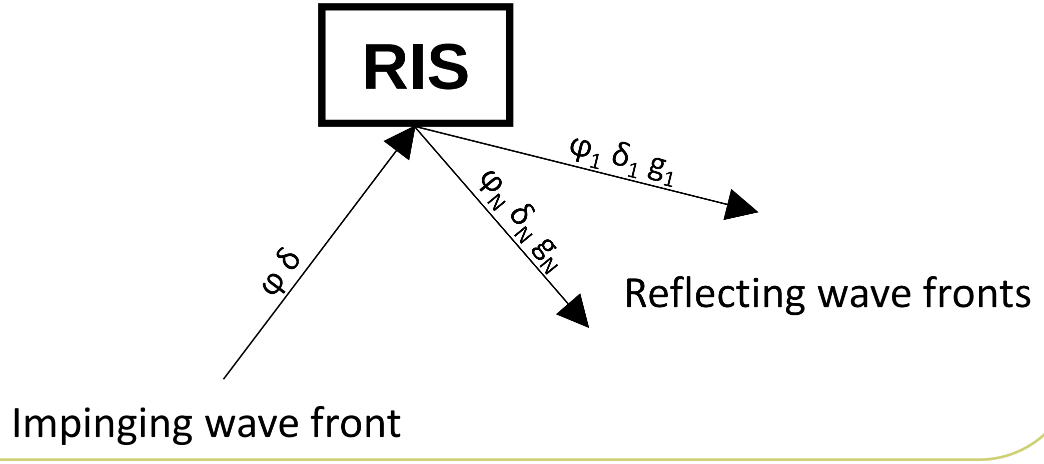
Link-level signal modelling

Link modelling of 6G physical layer: link-level simulator



KPIs of simulation: BER, BLER, SNR, spectral efficiency, throughputs

Hardware modelling of RIS: simulation and measurement of RIS in FR2



KPIs: radio coverage

Trustworthiness: Reliability given the ability of RIS to introduce spatial diversity in the radio propagation environment

Waveforms and modulations

Summary

- Waveforms and modulation schemes suitable for sub-THz frequencies → WPO 4.2

Enablers	Topics	Scope

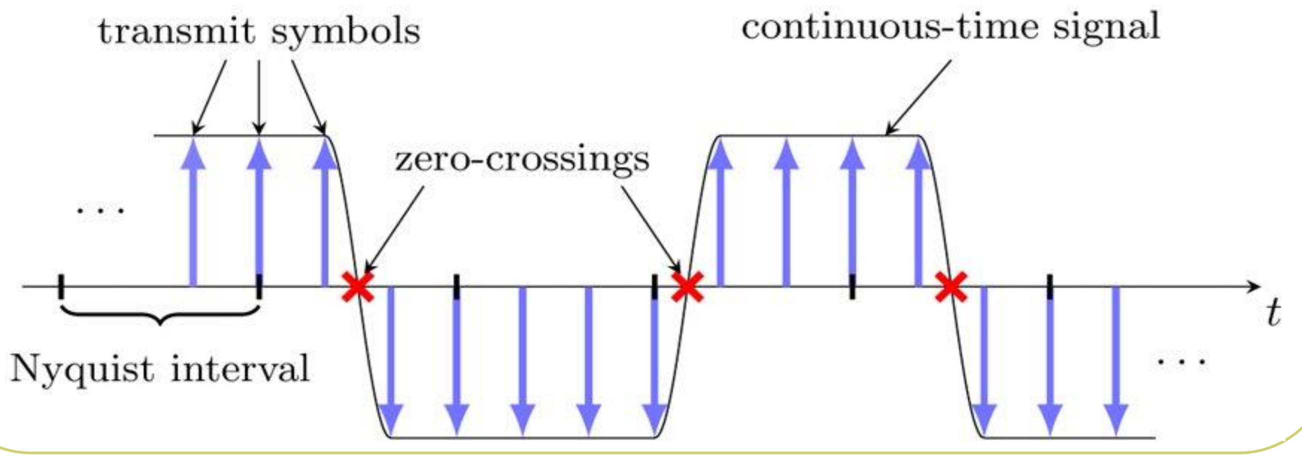
Waveforms and modulations	• Feasibility of the mainstream 6G waveforms at sub-THz frequencies	• Evaluate the suitability of waveforms for sub-THz frequency ranges
		  • Candidate waveforms: OFDM and SC-based waveforms
		  • Analysis of energy and spectral efficiency, PN tolerance and scalability

	• Zero-crossing modulation (ZXM)	• 1-bit ADC with temporal oversampling and information encoded in time-domain
		• Study the viability of ZXM as a waveform for specific scenarios in the presence of ample spectrum
		  • Energy and spectral efficiency
		  • Robustness to non-idealities

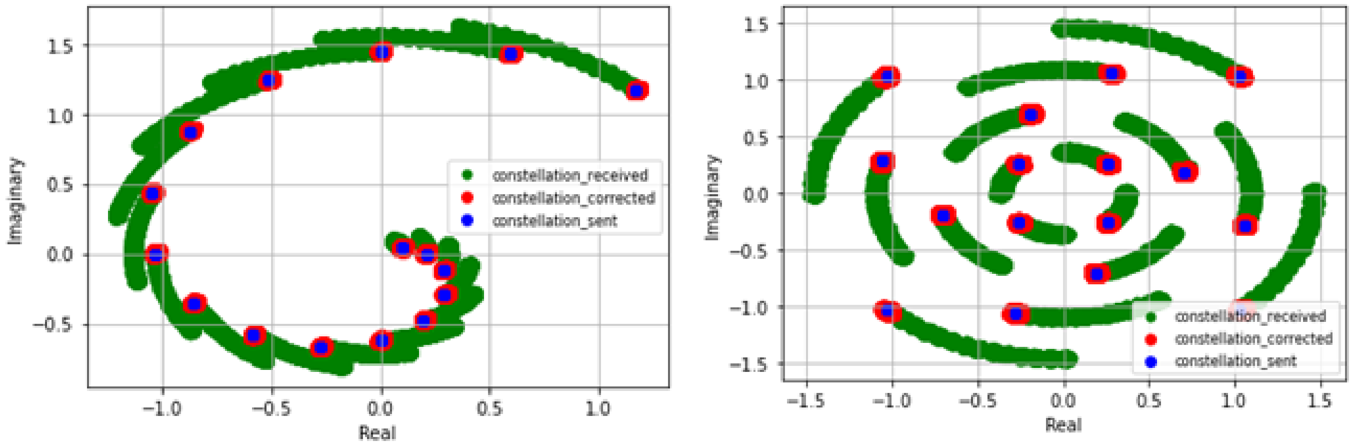
	• Polar constellations	• Analysis of new types of constellations combined with a multicarrier waveform • Robustness against PN and Doppler shift
	• Learned MIMO waveforms	• Investigation of end-to-end learning approaches to obtain waveforms that facilitate signal detection without the need of pilots

Waveforms and modulations at sub-THz frequencies

ZXM: 1-bit ADC with temporal oversampling and information encoded in time-domain



Polar constellations: robustness under phase noise and Doppler shift



KPIs: spectral efficiency, BER versus SNR and Doppler shift

KPIs: energy efficiency in terms of energy per bit

Sustainability: reduced energy consumption
Inclusiveness: Decreased computational and hardware complexity. Increased scalability over different frequency bands

Intelligent radio air interface

Summary

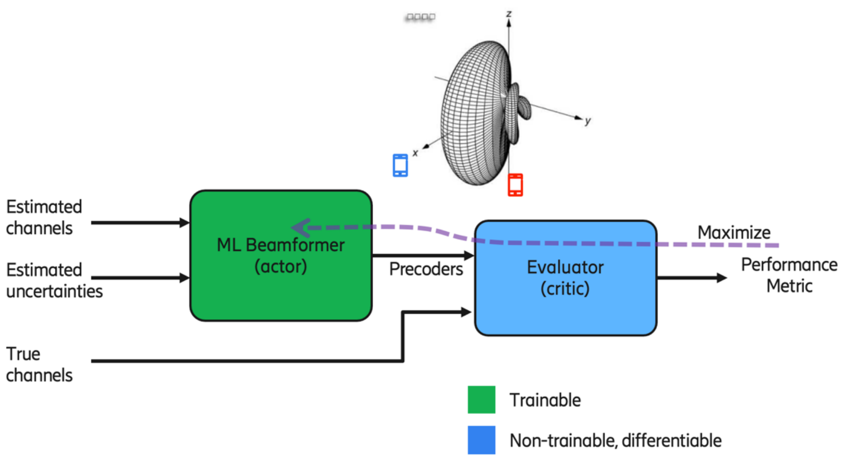
- Intelligent air interface design for enhancement of FR1 and FR2 spectrum → WPO 4.4

Enablers	Topics	Scope
Intelligent transmitter	• MIMO transmission • New flexible multicarrier waveform • Optimized coded modulation	• AI/ML-based beamforming in the presence of imperfect CSI estimates • Antenna muting patterns to achieve target spectral efficiency • AI-based scheduling in MU-MIMO under limited feedback scenarios • ML-based approaches for D-MIMO resource allocation and optimization • Adaptive multi-carrier modulation • AI/ML for coded modulation optimization
Intelligent receiver	• Power amplifier non-linearity compensation • AI-enabled CSI acquisition	• AI-based compensation of the PA non-linearity at the receiver • Framework for CSI prediction

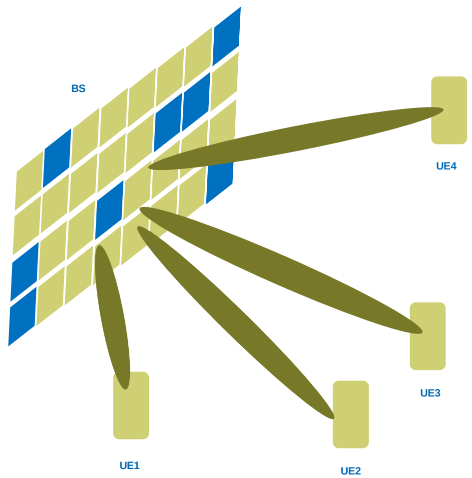
Intelligent transmitter and receiver	• Learned MIMO waveforms
	• AI-based CSI feedback
	• Energy efficient LDPC channel encoding/decoding schemes
	• MU-MIMO optimization in diverse device scenarios
		• E2E learning for constellation and blind MIMO detection
		• AI-based techniques for improving spectral efficiency and accuracy of channel state feedback (CSF) compared to CSI schemes
		• Methods for combined CSI precoding and compression
		• AI/ML-based optimization of LDPC matrix design to improve performance while minimizing hardware complexity and reducing energy consumption
		• MU-MIMO optimization methods for scenarios with massive number of diverse devices
		  • Intelligence at the receiver side for channel estimation and feedback
		  • Intelligence at the transmitter side for MU-MIMO precoding

Intelligent transmitter design

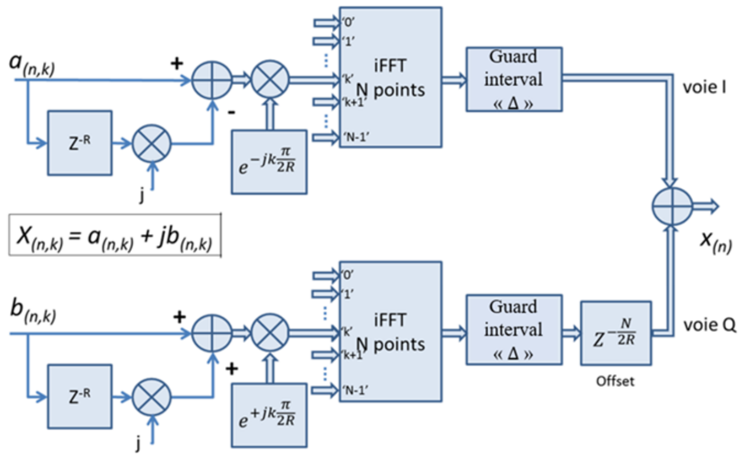
ML-based beamforming with imperfect CSI estimates



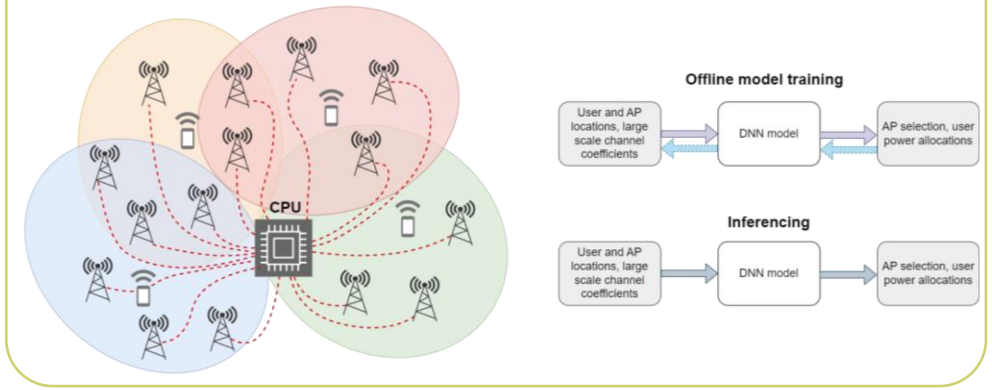
Antenna muting for massive MIMO



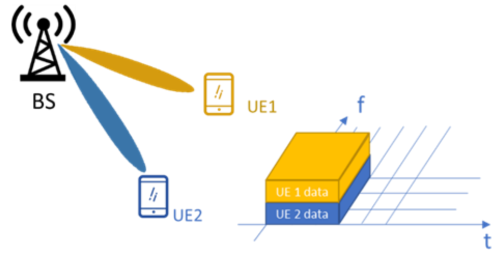
Flexible multicarrier waveform



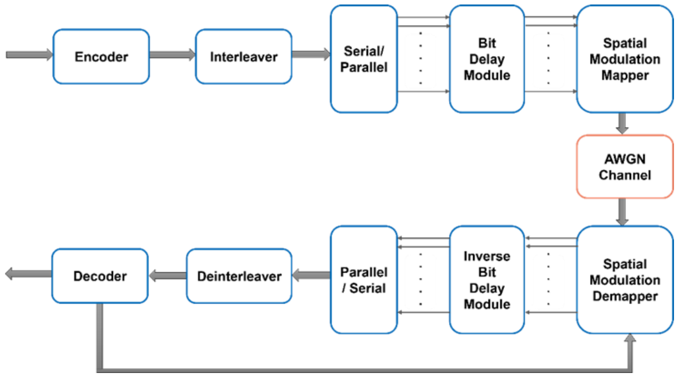
D-MIMO resource allocation



MU-MIMO pairing with limited feedback



Optimized coded modulation



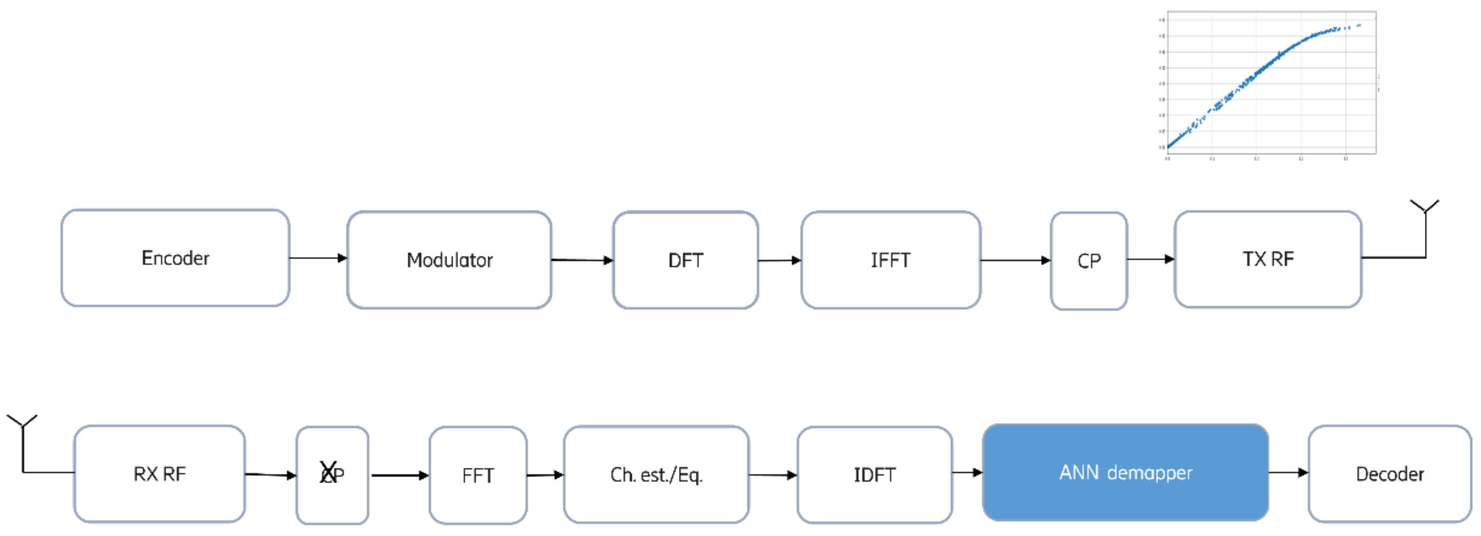
KPIs: spectral efficiency, latency, cell capacity, throughput, spectral density, FER, BER

KPIs: Energy consumption reduction, reduced computational complexity

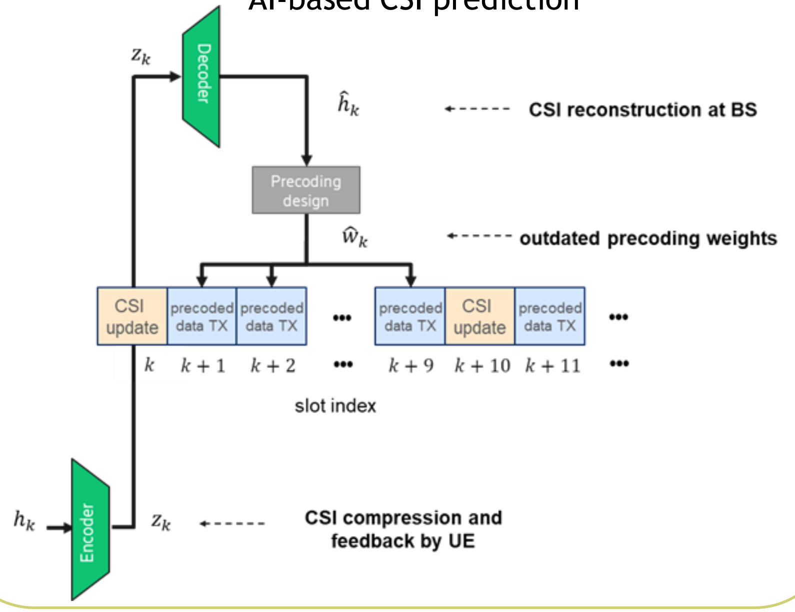
Sustainability: optimization for reducing energy consumption

Intelligent receiver design

PA nonlinearity compensation: using AI/ML at the receiver



AI-based CSI prediction



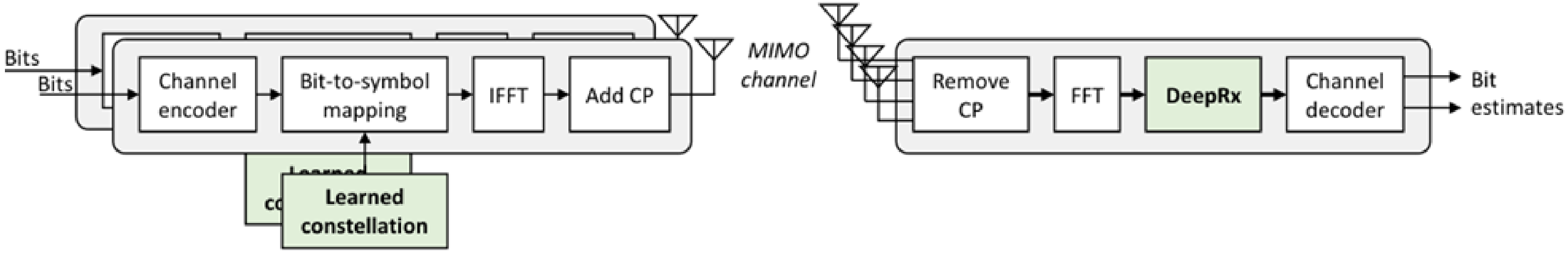
KPIs: uncoded BER, BLER, spectral efficiency, BLER, throughput

KPIs: energy efficiency

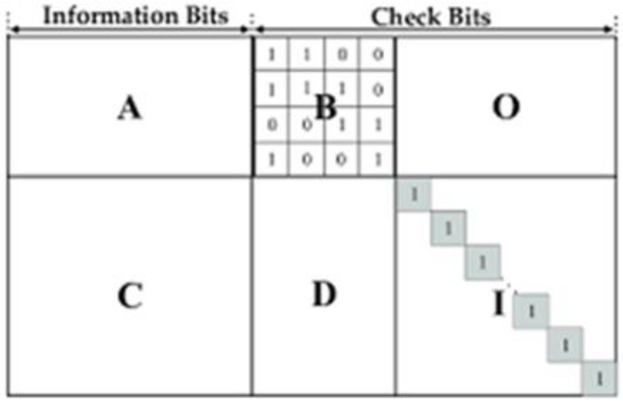
Sustainability: optimization for reducing energy consumption

Intelligent transmitter and receiver

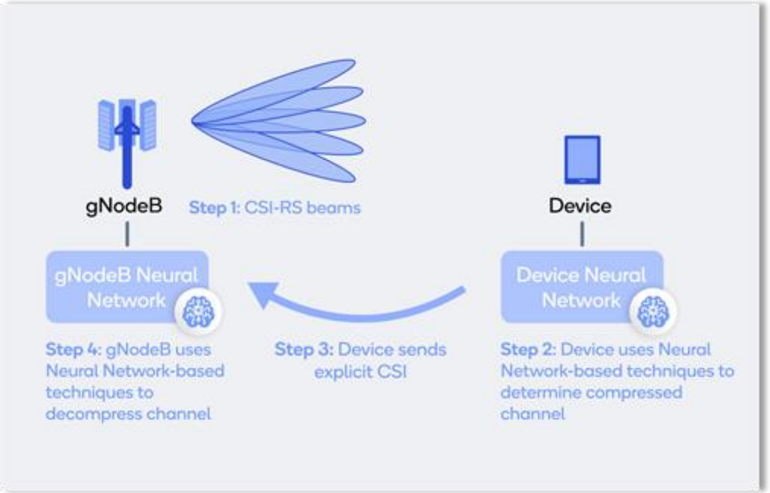
Learned MIMO waveforms



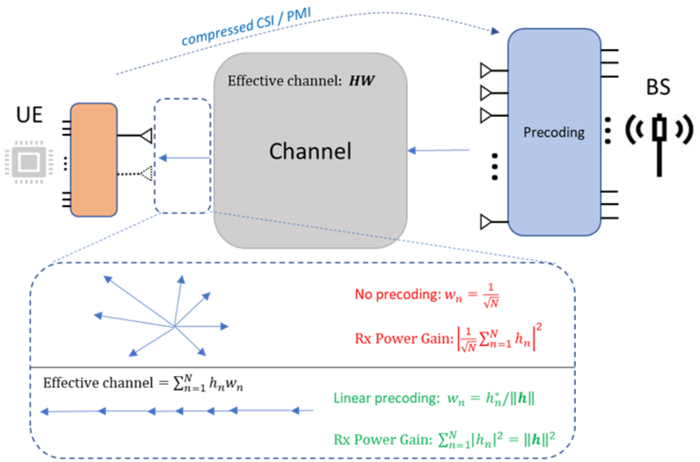
LDPC optimization



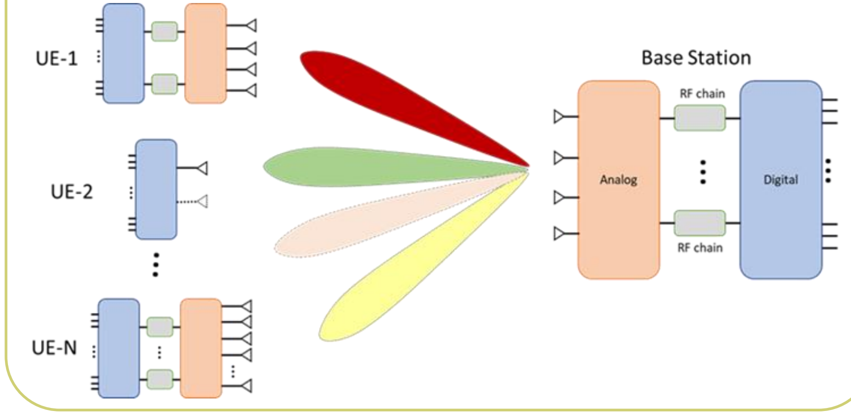
CSI feedback



CSI compression



MU-MIMO optimization



KPIs: spectral efficiency, throughput, spectral density, BLER, FER, BER

KPIs: reduced complexity, efficient resource usage, reduced energy consumption, trade-off performance and complexity

- Trustworthiness: via increased integrity of the physical layer transmission
- Sustainability: energy-efficient air interface

MIMO Transmissions

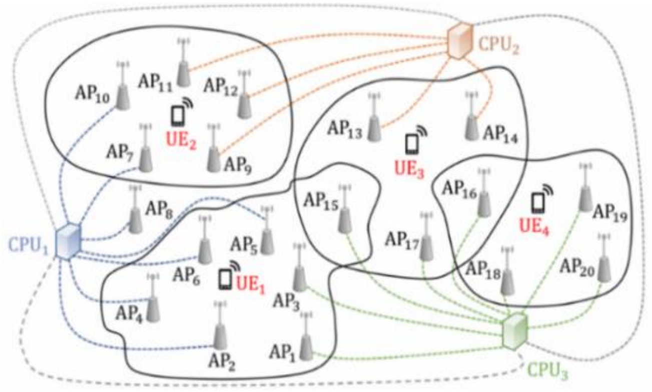
Summary

- MIMO techniques: architectures and transmission schemes → WPO 4.2, WPO 4.4

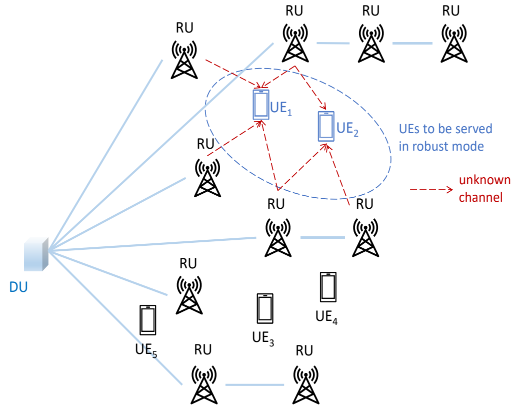
Enablers	Topics	Scope
D-MIMO schemes and architectures	• Coherent joint transmission • Non-coherent joint transmission • Scalable transmission • Distributed massive MIMO for machine type communication • RIS-assisted IAB • Decentralized transmission • One-bit ADC for multi-cell setup • Multi-antenna location-dependent coded caching • EMF evaluations for distributed transmissions	• Study the feasibility of analogue fronthaul, model blockage and reduce its likelihood in coherent joint transmission • Enhance diversity in non-coherent joint transmission with orthogonal codes • AI/ML-based approaches for resource allocation to enable scalability • Outage probability in centralized and distributed massive MIMO setups • Performance analysis of RIS in integrated access and backhaul (IAB) networks, with focus on reliability and throughput in backhaul links • Study cooperative beamforming strategies with bi-directional training • Evaluate 1-bit ADCs/DACs with power tuning in multi-cell setups • Investigate a multi-antenna content delivery scheme based on coded caching for high data-rate connectivity and strict delay constrains • Simulation for EMF exposure assessment for different antenna precoding
Massive MIMO schemes and architectures	• Hybrid analogue-digital architectures • Fully digital architectures with low-resolution ADCs/DACs	• Beam search in sub-THz D-MIMO network assisted with sub-6 GHz links • Analytical framework for comparing different architectures in terms of spectral and energy efficiency
RIS-assisted transmission	• RIS control procedure, interface and integration • D-MIMO assisted with RIS • Channel estimation for RIS • Learn RIS-reflecting modulation (RM)	• Analyse the signal level obtained with RIS in a simplified scenario • Design control procedures for RIS integration in radio networks • Control procedures for externally controlled RIS • Provide guidelines for deployment, selection and control of RISs • ML-based channel estimation for RIS aided systems under mobility conditions • ML-based approach to learn the signalling set for

D-MIMO schemes and architectures

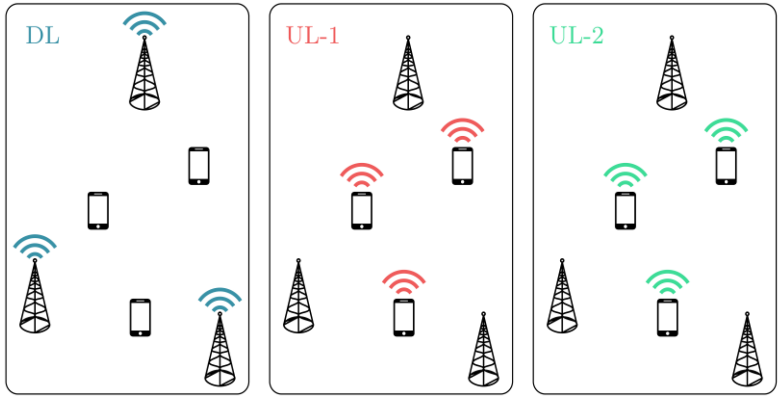
Coherent joint transmission



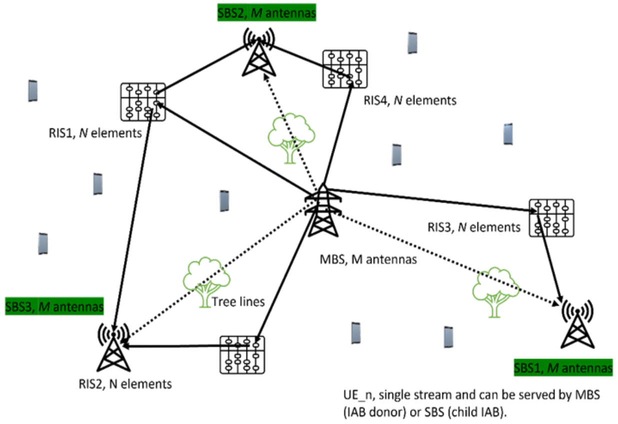
Non-coherent joint transmission



Decentralized Transmission



RIS-assisted integrated access and backhaul



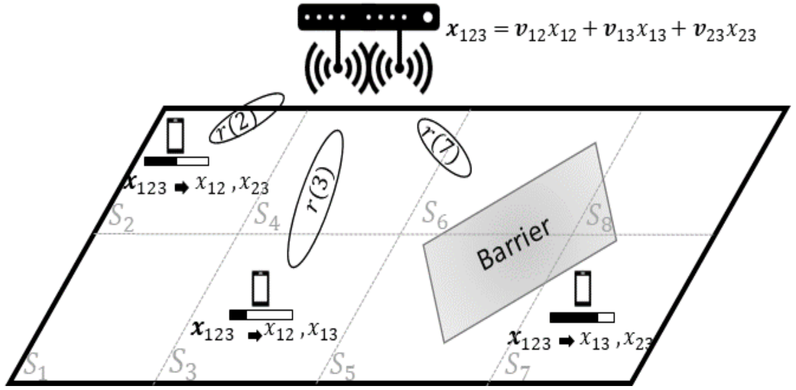
KPIs: spectral efficiency, BER, cell capacity, throughput, coverage

KPIs: Energy consumption reduction, reduced cost

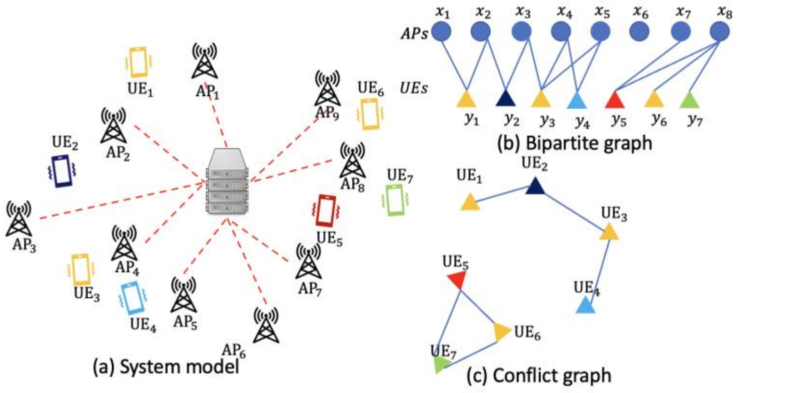
- Sustainability: reduced energy consumption
- Inclusiveness: coverage extension
- Trustworthiness: higher reliability

D-MIMO schemes and architectures

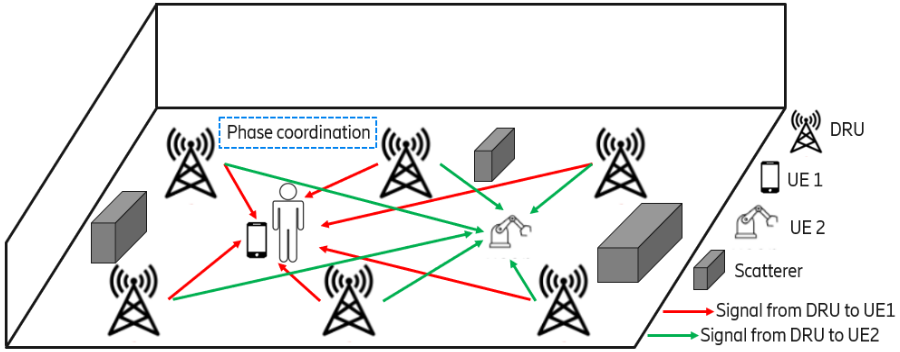
Multi-antenna coded-caching



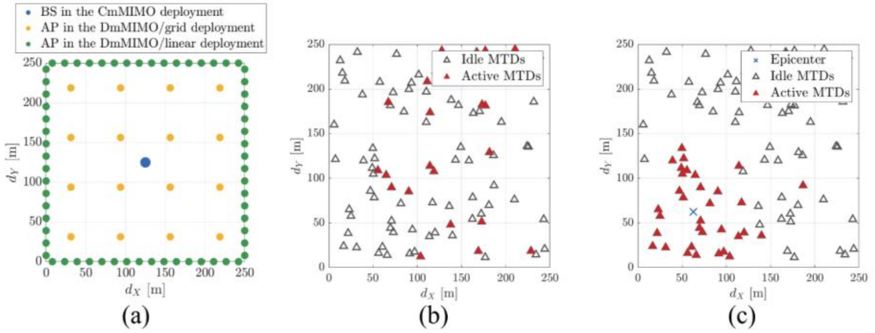
Joint UE / AP selection for scalable transmission



EMF evaluation for distributed transmissions



Distributed massive MIMO for MTC



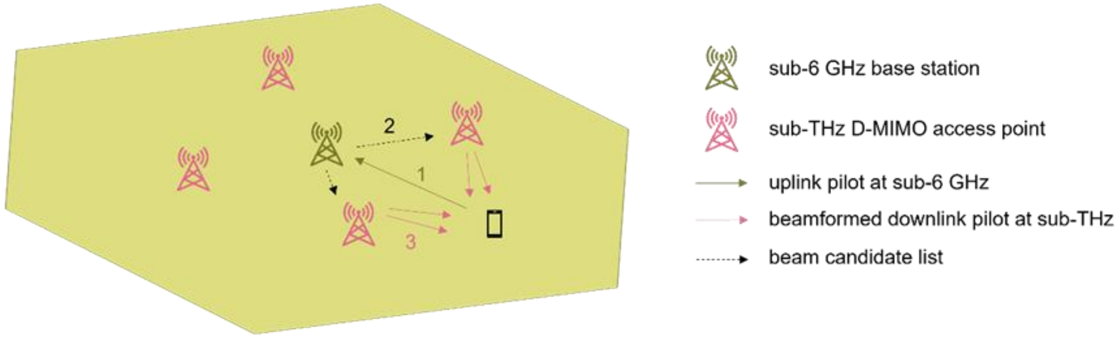
KPIs: spectral efficiency, Latency, BER, cell capacity, throughput, coverage

KPIs: Energy consumption reduction, reduced complexity

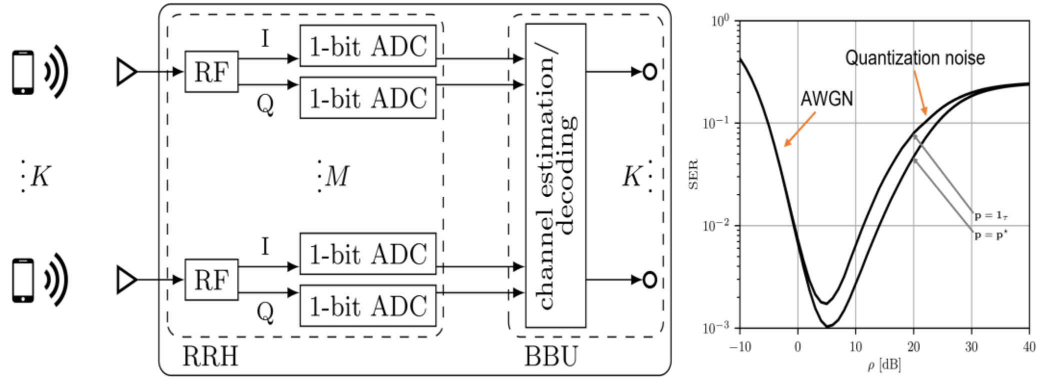
- Sustainability: reduced EMF exposure
- Inclusiveness: coverage extension

Massive MIMO schemes and architectures

Sub-THz D-MIMO assisted by a sub-6 GHz macro network



Fully digital architectures with low-resolution ADCs/DACs



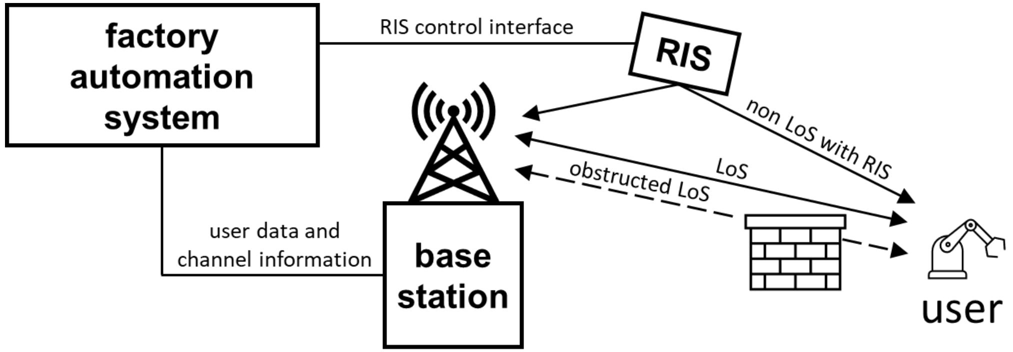
KPIs: spectral efficiency, BER, cell capacity, throughput, coverage

KPIs: reduced complexity, reduced cost

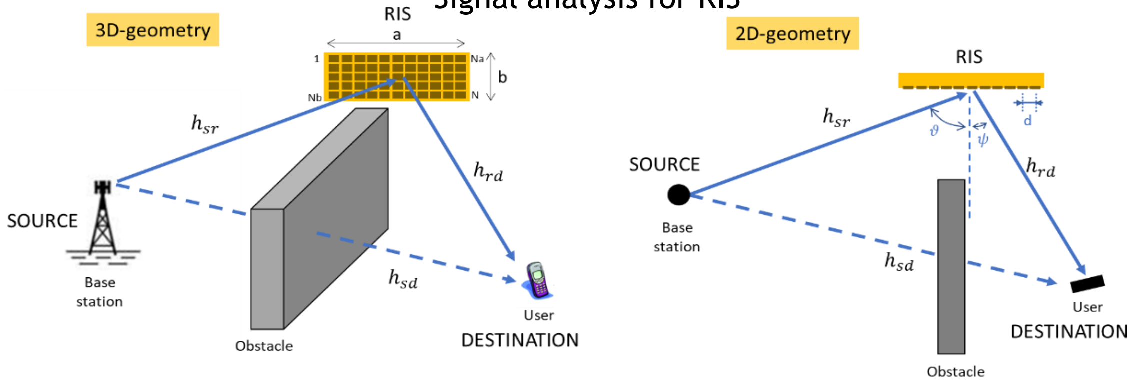
Inclusiveness: Lowering cost for device

RIS-assisted transmission

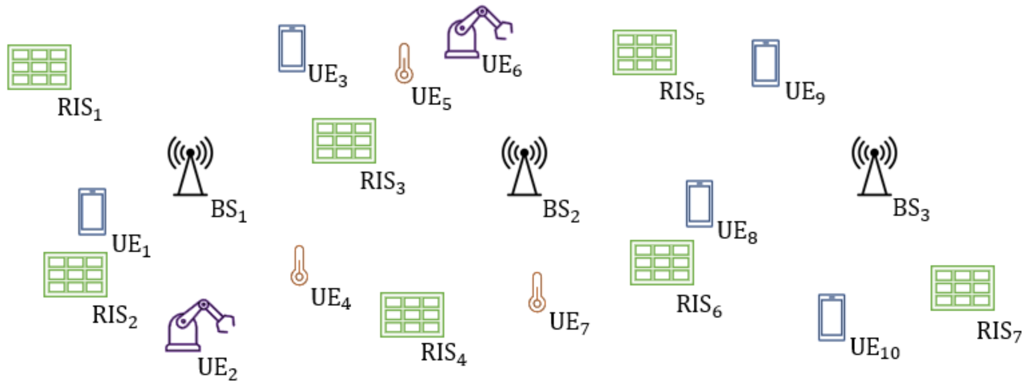
Control procedures for externally controlled RIS in industrial environments



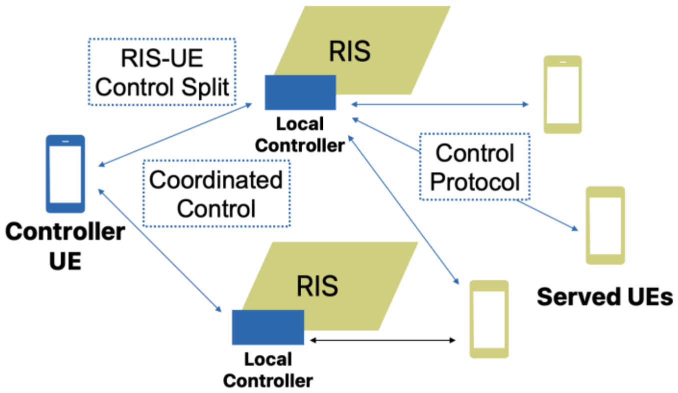
Signal analysis for RIS



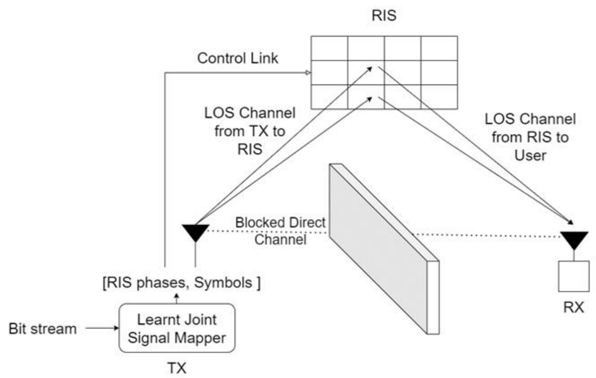
RIS-assisted D-MIMO



Control procedures for personal RIS



Learn RIS-RM



KPIs: spectral efficiency, BER, cell capacity, throughput, coverage

KPIs: reduced energy consumption

Inclusiveness: increasing coverage, lowering cost, increased service availability
Sustainability: lowering EMF exposure

Flexible spectrum access solutions

Summary

- Spectrum access solutions→ WPO 4.5

Enablers	Topics	Motivation
Spectrum sharing, coexistence	• assumptions and models to determine sharing possibilities • TN-NTN spectrum coexistence and sharing • multi-RAT spectrum sharing	Spectrum is valuable and scarce. The ability to leverage spectrum that is already allocated to existing services is essential. Additional emerging non-terrestrial connectivity leads to new interference scenarios requiring further research.
Low-latency random access	• sub-THz access methods • risk-informed random access	Many services require low-latency access to spectrum for a good and reliable user experience. Sub-THz propagation characteristics as well as localised services require rethinking of spectrum access methods.

Sustainability	*Inclusion*	*Trustworthiness*
NW- and device-side energy efficient solutions.	Fair access to spectrum for all.	Dependable access to spectral resources.

Spectrum Sharing, Coexistence

FR1 spectrum sharing with 5G. Expected output:

- Dynamic sharing strategies, transparent to legacy 5G systems.

Assumptions and models to determine sharing possibilities between mobile networks and other radio services. Expected output:

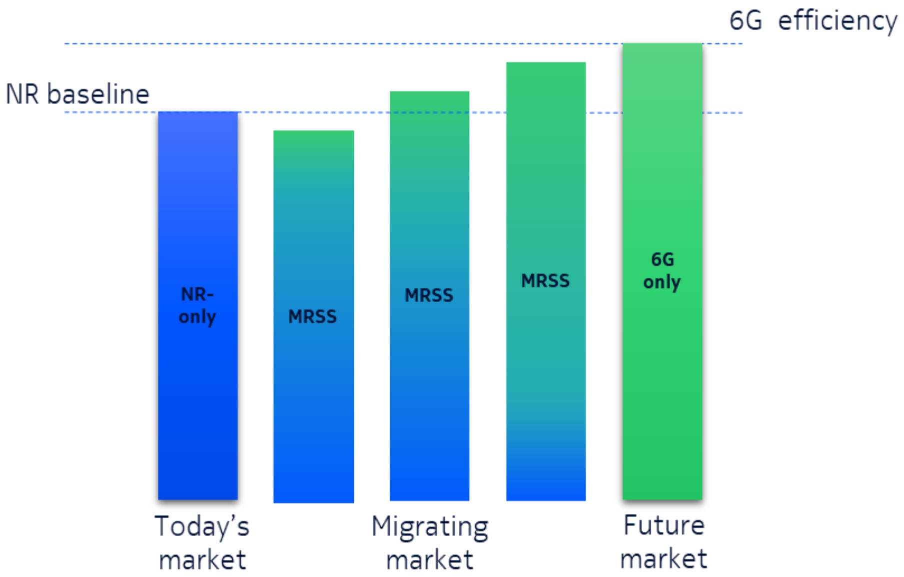
- Better coexistence conditions between IMT and other radio services, e.g., shorter separation distances.

TN-NTN spectrum sharing in the centimetric range (3–30 GHz) using sensing, AI, etc. Expected output:

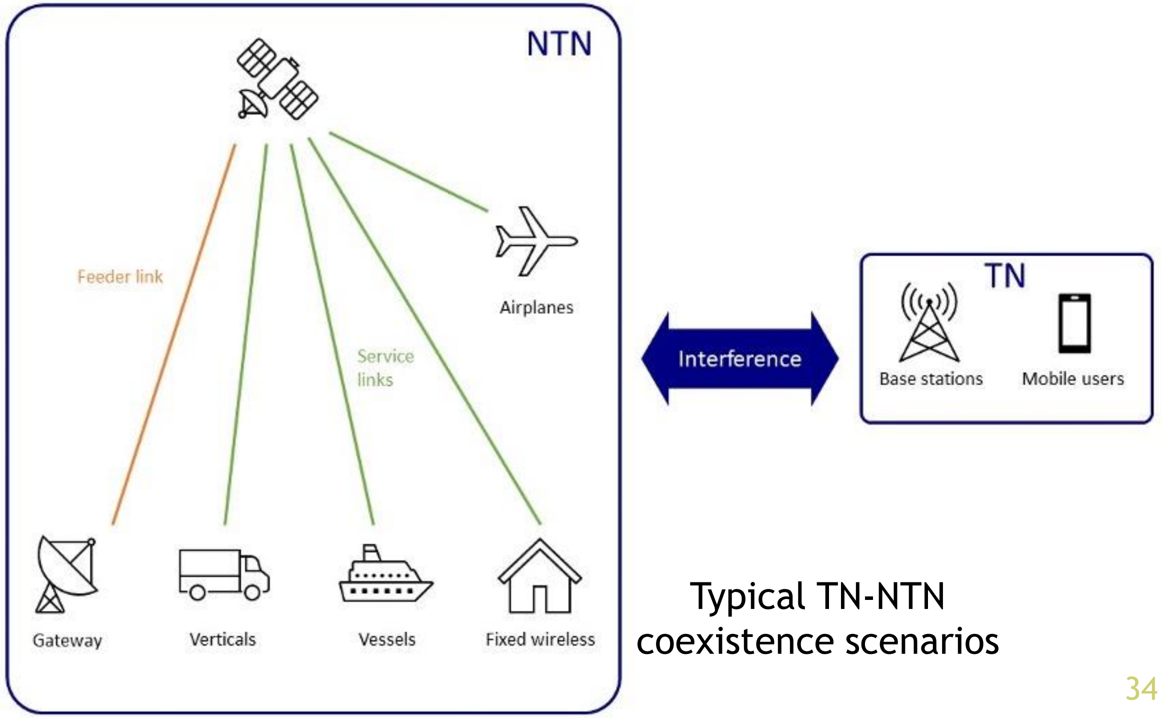
- Understanding interference patterns and risks between TN and NTN, including also other satellite services.

TN-NTN coexistence: interference management, spectrum sharing frameworks. Expected output:

- Spectrum sharing strategies and algorithms.



Multi-RAT Spectrum Sharing opportunities between 5G and 6G, specifically in FR 1



Typical TN-NTN coexistence scenarios

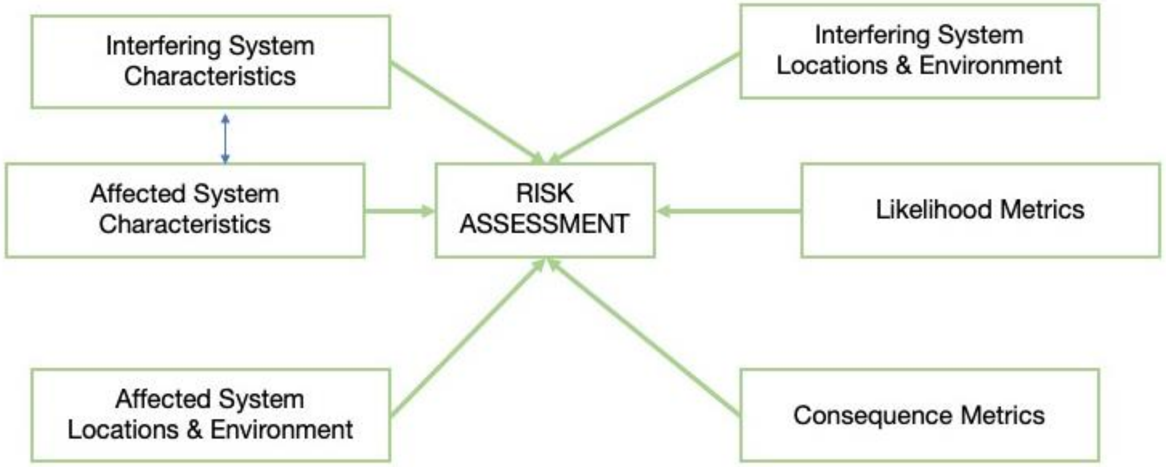
Low-Latency Random-Access

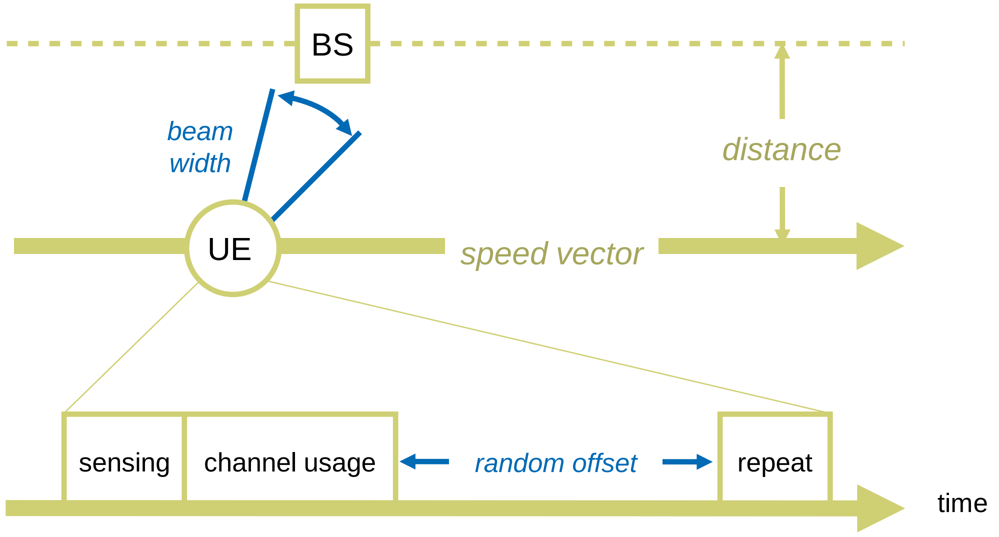
Risk-informed random access to localized communication: non-coordinated random access, if risk for interference is low. Expected output:

- KPI metrics definition; what do we mean with low risk?
- Required regulatory and technical enablers.

Define and assess sub-THz spectrum access methods, covering initial search, initial access, idle and connected mode access. Expected output:

- Specification of sub-THz access schemes.
- Latency and capacity assessment of selected access schemes.





KPIs and KVIs

KPIs

- Accuracy
- Access latency
- Capacity
- Throughput
- Spatial separation distance
- Energy efficiency

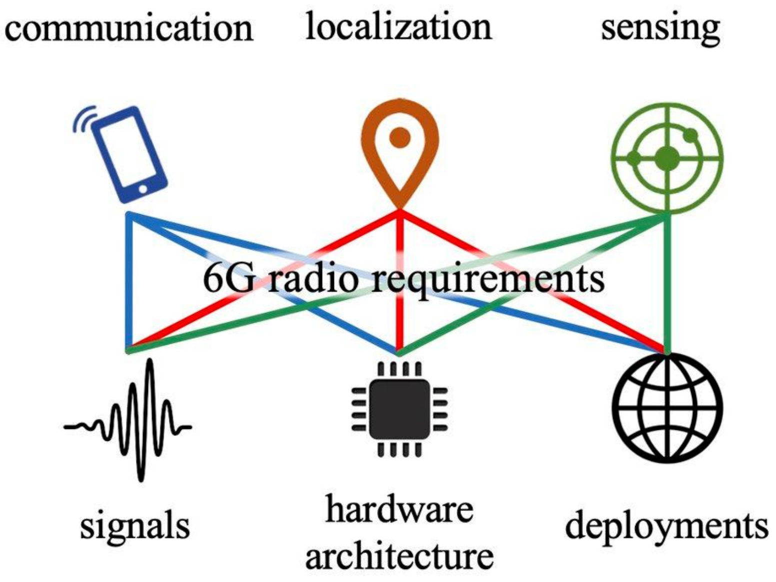
KVIs

- **Sustainability**
  - More efficient use of resources
  - Network- and device-side energy efficient solutions
- **Inclusiveness**
  - Connection to remote areas with fair access to spectrum for all
- **Trustworthiness**
  - Higher reliability
  - Dependable access to spectral resources

Joint Communications and Sensing

Terminology: radio positioning, localization, sensing, JCAS

- Positioning refers to the estimation of the position of a connected device. Positioning may rely on sensing information.
- Localization includes also the estimation of the position of a passive object / target (e.g., device-free localization).
- Sensing comprises: Receiving a radio signal or a set of radio signals and processing these radio signals to extract information relevant for a service. The received radio signals in general depend on the geometric state of the transmitter, receiver, and the environment (e.g., radar sensing), though not all sensing services rely on this geometry (e.g., pollution monitoring).
- JCAS (considered equivalent to ISAC) wireless systems that combines communication and sensing functionalities to re-use hardware, save resources (vs. having 2 systems), and/or for a cross-functional benefit. Not restricted to a particular usage of pilots or data symbols.



Summary

- Joint communication and sensing over a unified radio infrastructure→ WPO 4.3

Aspects	Topics	Scope

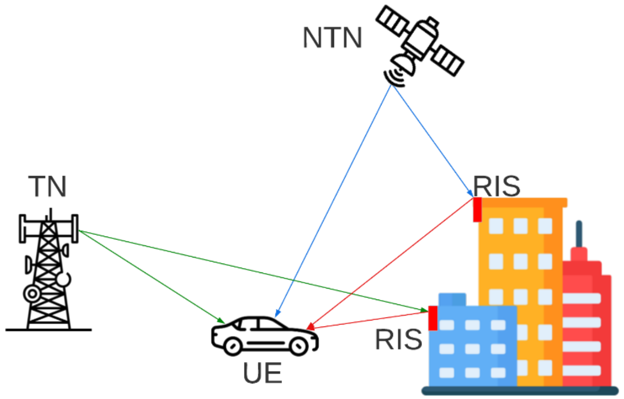
Architectures	• NTN-aided localisation
	• Integrated communication and monostatic sensing
	• Integrated monostatic and bistatic sensing
	• Multi-static sensing
		• Investigating multiple sensing and localization deployment scenarios to provide a positioning/sensing solution that is:
		  • Accurate
		  • Available

Waveforms, frame structures, & resource allocation	• Flexible baseband transceiver for JCAS
	• Waveform learning for JCAS
	• Optimization of OFDM-based bistatic sensing
	• Resource allocation in/for:
	  • Multiband hybrid-beamforming transceiver
	  • 6D tracking in JCAS scenarios
	  • Inter-UE sensing
	• Power consumption of JCAS
		• Investigating methods to re/co-use communications infrastructure (waveforms and frames) for sensing and localisation purposes
		• Optimal precoding and resource allocation through model-based and data-driven techniques
		• Studying the power consumption of UEs under various sensing deployment scenarios and KPI requirements.

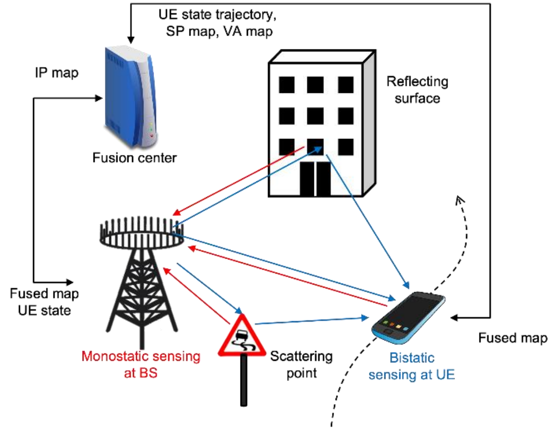
Security & Privacy	• Privacy and security for JCAS • UE-related security aspects of JCAS • Jammer localisation	• Studying security aspects of JCAS systems from the point of view of both the UE and the network • Investigating methods to locate jammers for mitigation purposes

JCAS architectures

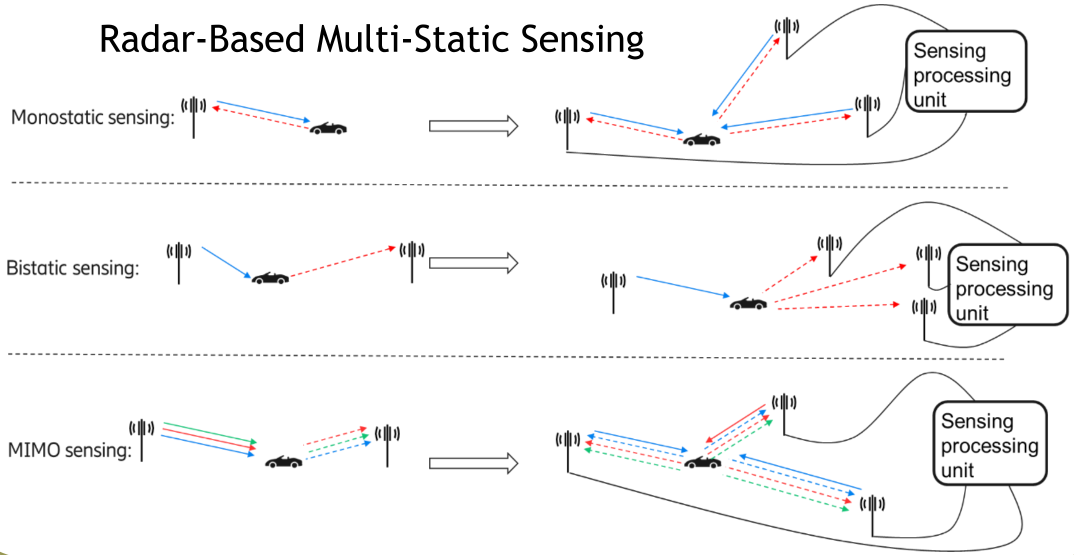
NTN localization and integration with TN and RIS



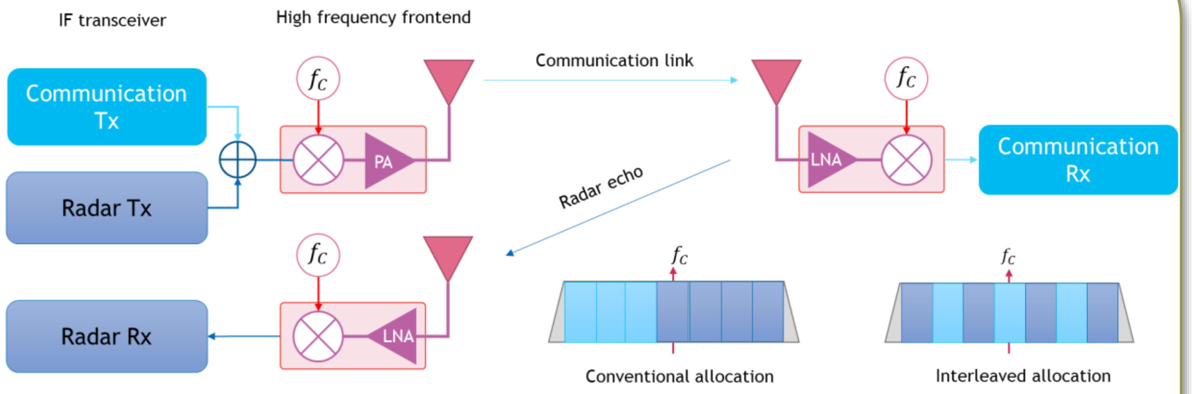
Integration of monostatic and bistatic sensing



Radar-Based Multi-Static Sensing

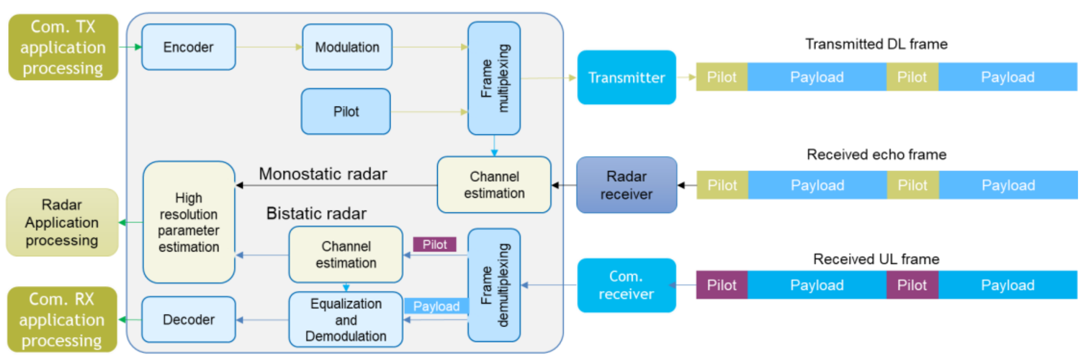


Integrated communication and monostatic sensing

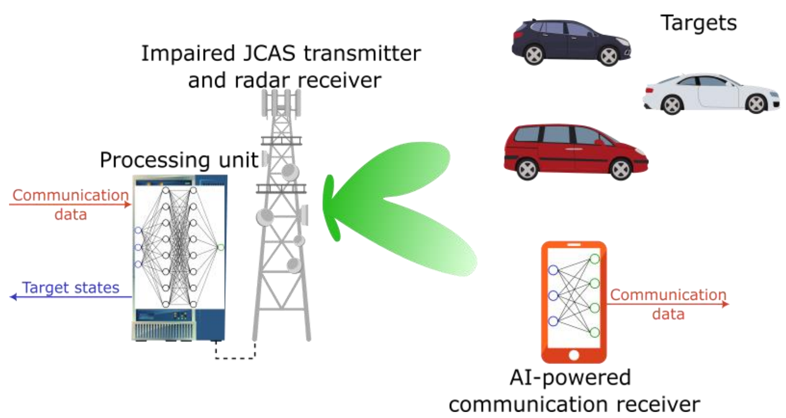


JCAS waveforms, frame structures, and resource allocation

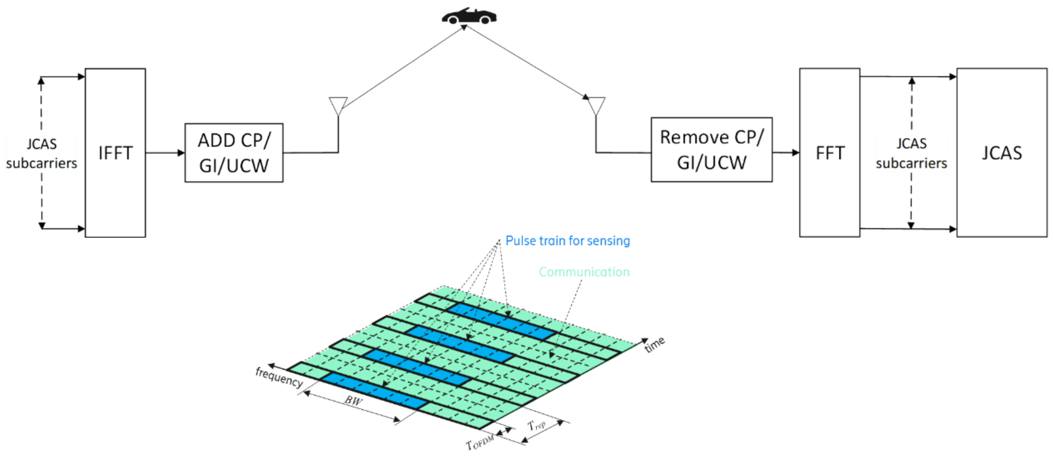
Flexible JCAS transceiver for monostatic and bistatic sensing



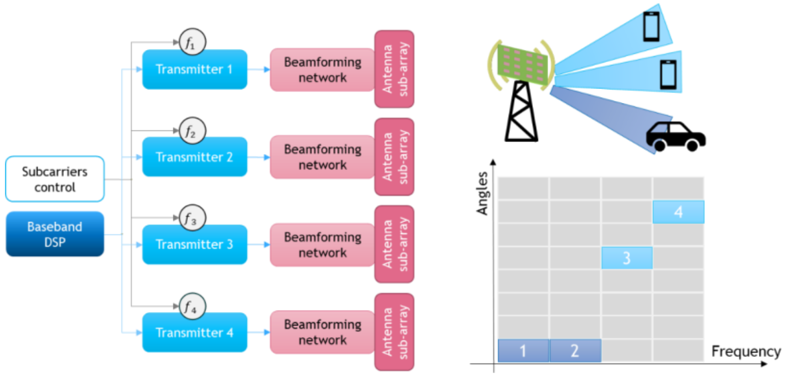
End-to-end learning for JCAS



Optimization of OFDM-Based Bistatic Radar Sensing

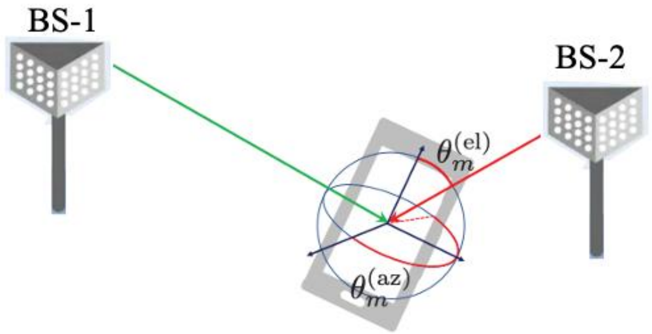


Resource allocation in multiband hybrid-beamforming transceiver

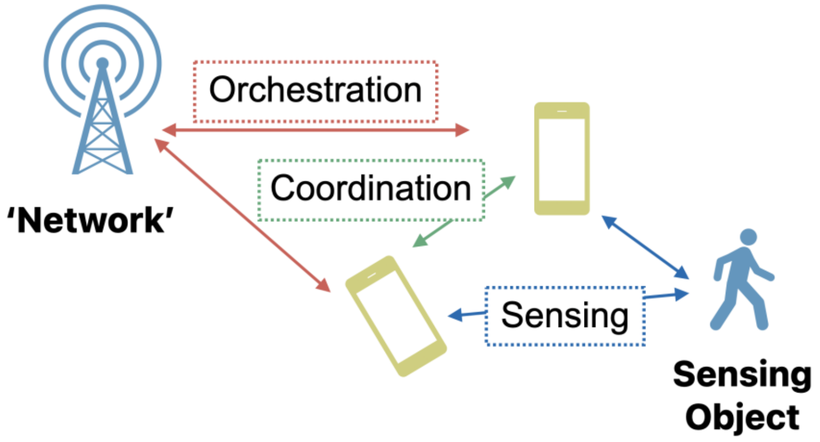


JCAS waveforms, frame structures, and resource allocation

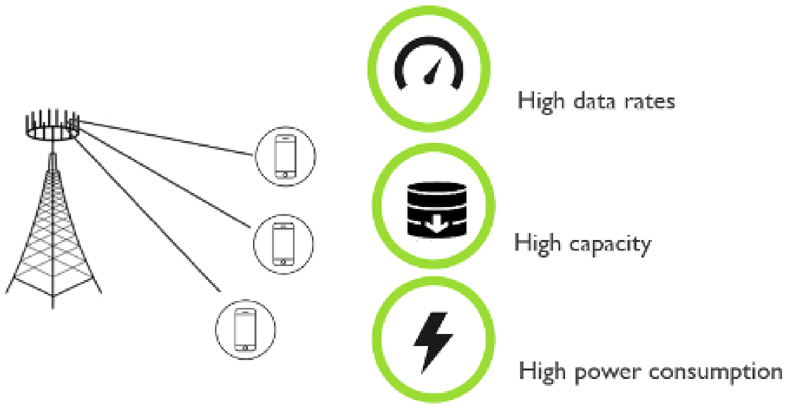
Resource allocation for 6D tracking in JCAS scenarios



Resource allocation and protocols for inter-UE sensing

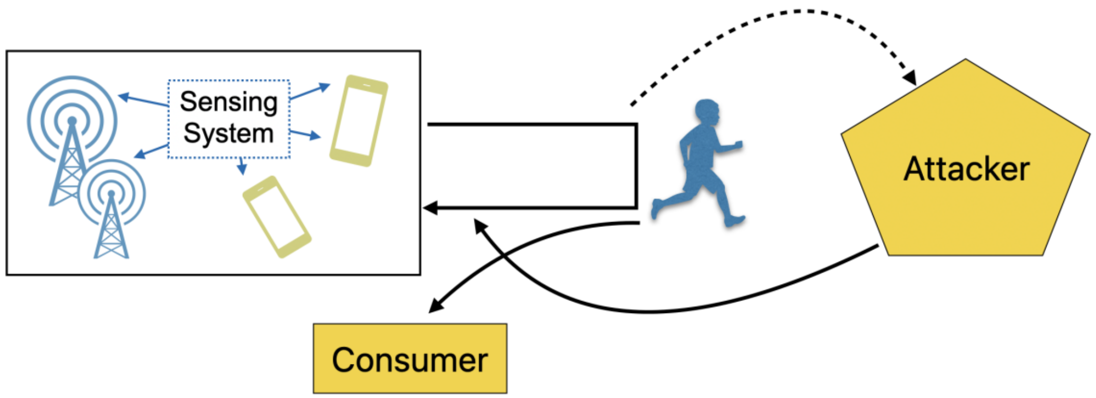


Power consumption of JCAS

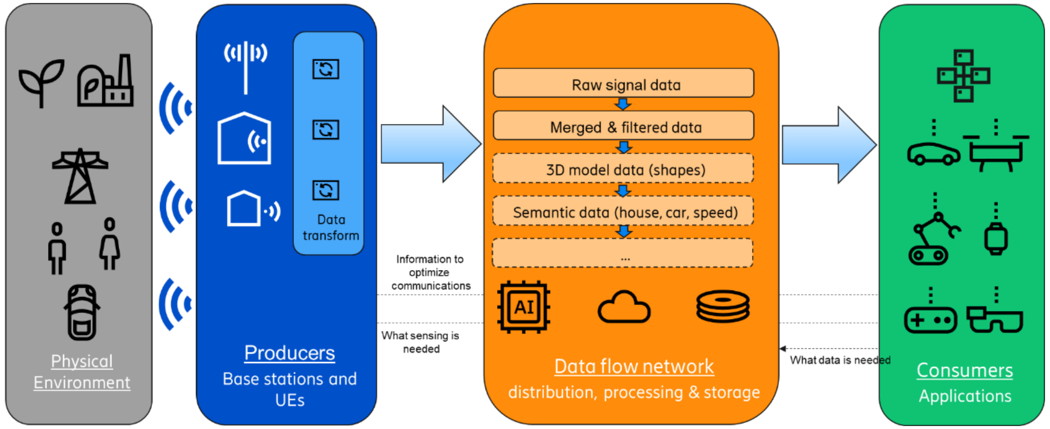


JCAS security and privacy

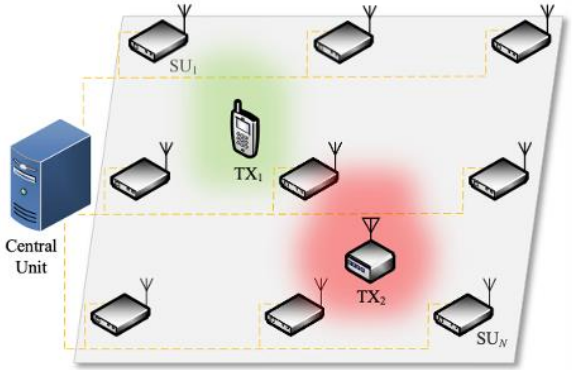
UE-related security aspects of JCAS



Privacy and security for JCAS



Blind transmitter (jammer) localization in cellular networks



KPIs and KVIs

KPIs

- Positioning (also orientation) accuracy
- Positioning latency
- Positioning availability
- Sensing accuracy (GOSPA, detection probability)
- Sensing resolution
- Communication rate, spectral efficiency, SNR, EVM
- Power consumption and energy efficiency

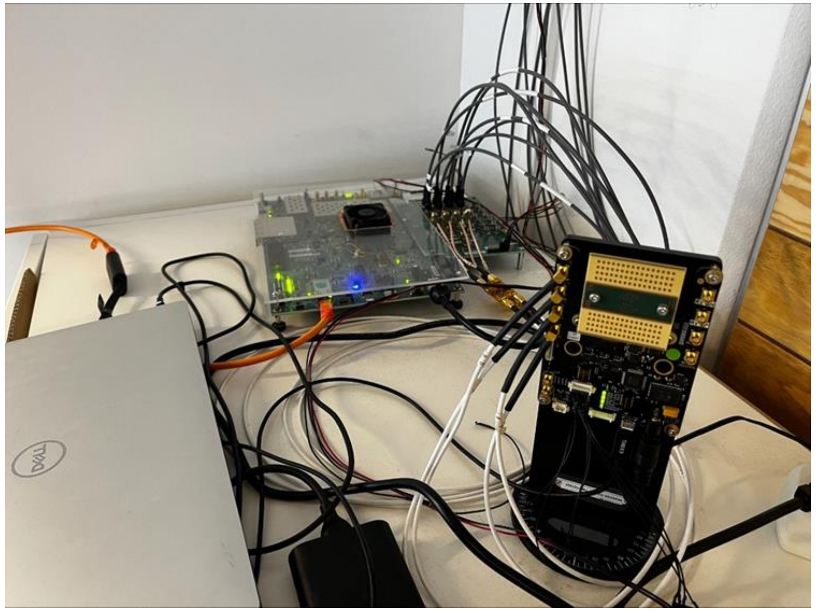
KVIs

- **Sustainability**
  - Accurate positioning enables services that can lead to energy reduction
  - Model-driven AI require less training
- **Inclusion**
  - Expanding coverage (e.g., NTN)
- **Trustworthiness**
  - Robust solutions via redundancy
  - Locating jammers allows mitigating their effect
  - Model-driven AI provides interpretability
  - Inter-UE sensing provides user with more control
  - Studies on security and privacy

Proof of Concepts

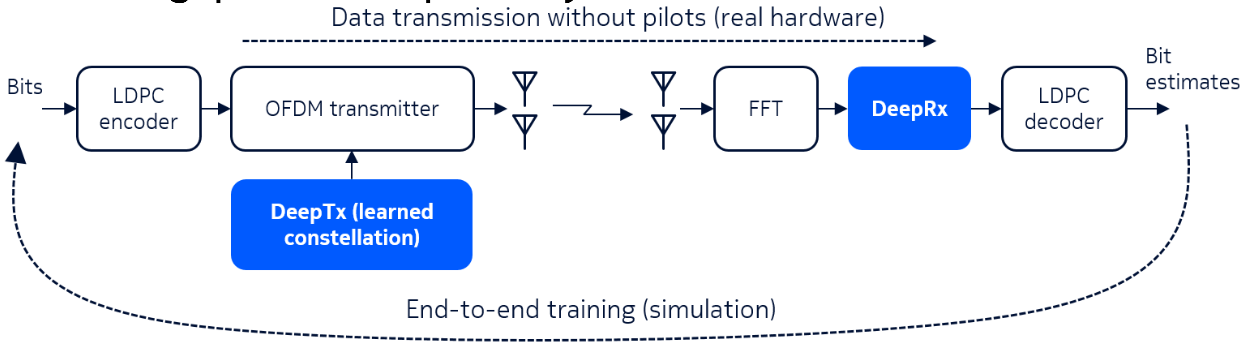
Proof of Concepts

- PoC# C.1 JCAS demonstrator: to show the possibility of using the same hardware for both communication and sensing

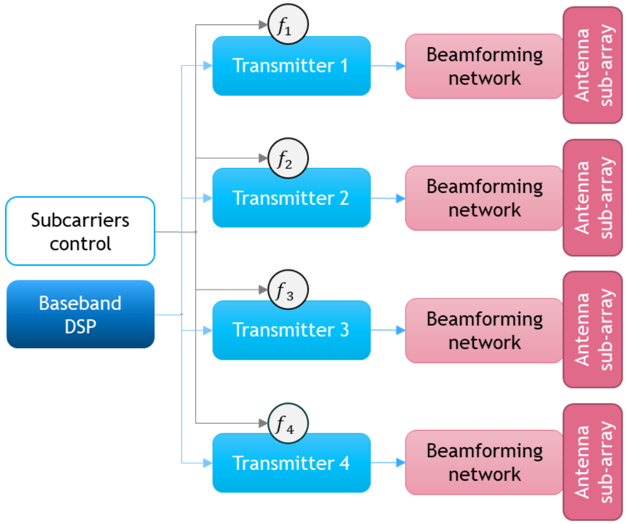


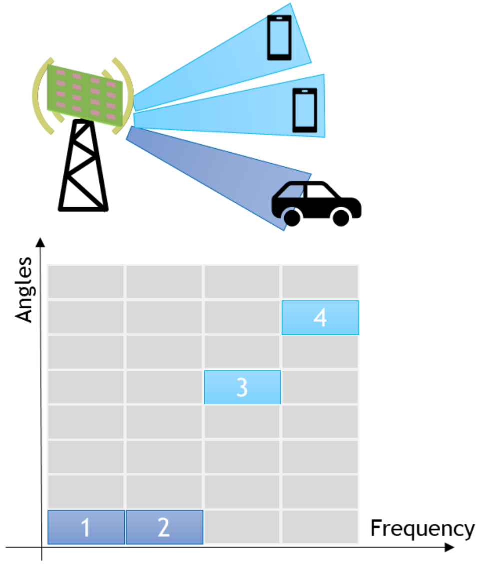
- PoC#C.6 Radio propagation measurements to collect data for radio channel modelling

- PoC#C.2 AI-native air interface: to demonstrate higher throughput with a partially learned air interface



- POC#C.5: Flexible modulation and transceiver design: integration of multiband IF transceiver with high frequency frontend

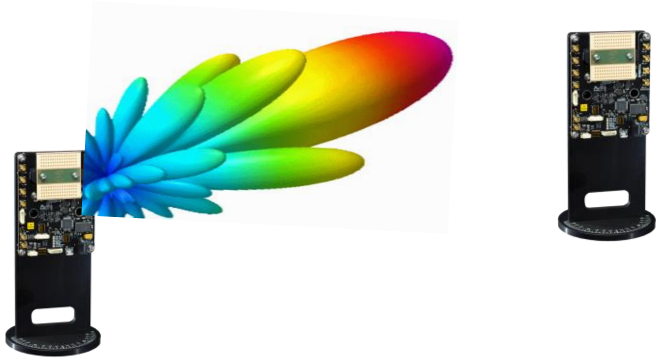




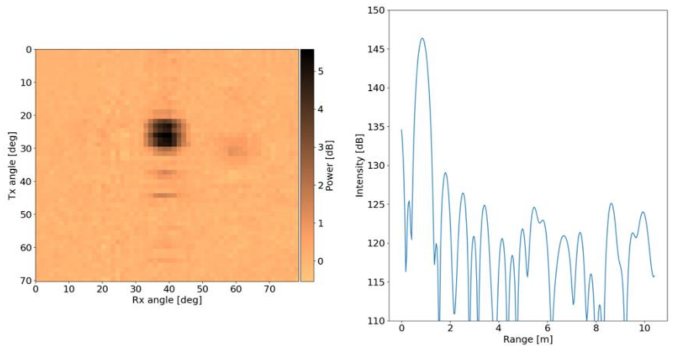
PoC#C.1: Joint Communications and Sensing

Show the possibility of using the same hardware for both communication and sensing

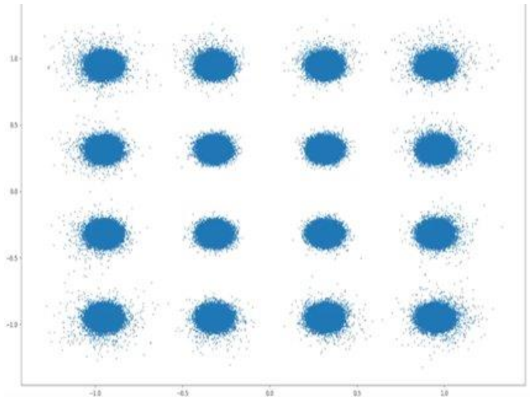
Bistatic and multi-static sensing



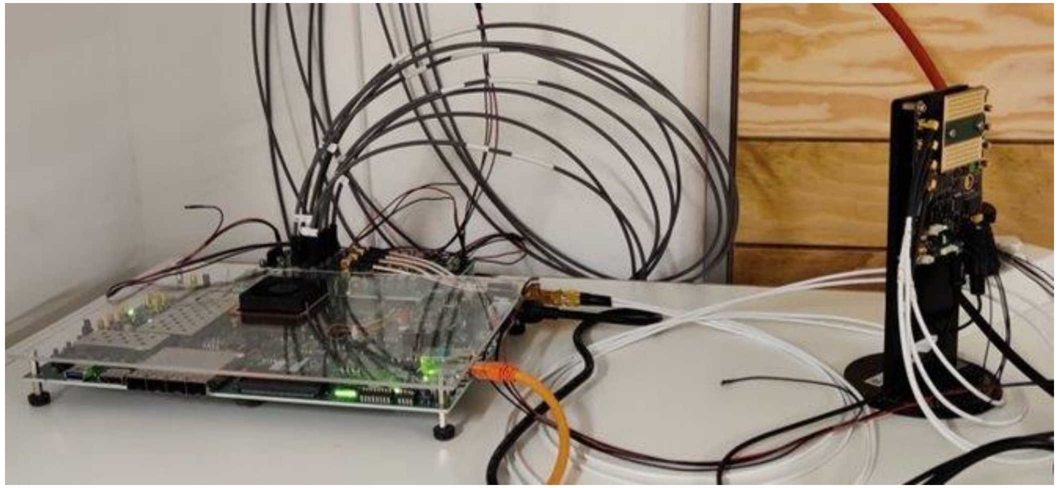
Range and angle processing



High rate communication

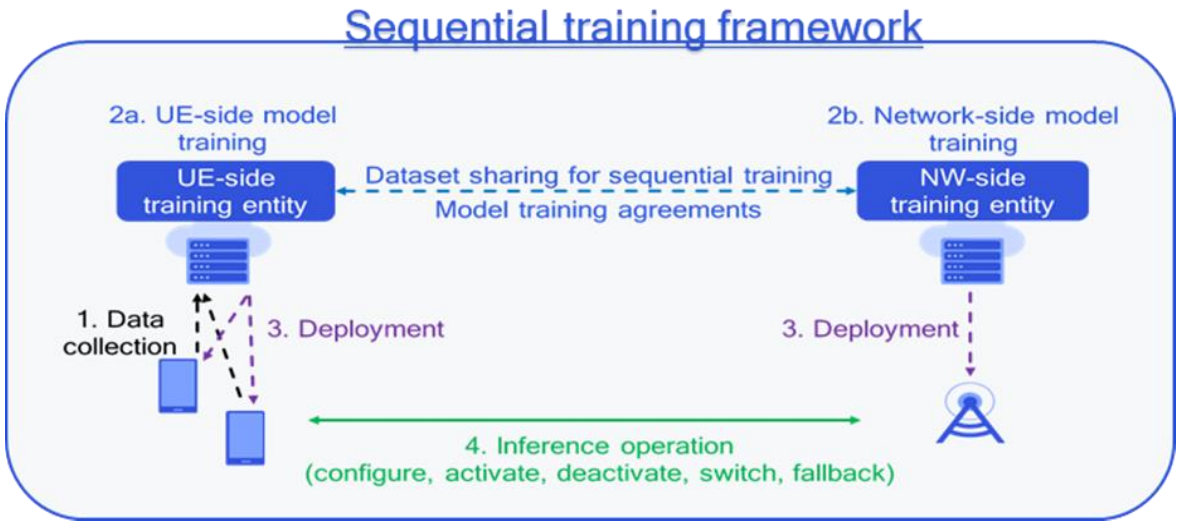


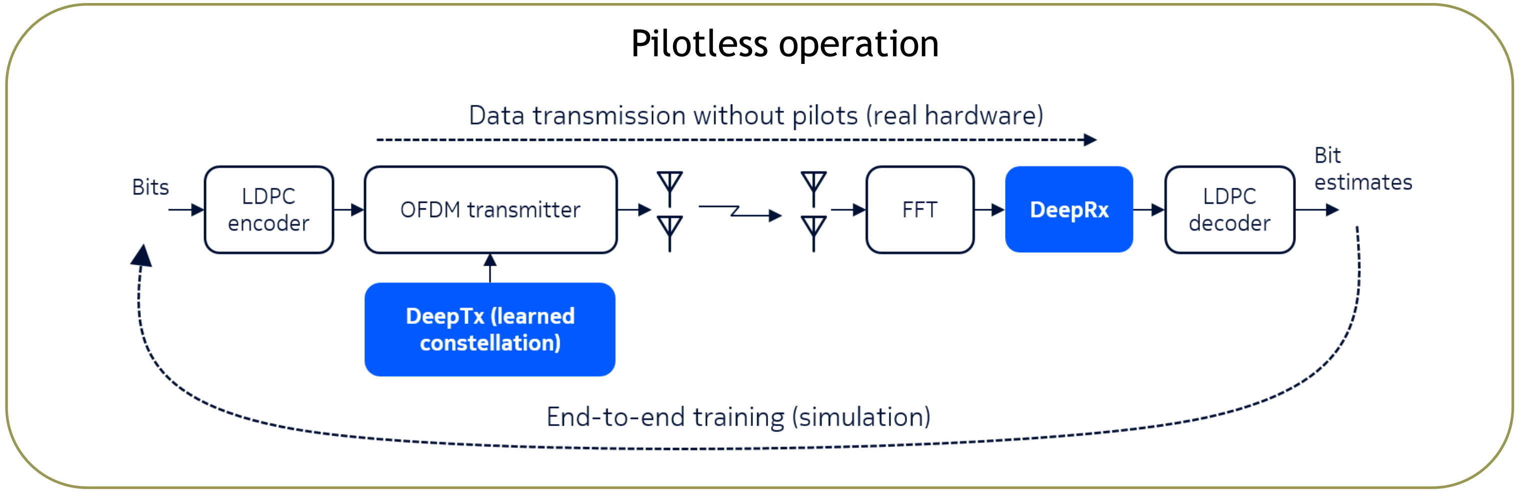
57-71 GHz radio
RFSoC board for signal processing
PC for controlling the setup
CP-OFDM and DFT-S-OFDM waveforms
Bi-static or multi-static mode



PoC#C.2: AI-Native Air Interface

Demonstrate higher throughput with a partially learned air interface

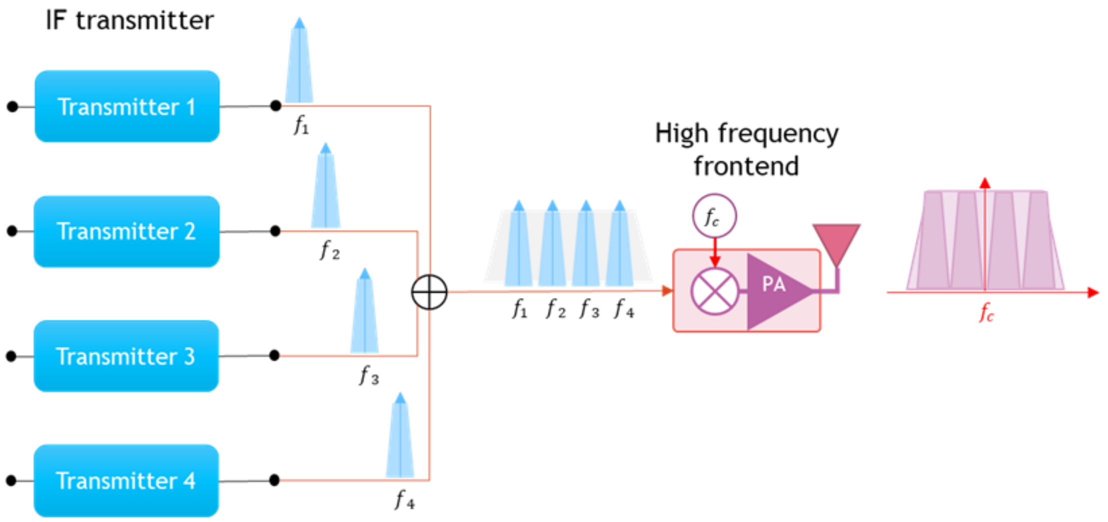




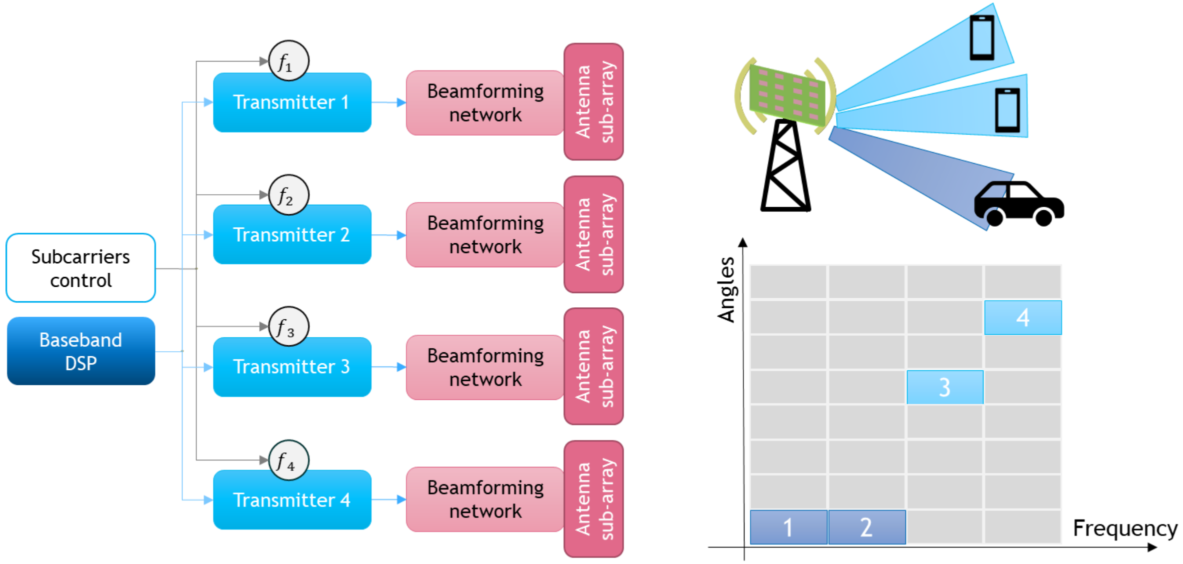
PoC#C.5: Flexible modulation and transceiver design

Implementation of flexible transceiver architecture

Integration of multiband IF transceiver
with high frequency frontend



Hybrid beamforming configuration
with flexible angular-frequency allocation



PoC#C.6: Channel Measurement Data and Model

Collect channel measurements and develop channel model for sub-THz band

1. Perform measurements bellow and above 100 GHz
2. Use 3GPP channel model with validity up to 100 GHz as benchmark
3. Assess validity of measurements
4. Derive parameters at 142 GHz (indoor and outdoor)
5. Use newly derived parameters as input to benchmark
6. Conduct future measurement campaigns at 140 GHz-320 GHz
7. Extend model for new frequency range

HEXA-X-II

HEXA-X-II.EU //

Co-funded by the European Union

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