6G series workshop
February 12, 2025

Hexa-X-II WP5
Future Devices and Flexible Infrastructure



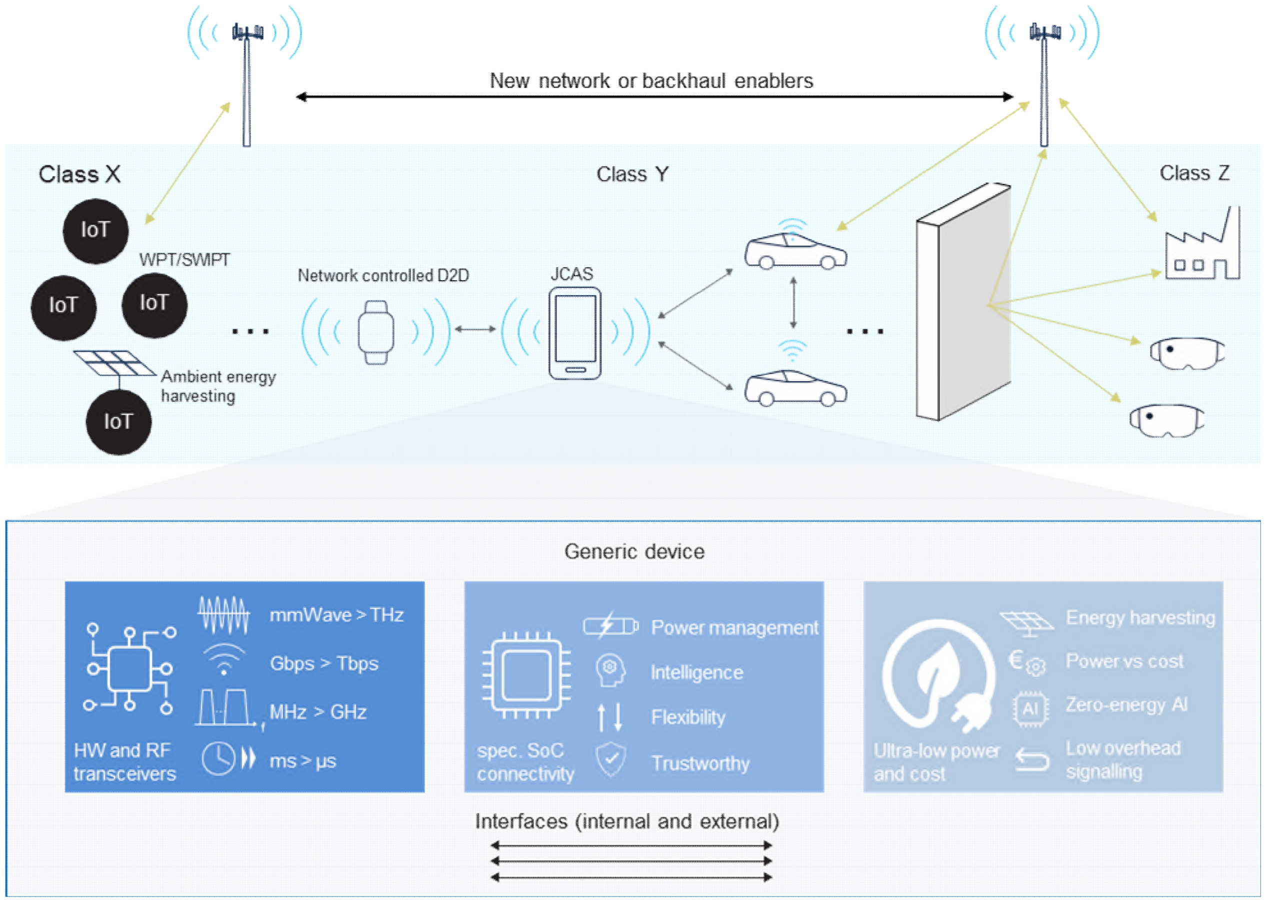


Jeroen Famaey (IMEC)
WP5 lead

Hexa-X-II

hexa-x-ii.eu

Hexa-X-II - WP5
Future devices and flexible infrastructure



Hexa-X-II

HEXA-X-II

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

Deliverable D5.5
Final design of enabling technologies for 6G devices and infrastructure

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

Dissemination level: Public   Page 1 / 5

Coming April 2025

Device characteristics and classification

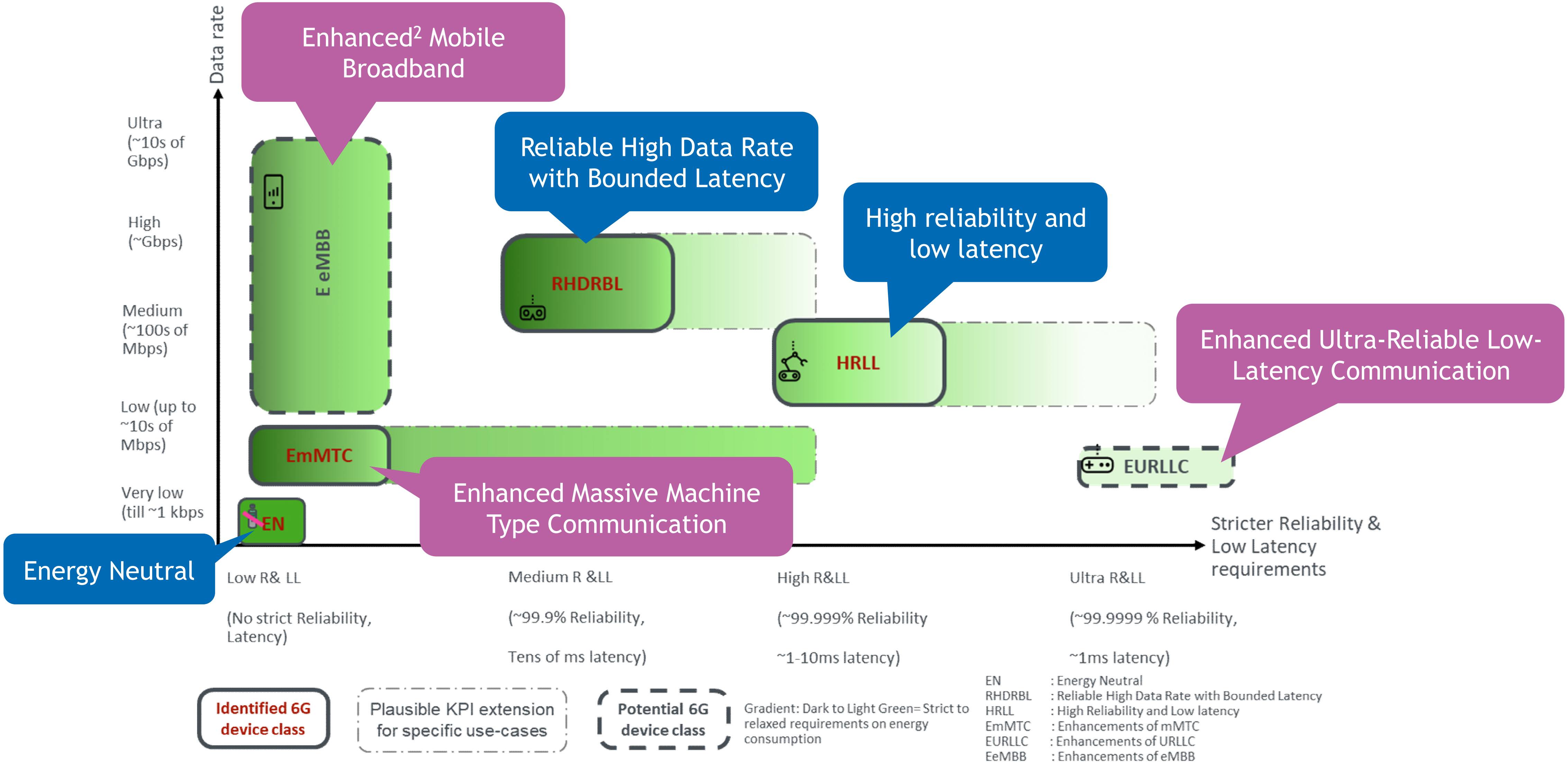
FR1-FR2-FR3 transceiver design

Sub-Terahertz transceiver design

Trustworthy and modular SoCs

Energy neutral devices

Device classification

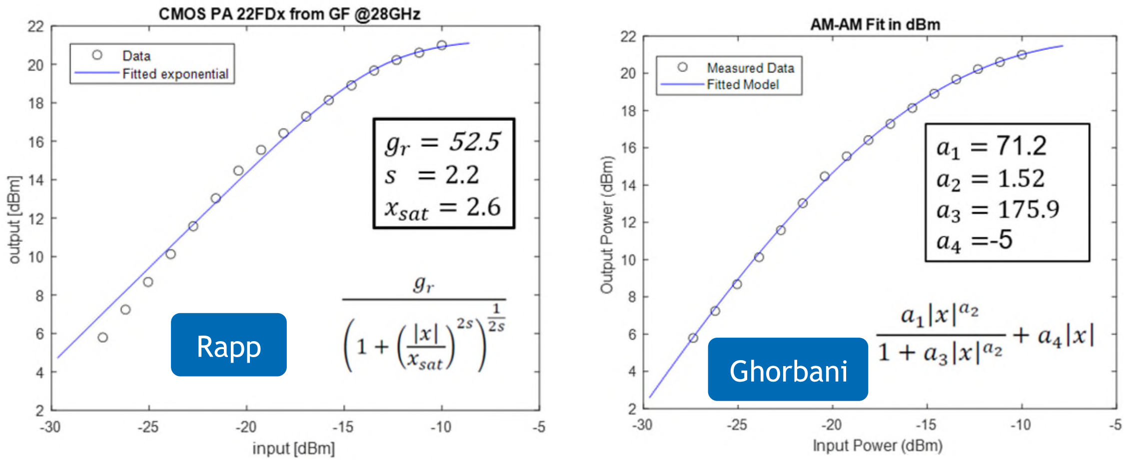


EN : Energy Neutral
RHDRBL : Reliable High Data Rate with Bounded Latency
HRLL : High Reliability and Low latency
EmMTC : Enhancements of mMTC
EURLLC : Enhancements of URLLC
EeMBB : Enhancements of eMBB

6G transceiver design

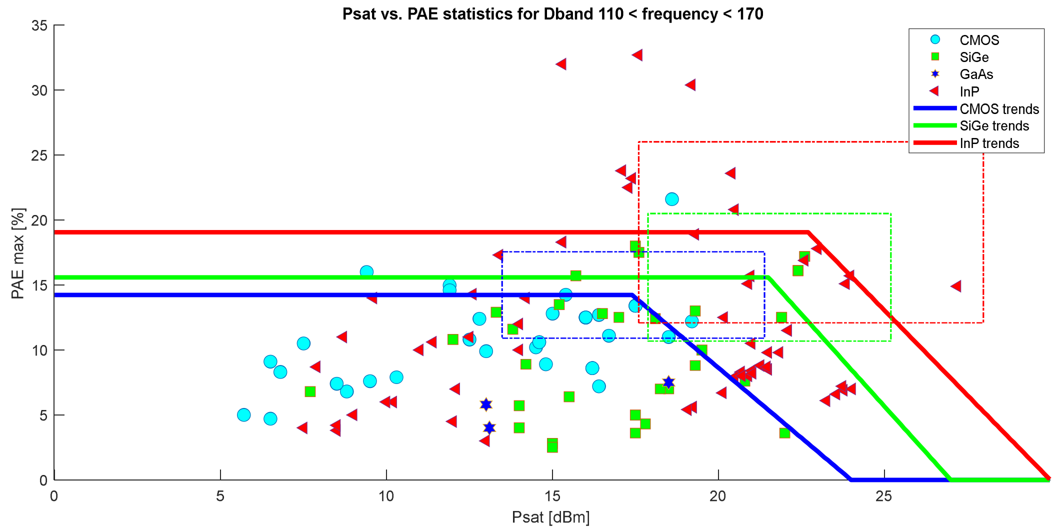
Transceiver hardware models

Recommended FR2/FR3 power amplifier models



- Non-linear power amplifier model for FR2 UEs
  - CMOS Class AB amplifier
  - Ghorbani model can more accurately model complex non-linearities
  - Ghorbani has higher complexity than Rapp model
- FR3 band complexities
  - Lower frequency → Less UE antennas
    → Higher output power per PA (non-CMOS?)
  - Integration of PA with LNA and TX/RX switches
  - Advanced PA topologies (Doherty, Polar, …)

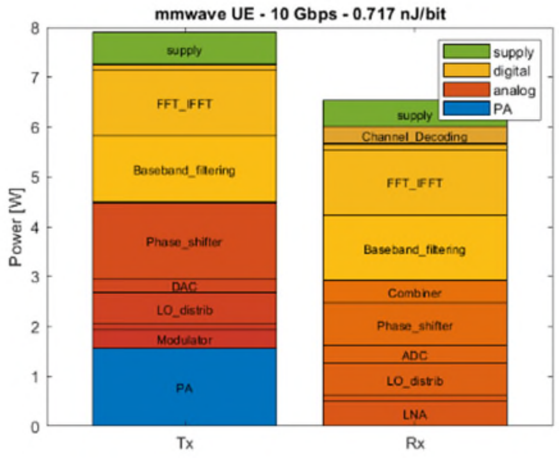
Sub-THz non-ideality models

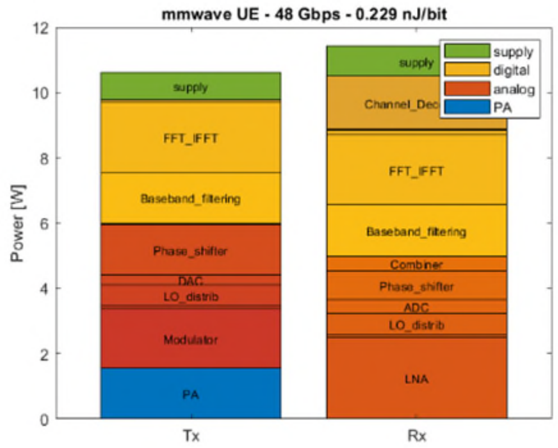


- Models for main non-idealities of sub-THz transceivers
  - Phase noise, power amplifier non-linearity, I/Q imbalance, DAC/ADC accuracy, and phase shifter accuracy
- Power amplifier non-linearity models
  - Output power of different technologies for D-band
  - Memory-less Rapp model for D-band
  - Memory-based model using Look-Up Table

Sub-THz transceiver design

Sub-THz analog-digital transceiver dimensioning

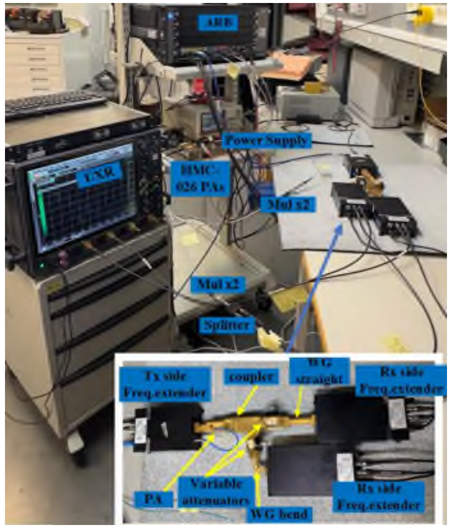


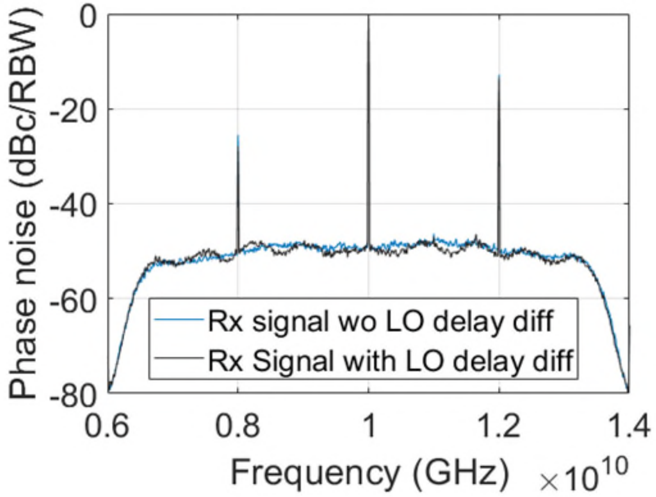


- Digital component power consumption increases at sub-THz frequencies
- Full digital vs. hybrid vs. analog beamforming
- Architecture affects data rate, energy efficiency, and power consumption
- Data rate vs. power consumption trade-off

Wideband phase noise (PN) mitigation

- Asymmetrical local oscillator (LO) routing can be exploited to mitigate wideband phase noise
  - Different LO delays of different signal paths, delays PN
  - Reduces wideband PN by causing notches in PN spectra
- Experimental validation over multiple RXs at D-band
  - Different-length cables result in multiple PN ripples
  - EVM reduction for 64-QAM waveform from ±10 to 8%



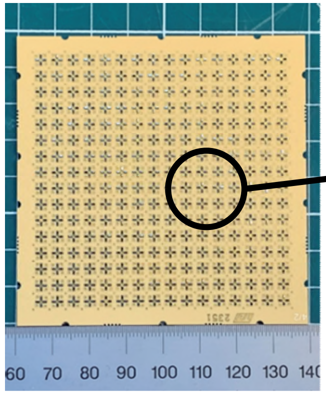


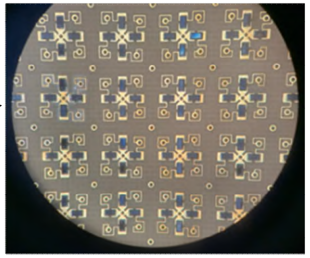
RIS prototyping and control inferfaces

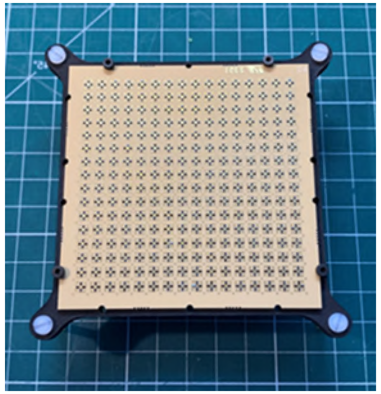
FR2 RIS prototype calibration

Manufactured 16x16 RIS tile

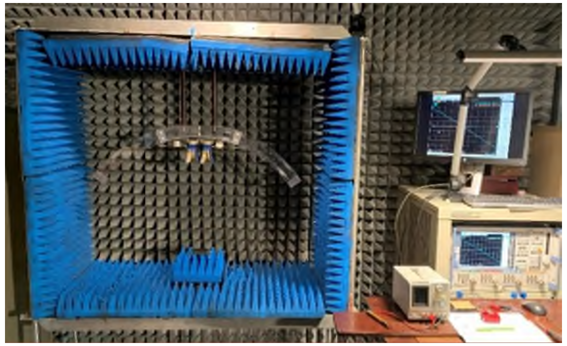
Control interface

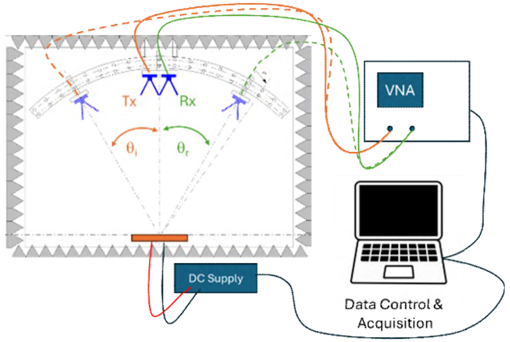






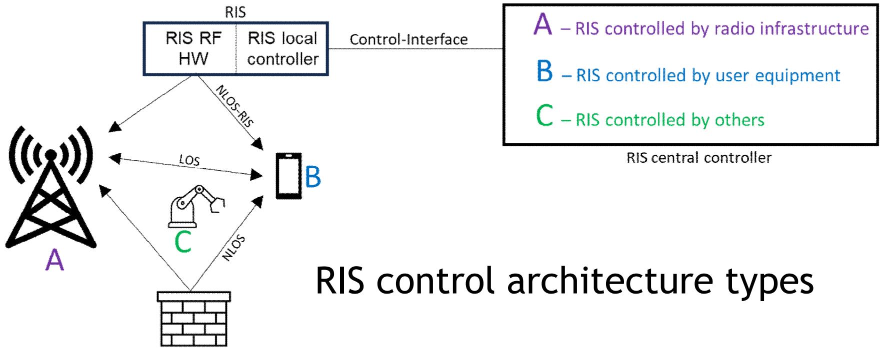
Calibration shows good match between measurements and simulations





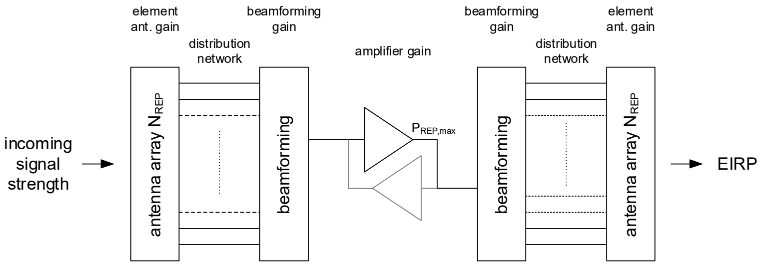
RIS as 3GPP network-controlled repeaters (NCR)

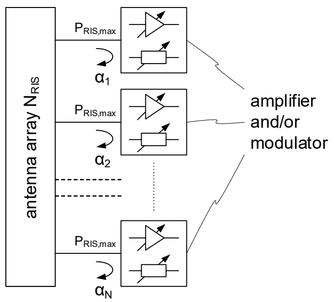
- NCR standard can largely be applied to RIS
- Additional standardization for control of RIS needed



RIS control architecture types

Simplified NCR RF architecture vs. RIS RF arch.



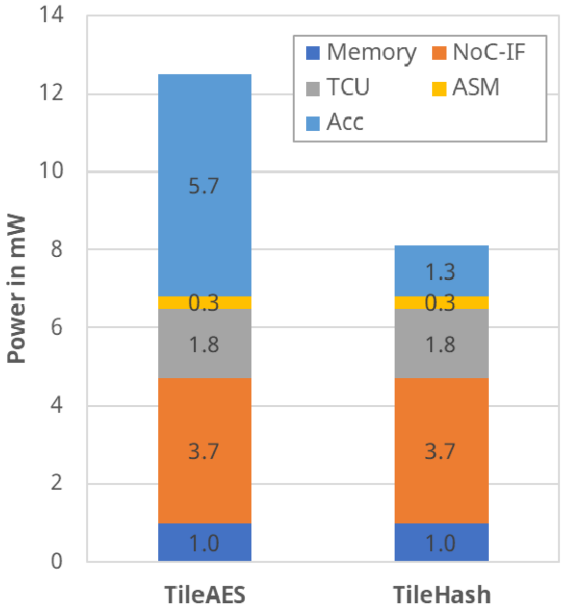


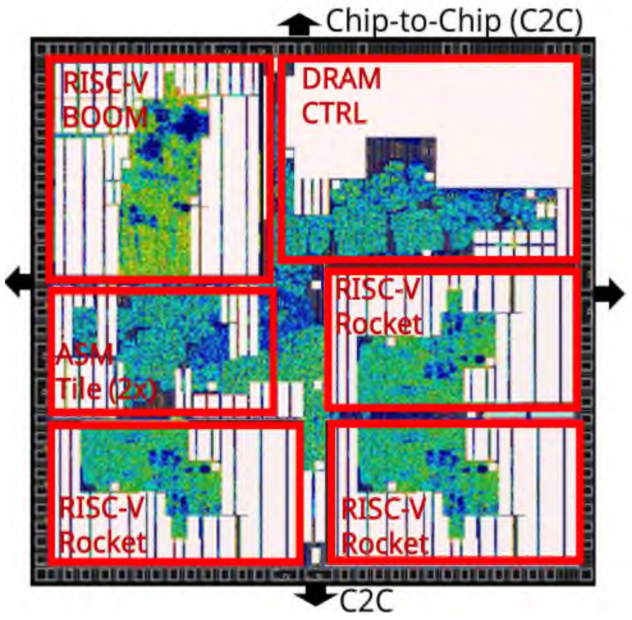
Trustworthy System on Chip (SoC) components

Secure integration of SoC accelerators

Secure and scalable SoC architecture

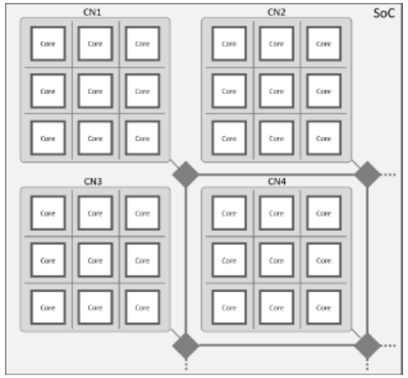
- Hardware-supported application isolation using trusted communication unit (TCU)
- Accelerator Support Module (ASM) to integrate accelerators
- Initial area and power consumption analysis based on test chip



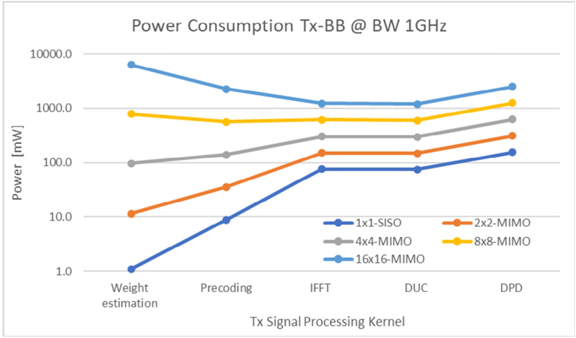


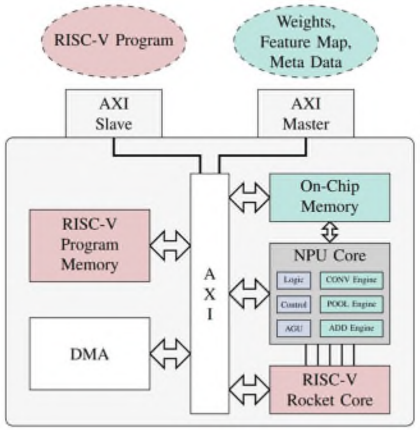
Signal and AI processing accelerators

- Investigation of SoC architectures
- Performance and energy consumption analysis of vector signal processors and AI accelerators

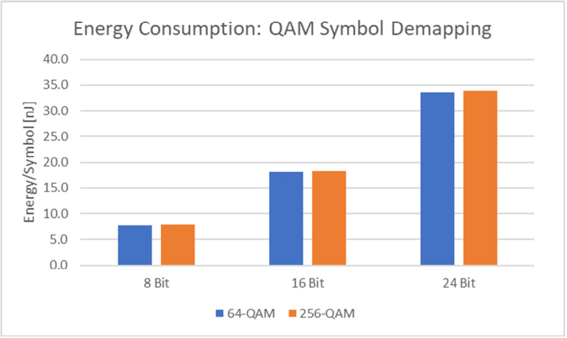


Vector Signal Processors





AI Accelerators

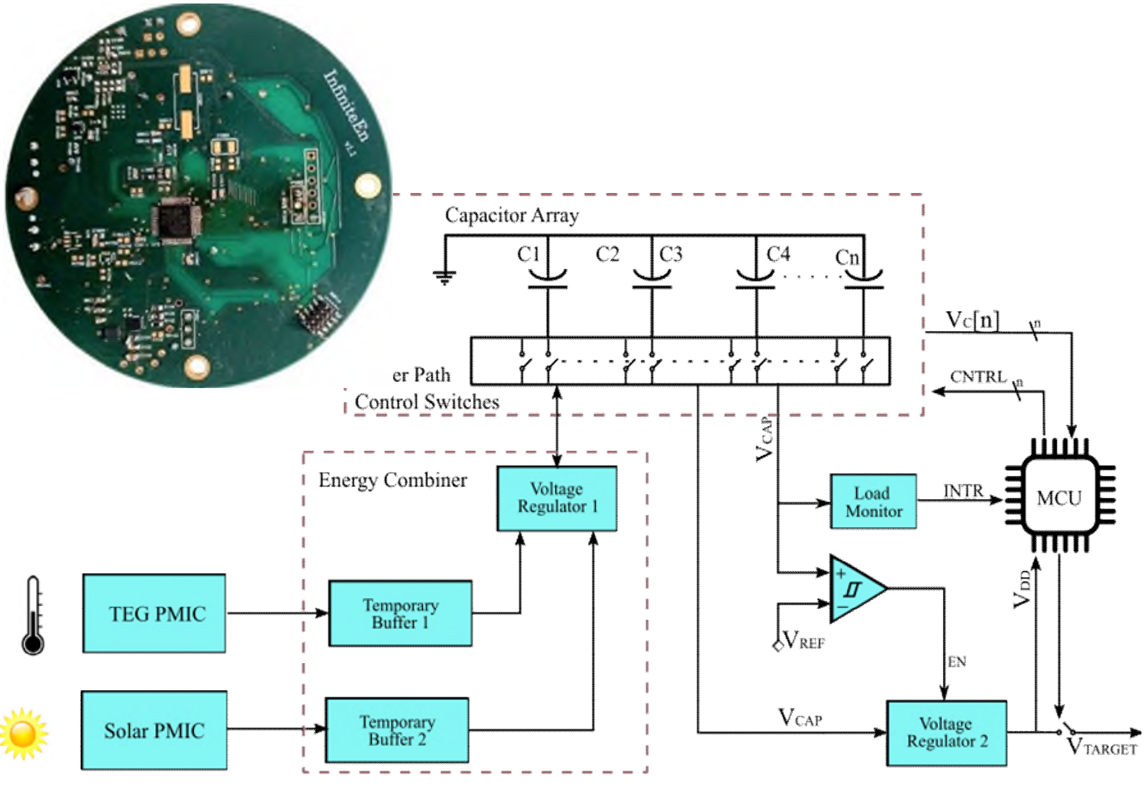


Low-power and energy neutral devices

Energy harvesting

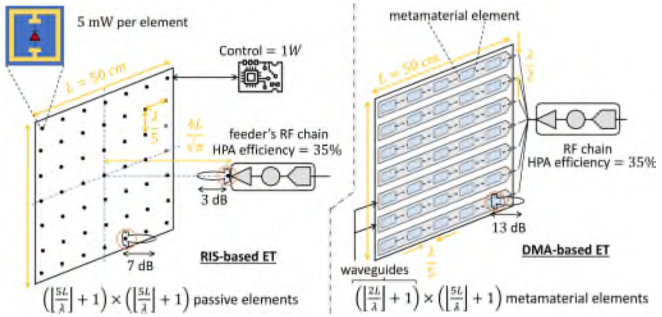
Multi-source energy harvesting PMU

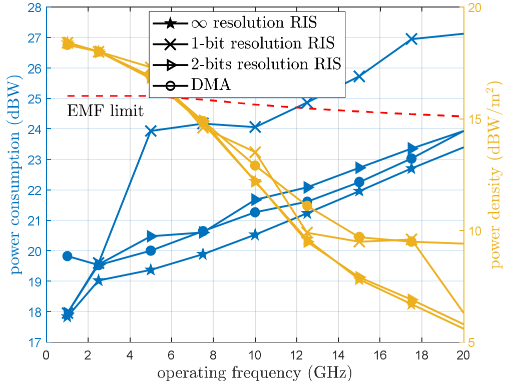
- Energy Combiner for multi-source energy harvesting
- Self-consumptions less than 0.5%, 88% efficiency
- Energy-aware operations through real-time harvesting & load monitoring



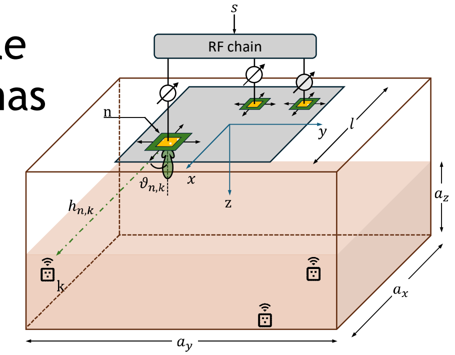
RF wireless power transfer (WPT)

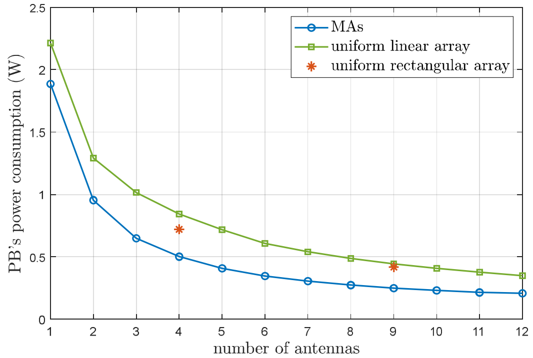
- Explored RIS and DMA for RF-WPT
- RIS & DMA can achieve lower power consumption than traditional antenna's with digital beamforming
- RIS with 2 control bits per element close to continuous phase shift configuration





Movable Antennas

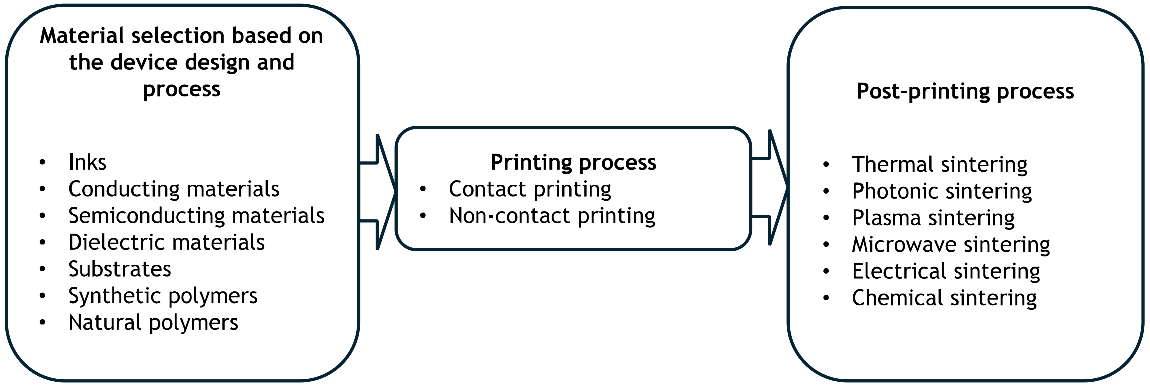




Cost, materials, and performance

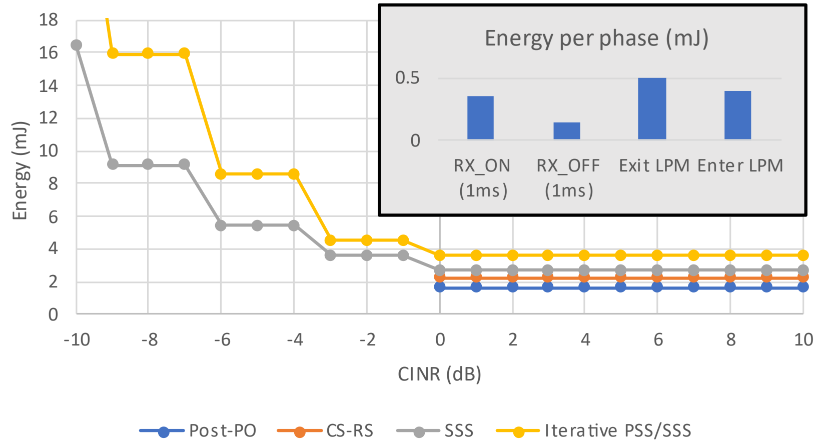
Sustainable manufacturing of printed electronics

- Methodology that combines material selection, circuit printing methods, and post-processing
- Supports cost-effective, scalable, sustainable, and flexible production of electronic circuits
- Method was used to manufacture multi-antenna backscatter device



Energy and cost analysis of emMTC devices

- Consolidation of models for cellular IoT modem
- Model calibration based on measurements
- Component/device cost assessment
- Optimization of operations (e.g., comparing synchronization methods)

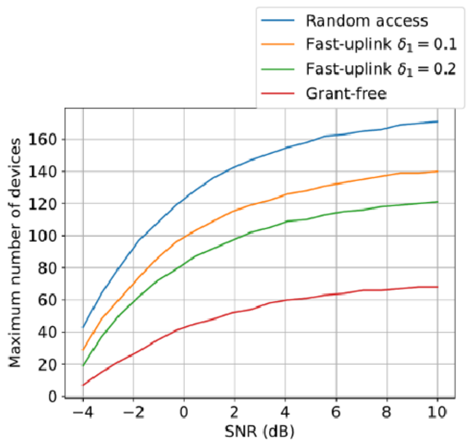


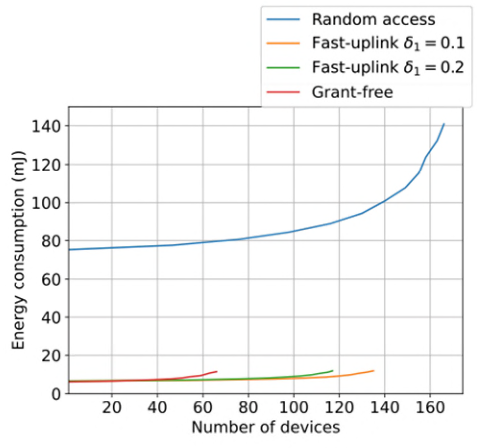
Cost Component	Cat-NB1 (HD-FDD)	Cat-M1 (HD-FDD)	Cat-1bis (FD-FDD)	eRedCap (FD-FDD)
Total	~40%	~50%	100% (Ref)	~120 %

Lightweight and energy-aware protocols

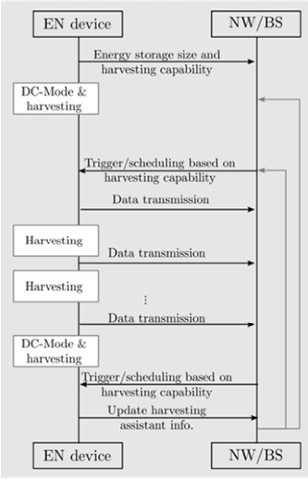
Lightweight and low-power protocols

- Random vs. fast uplink vs. grant-free channel access



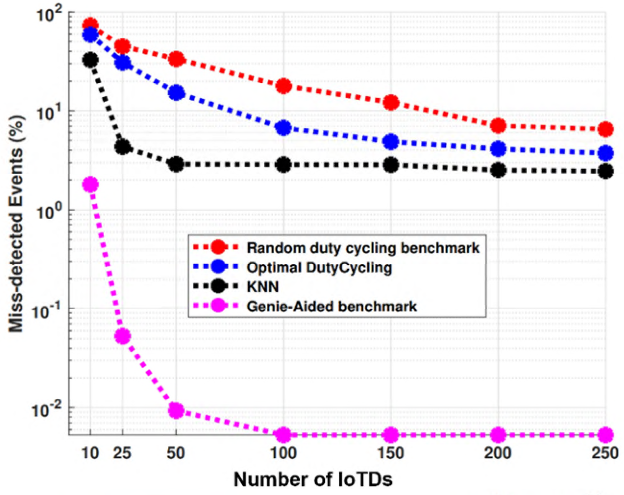


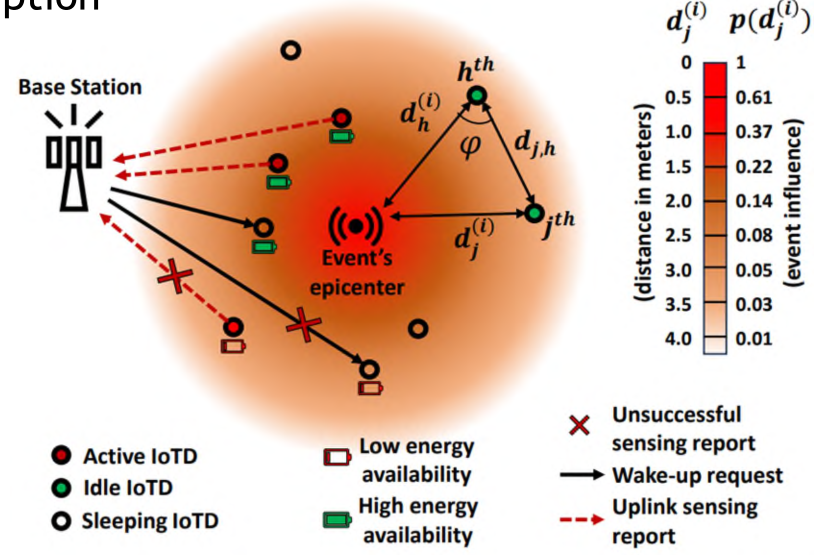
- User plane solution to connect energy neutral devices
  - Circumvent PDU session establishment
  - No need to overhaul legacy network (cost saving)
- Protocol adaptations for energy-aware scheduling of UL/DL



Duty cycling and wake-up protocols

- Device wake-up spatially correlated with event location
- Base station can use Wake-up-Radio to collect data from additional nearby devices
- Trade-off between energy consumption and detection accuracy

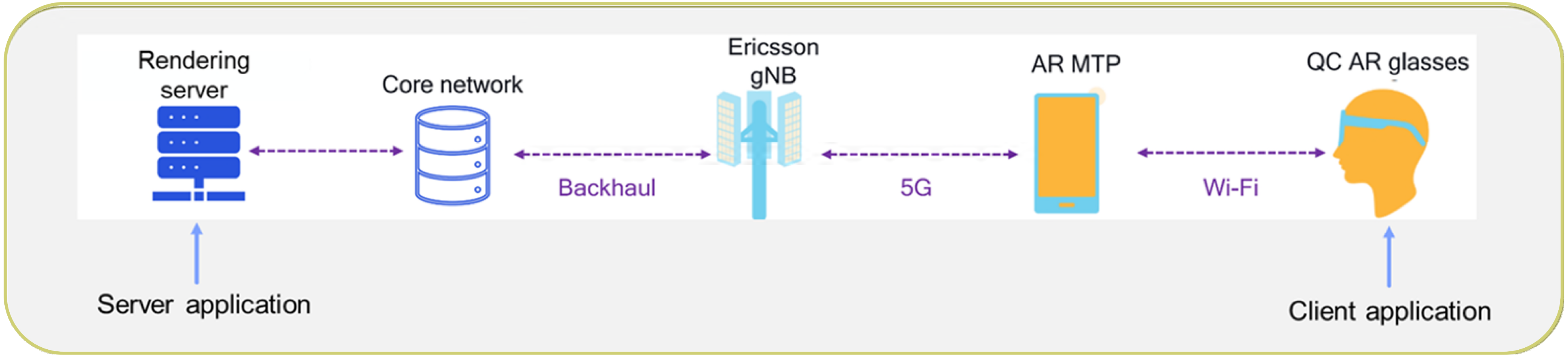




Contributions to integrated Hexa-X-II Proof of Concepts

E2E Extended Reality

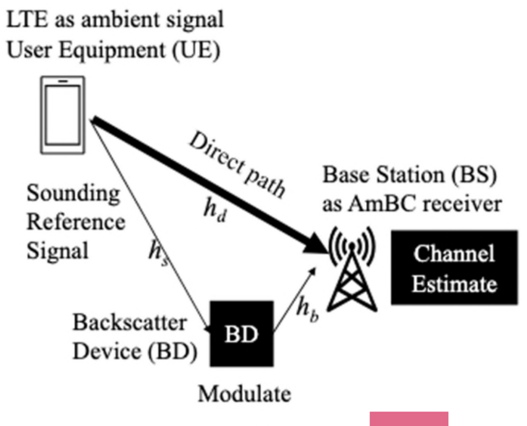
- This PoC demonstrates the capability of offloading heavy processing tasks to a remote rendering server. Adjusting the Application data rate according to the radio and network conditions.
- Improves user experience by reducing stuttering and enhancing battery life and form factor



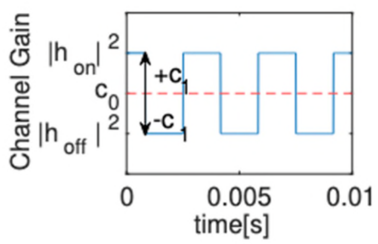
Setup: the testbed utilizes devices that provide wireless connectivity, sensing and compute capabilities to demonstrate the advanced XR services and the convergence of physical and digital worlds.

- This PoC is in progress, with ongoing integration of all components.

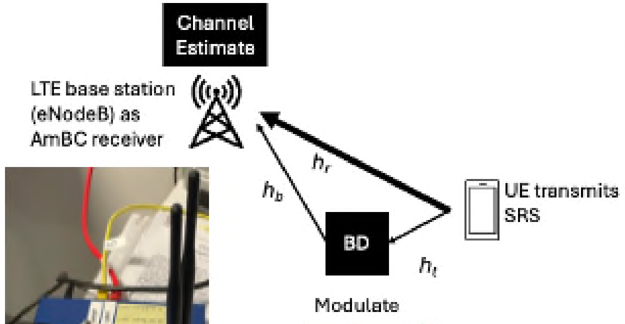
Ambient Backscatter Zero Energy Tag

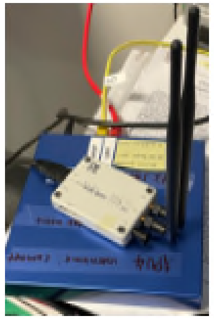


(a)

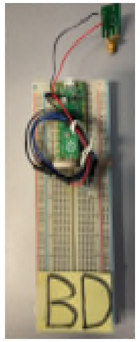


(b)

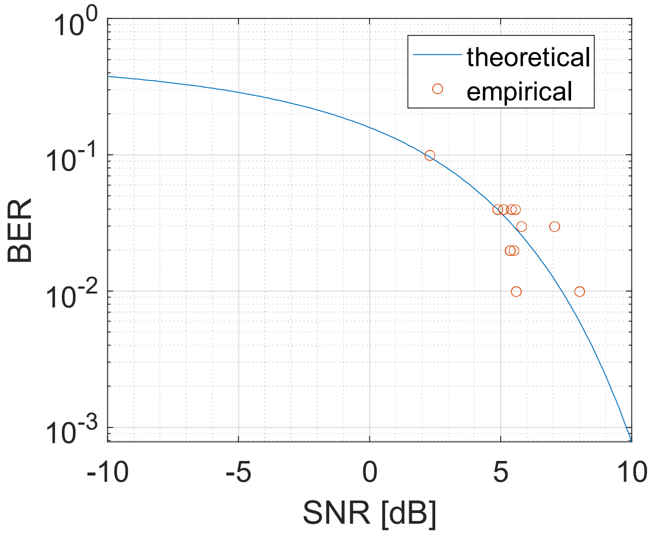




srsRAN
and
Cumucore CN



Commercial mobile
phone



Concluding remarks

Contributions to Hexa-X-II quantified targets

Access links with high rate (>0.1 Tbps), EMF compliance

- Sub-THz transceiver design & dimensioning
- Sub-THz antenna integration
- Sub-THz phase noise mitigation
- Sub-THz power amplifier modelling

Reducing energy consumption per bit in networks by (>90%)

- Energy-optimization of transceiver architecture
- RF wireless power transfer power beacon design
- Federated and low-power on-device machine learning
- Energy neutral in-band ambient backscatter
- Lightweight and energy-aware protocols

(>25%) reduction in OPEX by using zero-touch automation

- High-power long-range RF charging of batteries
- In-band ambient backscatter without dedicated reader

Want to learn more about Hexa-X-II WP5?

D5.2 - Characteristics and classification of 6G device classes

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 D5.2
Characteristics and classification of 6G device classes

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

D5.3 - Initial design and validation of technologies and architecture of 6G devices and infrastructure

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 D5.3
Initial design and validation of technologies and architecture of 6G devices and infrastructure

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:	dd/mm/2024	Version:	0.2
Project reference:	101095759	Call:	HORIZON-JU-SNS-2022
Start date of project:	01/01/2023	Duration:	30 months

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

D5.5 Coming April 2025

HEXA-X-II

HEXA-X-II.EU //

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.