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## The 6G series workshop by Hexa-X-II

# Holistic 6G radio design framework




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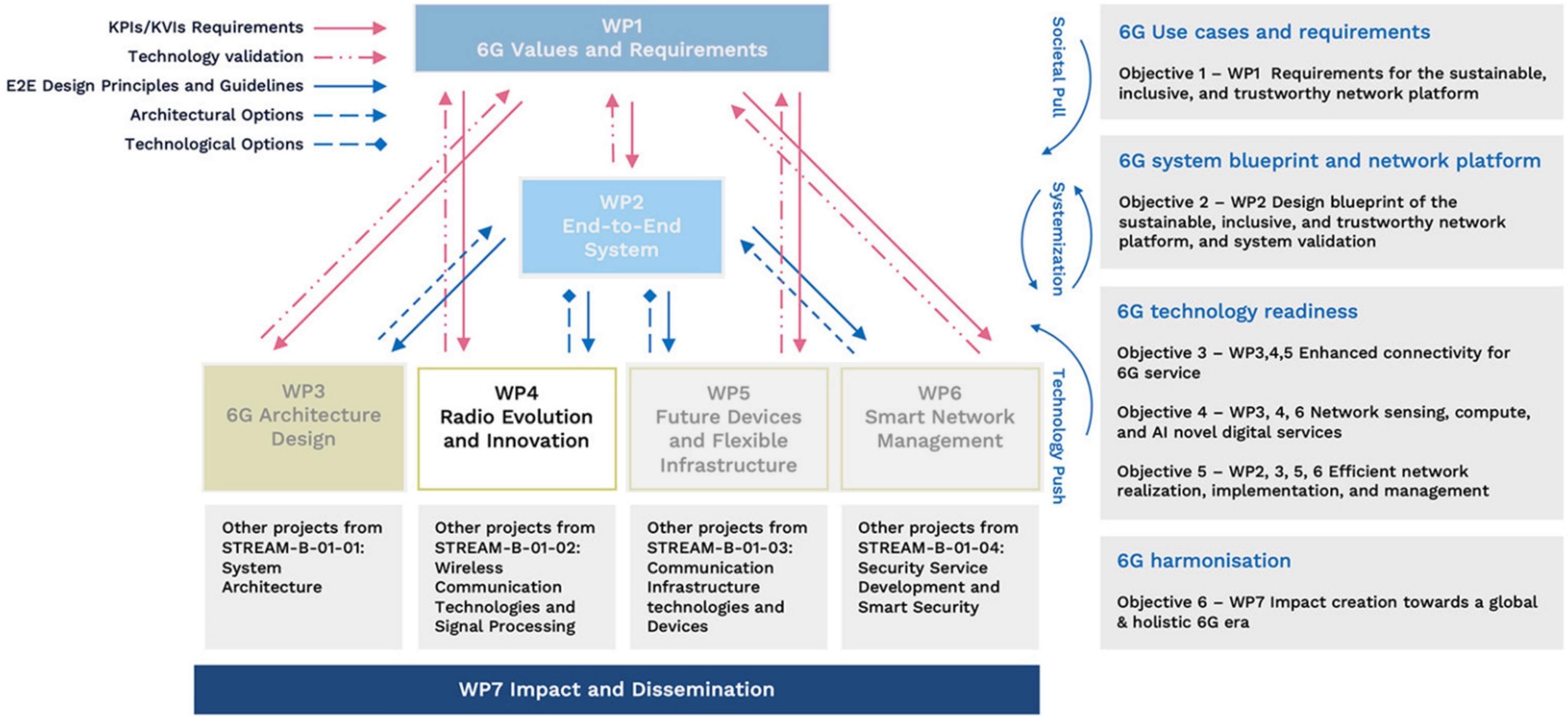
**Many thanks to the HEXA-X-II work package 4 (WP4) team for the contributions across various areas of radio design!*

# Holistic 6G radio design framework in Hexa-X-II



# Holistic 6G radio design team

Service providers

Applications and software

WP leads

Platform

System and technology

Chipset and hardware

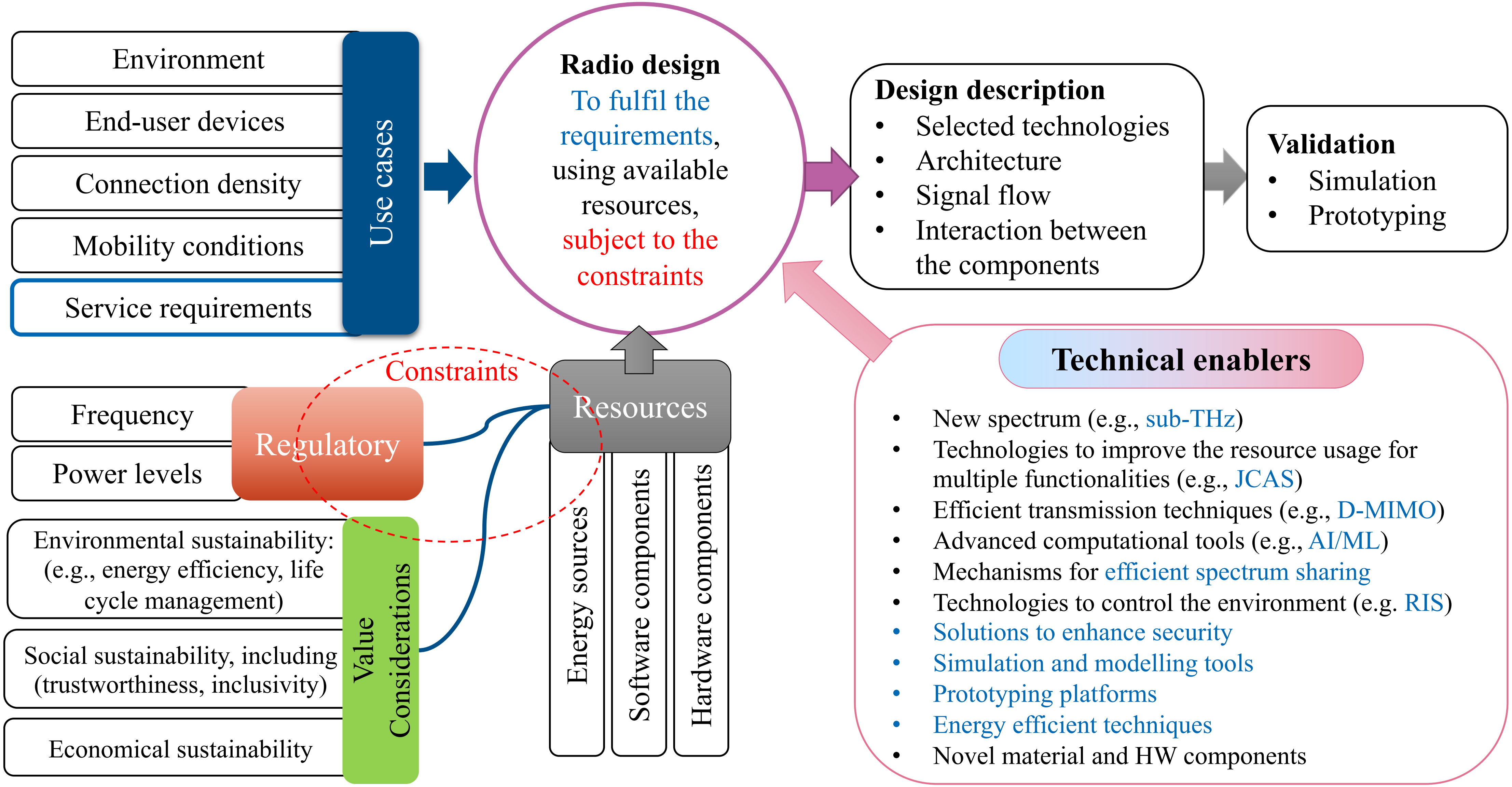
6G ecosystems and offering

Academia and RTO

SME

Large enterprise

# Radio design process



# Use cases analysis and scenarios

**Inputs from WP1 and WP2**

Wide range of use cases → Clustering to families based on usage and challenges →

### Service requirements

**Communication**
- Availability
- Reliability
- Latency
- Data rate
- Connection density

**Sensing/localization**
- Availability
- Reliability
- Accuracy
- Refresh rate
- Latency
- Resolution

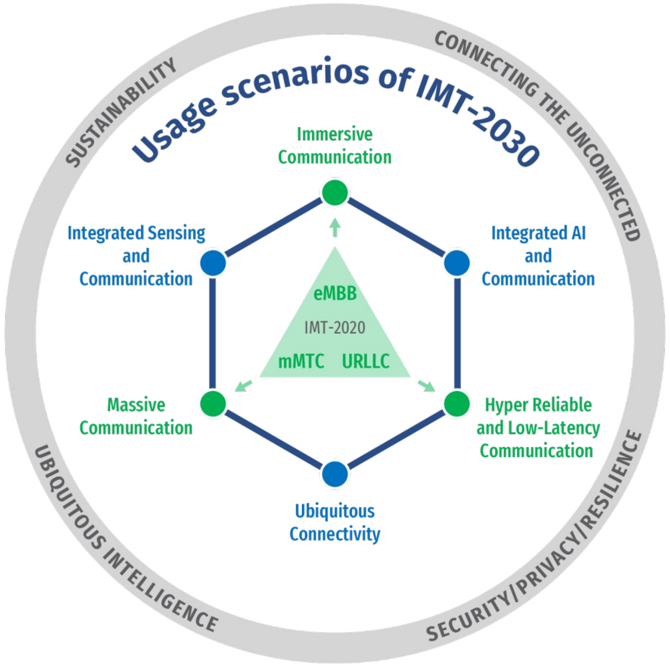
→

### Radio requirements

**Communication**
- Coverage
- Link reliability
- Air interface latency
- Peak data rate
- Traffic capacity
- Connection density

**Sensing/Localization**
- Sensing accuracy
- Sensing refresh rate
- Sensing measurement latency
- Sensing resolution

External input




## Hexa-X-II radio scenarios

- Extreme data rate
- Extreme RLLC
- Extreme connection density
- Extreme coverage

AI and sensing are included in each scenario

RLLC: reliable and low-latency communication

# 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 requirements with respect to sustainability

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

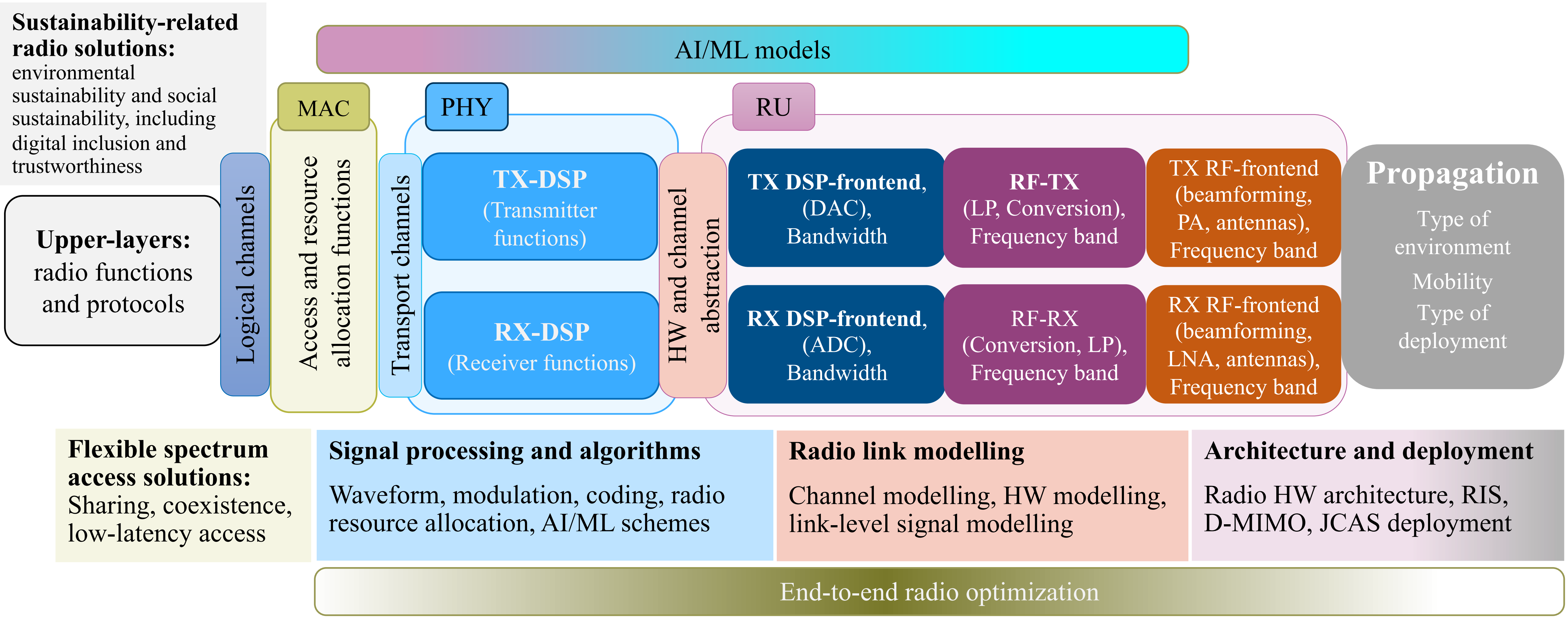
# Radio scenarios KPIs

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

| Radio scenario | ITU usage scenarios | HEXA-X-II use case family (representative) | Peak data rate | Link reliability | Air interface latency | Connection density | Coverage | Sensing capabilities |
|---|---|---|---|---|---|---|---|---|
| Extreme coverage | Ubiquitous connectivity | Fully connected world (Ubiquitous network)<br>Physical awareness (Network-assisted mobility) | Low<br>Medium<br>< 1 Gbit/s | Variable | Variable | Variable | Ultra-wide<br>Extreme-wide<br>Availability (99.99%-99.999999%) | Variable |
| Extreme data rate | Artificial intelligence and communication<br>Immersive communication | Immersive experience (Seamless immersive reality) | Ultra-high<br>Extreme-high<br>(10-100 Gbit/s) | Variable | Variable | Low<br>Medium<br>$<10^4$ device/km$^2$ | Local | Variable |
| Extreme connection density | Immersive communication<br>Massive communication | Digital twins (Realtime digital twins)<br>Trusted environment (Human-Centric Services) | Medium<br>High<br>< 10 Gbit/s | Variable | Variable | Ultra-high<br>Extreme-high<br>($10^6$-$10^8$) device/km$^2$ | Variable | Variable |
| Extreme low latency and high reliability | Hyper reliable and low-latency communication<br>Integrated sensing and communication | Collaborative robots (Cooperative mobile robots) | Low<br>< 10 Mbit/s | Ultra-high<br>Extreme-high<br>(99.999%-99.99999%) | Ultra-low<br>Extreme-low<br>(0.1-10) ms | Variable | Local | Ultra-high<br>Positioning accuracy<br>(0.1-1) cm |

# Holistic radio design framework and enablers

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



# WP4: Radio evolution and innovation topics

## Towards THz communications

| Link modeling | Waveforms and modulations | Massive MIMO |
|---|---|---|

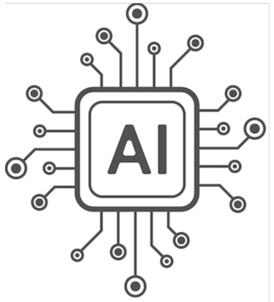
Resource optimization

Security

Deployment scenarios

Proof of concept

JCAS




**AI-driven air interface**
- Learning transmit signals
- CSI acquisition
- MIMO transmissions
- Hardware impairments compensations

**D-MIMO transmissions**
- Dealing with practicalities for CSI acquisition and synchronization
- Non-coherent joint transmissions
- Coherent joint transmissions

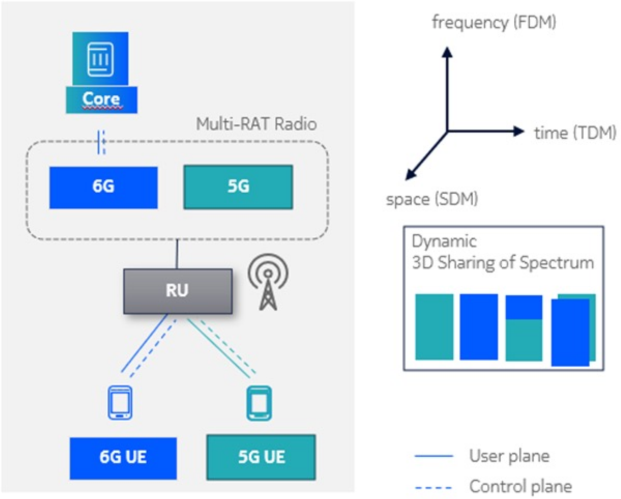
**RIS-assisted transmissions**
- Transmission schemes
- Integration for coverage extension
- Control procedure

Learning transmit signal (waveform, modulation and coding)

AI-based CSI acquisition (estimation, compression, feedback)

AI-based MIMO transmissions (beamforming, scheduling, resource allocation)

AI-based hardware impairment compensation (PA digital post distortion compensation)




Handover management

HAPS mounted NTN

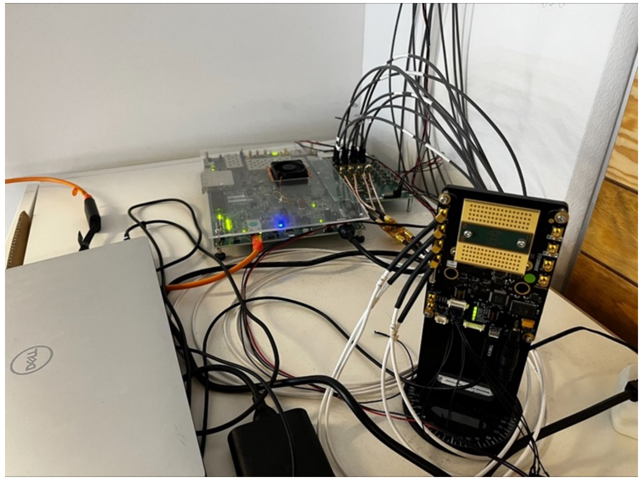
Secret key generation for D2D communications

Jamming analysis and jammer localization

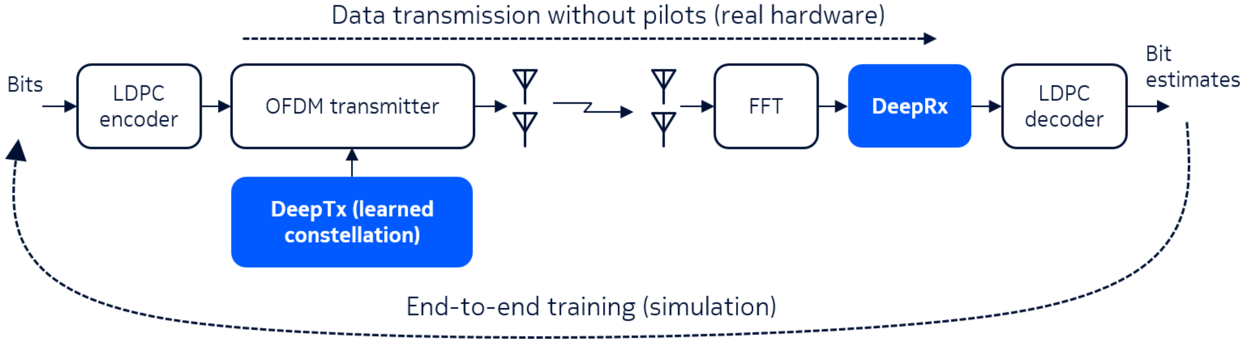
Security and privacy aspects of JCAS systems

# Proof of Concepts

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

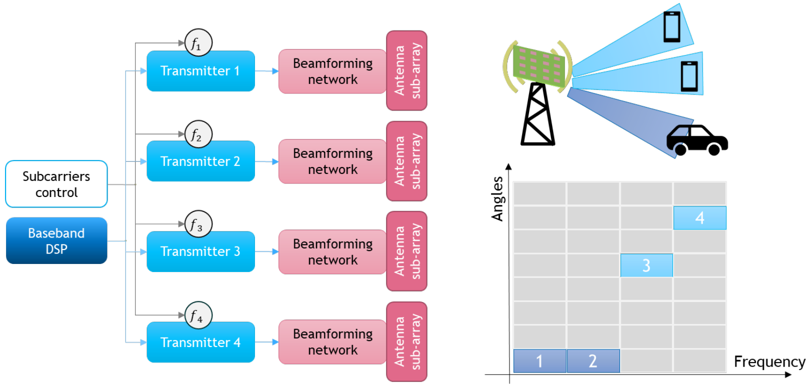


**AI-native air interface:** to demonstrate higher throughput with a partially learned air interface




**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

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

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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 D4.3

Early results of 6G Radio Key Enablers

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

**Document properties:**

| | |
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| **Document Title:** | Early results of 6G Radio Key Enablers |
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Available on Hexa-X-II website

https://hexa-x-ii.eu/results/

HEXA-X-II

HEXA-X-II.EU //

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