CENTRIC

Towards an AI-native, user-centric air interface for 6G networks

EuCNC & 6G Summit – The 6G Series Workshop by Hexa-X-II

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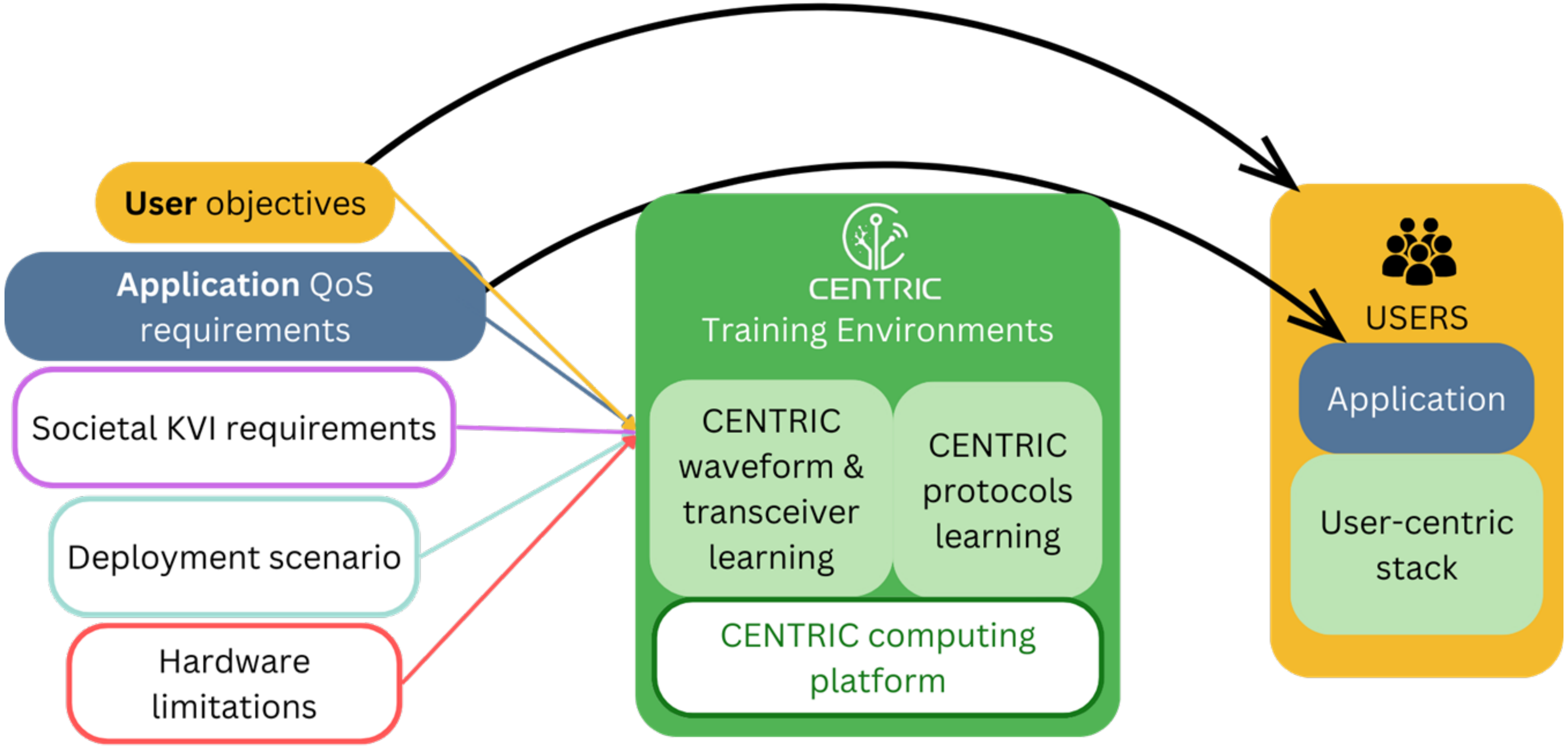
Key Facts

- CENTRIC is an SNS-JU phase 1 STREAM-B-01-02 – “Wireless Communication Technologies and Signal Processing” project
- Project Period: January 2023 – June 2025
- Budget: € 6,840,005.94 of budget (EU Contribution of €4,215,999.00)
- Consortium Partners:
    - Coordinator: Eurescom (DE).
    - Academic: Aalborg University (DK) (Technical Coordinator), CNIT (IT), CNR (IT), King’s College London (UK), University Oulu (FI).
    - Industry: Nokia Networks France (FR), NVIDIA (DE), Sequans Communications (FR), Keysight Technologies (ES), Interdigital Europe (UK), Nokia Solutions and Networks (DE)
    - SME: Synthara AG (CH)

Vision & Goal

"The goal of project CENTRIC is to enable sustainable, user-centric 6G networks through an AI-native Air Interface (AI-AI)."



Objectives

To develop AI methods for the discovery of **novel and efficient waveforms**

To develop AI methods for the discovery of **novel and efficient transceivers**

To develop AI methods for the discovery of **customized lightweight communication protocols**

To introduce novel **end-to-end hardware co-design solutions** for **energy-efficient AI-native transceivers**

To develop **training and monitoring environments** as enablers for AI-AI deployments

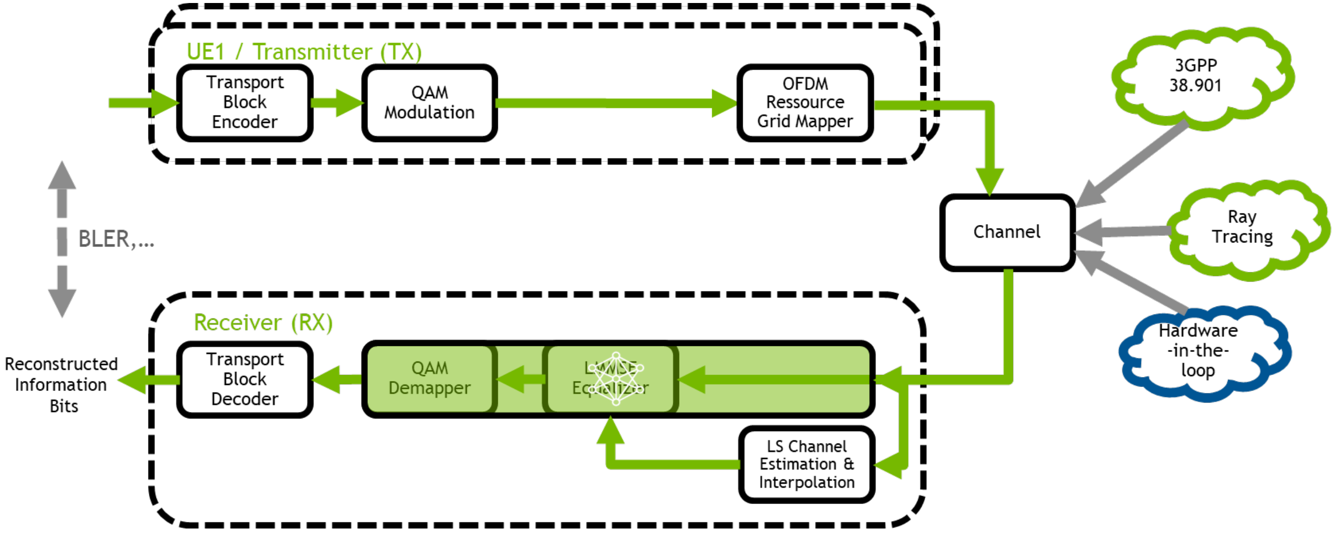
To **validate user-centric AI-AI** solutions in a lab setting

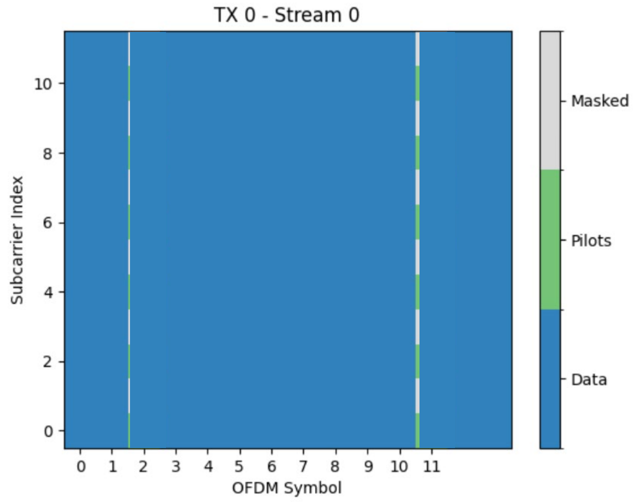
To **demonstrate and disseminate** AI-AI concepts

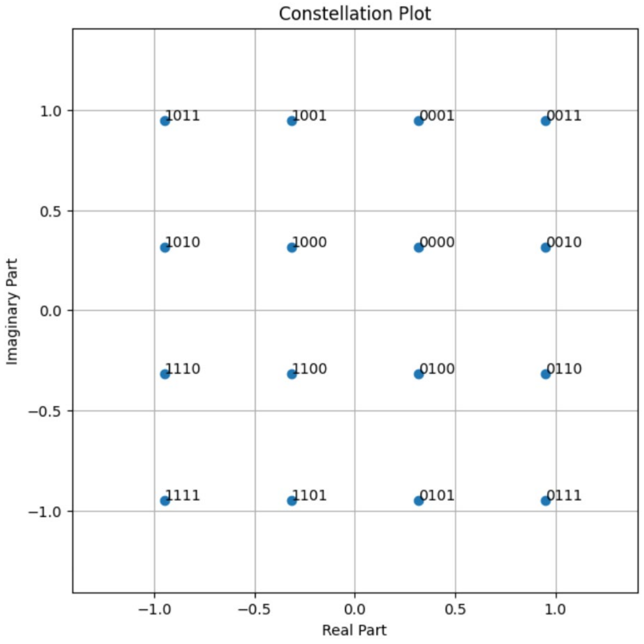
Selected AI-AI Concepts

Physical Layer Methods

Pilotless communications enabled by Neural Receivers







- **Core idea**: remove any DMRS [1] from PUSCH slots
- Trainable custom constellations replace *classical* QAM
- Neural receiver learns implicit channel estimation and equalization

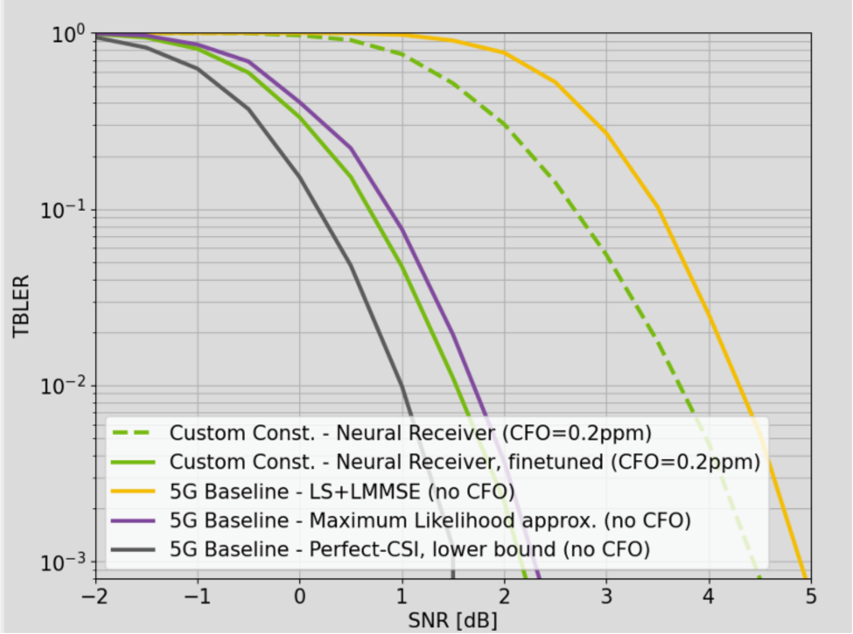
Only additional 32 real-valued trainable weights required

Trained in Simulations – Verified in the Lab

Mobile World Congress 2024 Demonstrator

Hardware-in-the-loop experiment

- 2x4 MIMO configuration
- 273 PRBs/100 MHz bandwidth @ 2.14 GHz
- Post-FFT signal processing by a neural network trained with data generated by NVIDIA Sionna
- Trained to compensate residual CFO up to 0.3 ppm

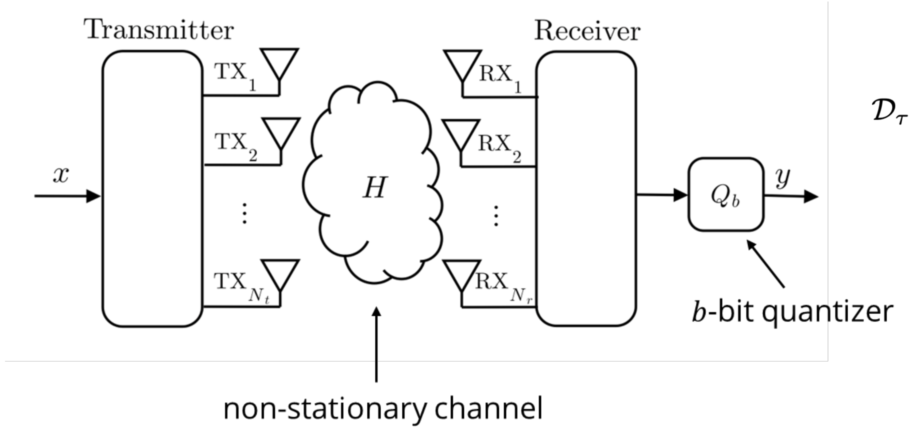


Verified by Rohde & Schwarz test equipment

- Modified 5G NR PUSCH signal
  - Custom constellations from NVIDIA Sionna
  - *DMRs-free* slots
- 428 Hz residual CFO (=0.2ppm)
- Fading profiles following the 3GPP conformance tests
  - TDL-B 100ns/400Hz

In-Context Learning for Adaptable Wireless AI

- Motivation:
  - Application of AI to wireless hinges on its adaptability in the face of changes in the environment conditions.
  - For example, AI receivers must adapt to non-stationary environments based on a few limited pilots.

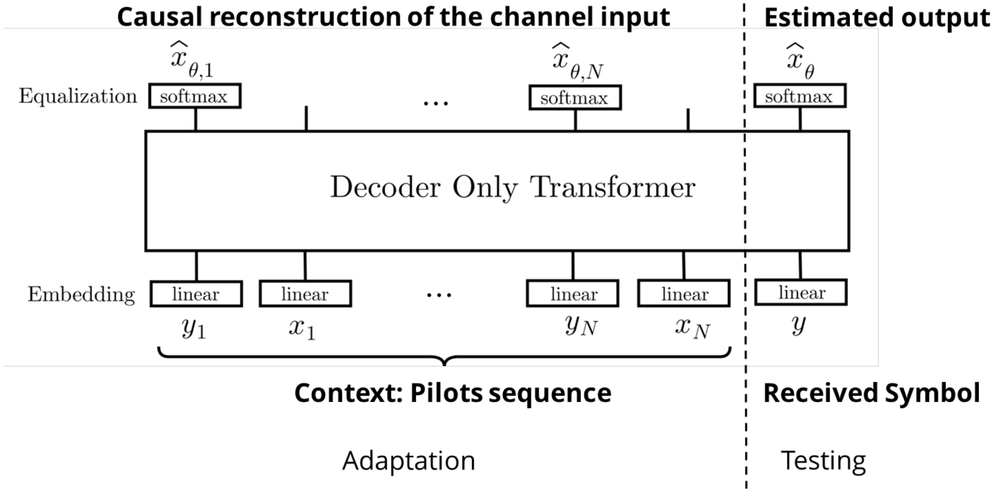


Pilots

$$\mathcal{D}_\tau = \{(x_i, y_i)\}_{i=1}^{N} \sim P_{y,x|\tau}^{\otimes N}.$$

Equalizer

$$\hat{x} = \hat{x}_\theta(\mathcal{D}_\tau, y)$$



- ICL-Based Equalization:
  - Transformer models can be trained to perform in-context learning (ICL).
  - Adaptation is based on the pilot sequence, without model parameter updates.

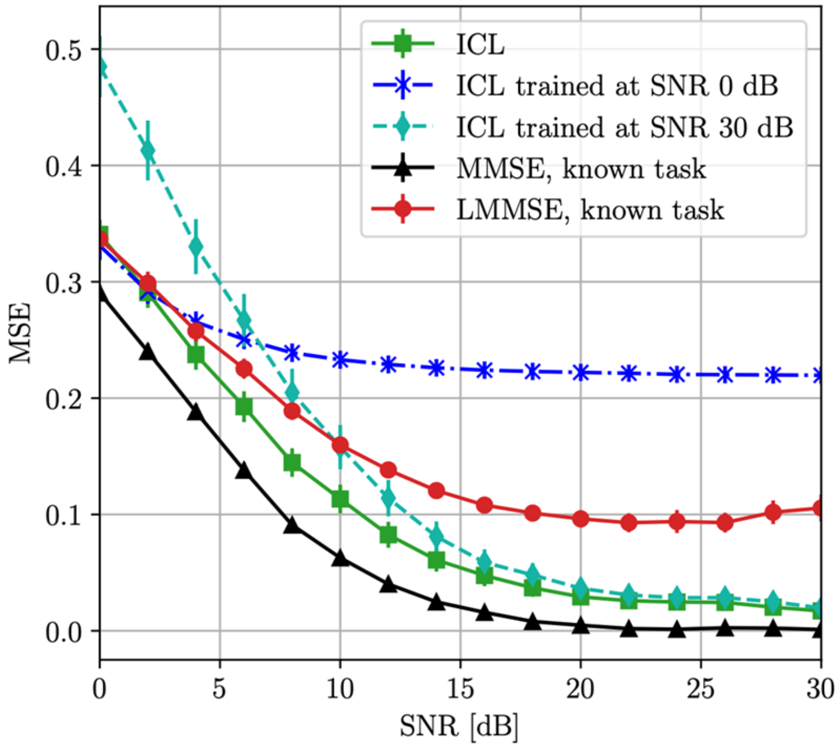
In-context Learning for MIMO Equalization

Channel-aware receivers:

- **MMSE** with channel knowledge (optimal)
- **Linear MMSE** with channel knowledge

Channel-oblivious receivers (10 pilots):

- ICL trained at 0dB SNR
- ICL trained at 30dB SNR
- ICL trained on diverse SNR tasks.



- ICL outperforms the **Linear MMSE** receiver.

- Task diversity improves the generalization of the model.

ICL can be used to produce highly adaptable equalizers!

Selected AI-AI Concepts

Learned Communication Protocols

Emerging multiple-access protocols for specialized services

Protocol definition: Logic and signaling necessary for distributed nodes to organize.

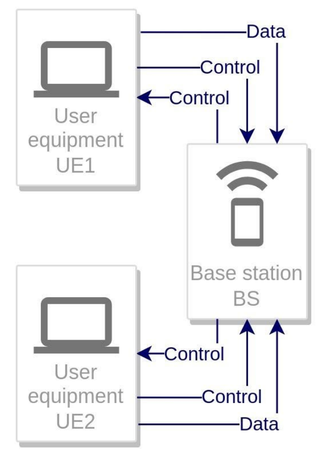
Problem:
- **General-purpose RAN protocols** do not leverage the properties of the scenarios they serve.

Q: Can we train scenario-tailored protocols as ML models?

- Short answer: “Yes, but…”

- It only works in very small scenarios
  - A handful of User Equipments
  - A handful of signaling messages

- Ambitious KPIs (latency, throughput, massive connectivity) are also required in 6G

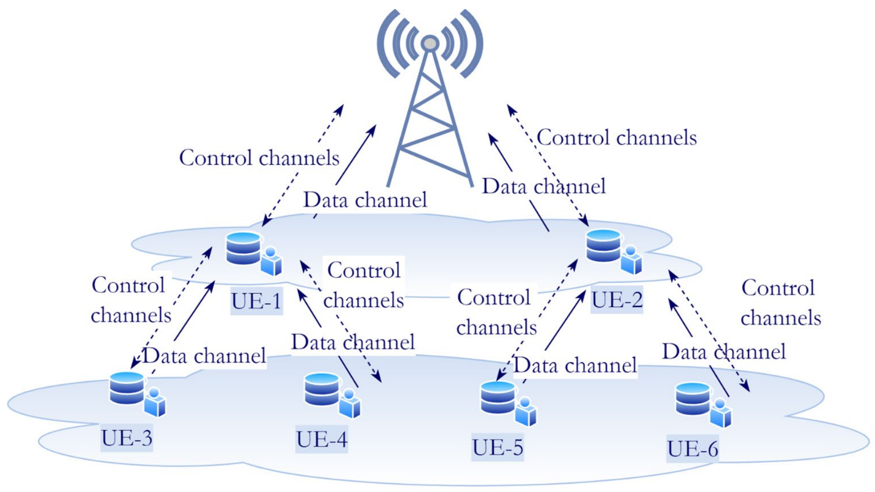


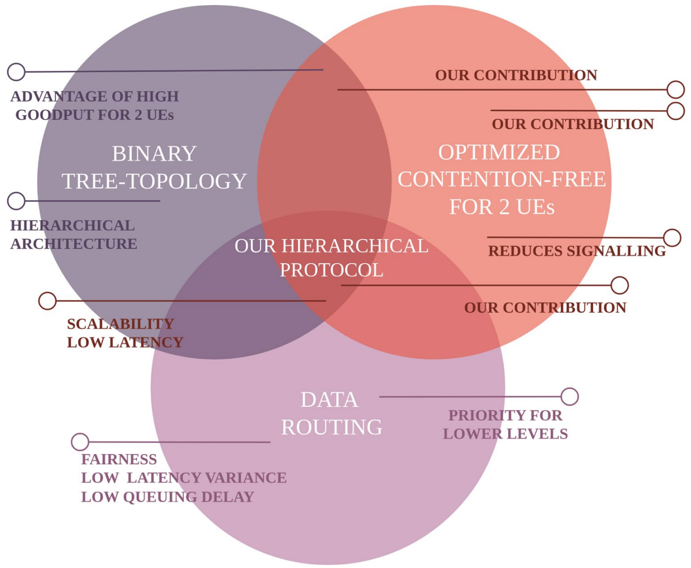
Wireless communication model

Emerging multiple-access protocols for specialized services

Proposed solution:

- Goal is to optimize contention-free access protocol with random scheduling
- New signaling messages for data transmission synchronization
- **Hierarchical architecture** based on a binary tree-topology that scales well to any number of UEs
- Hierarchical topology designed for a fair trade-off between latency and goodput





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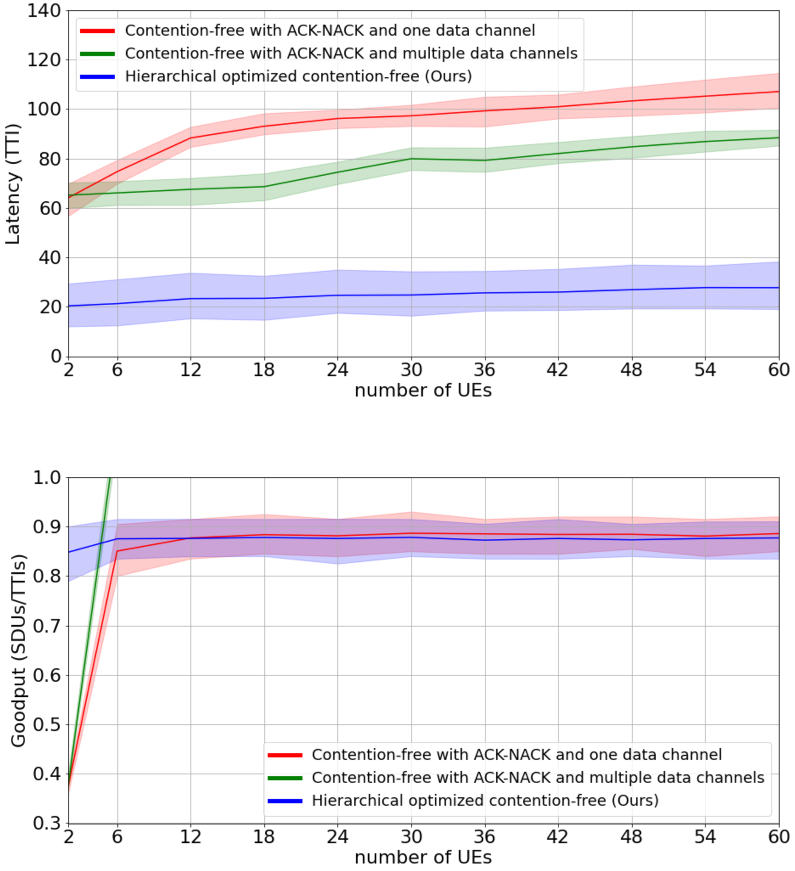
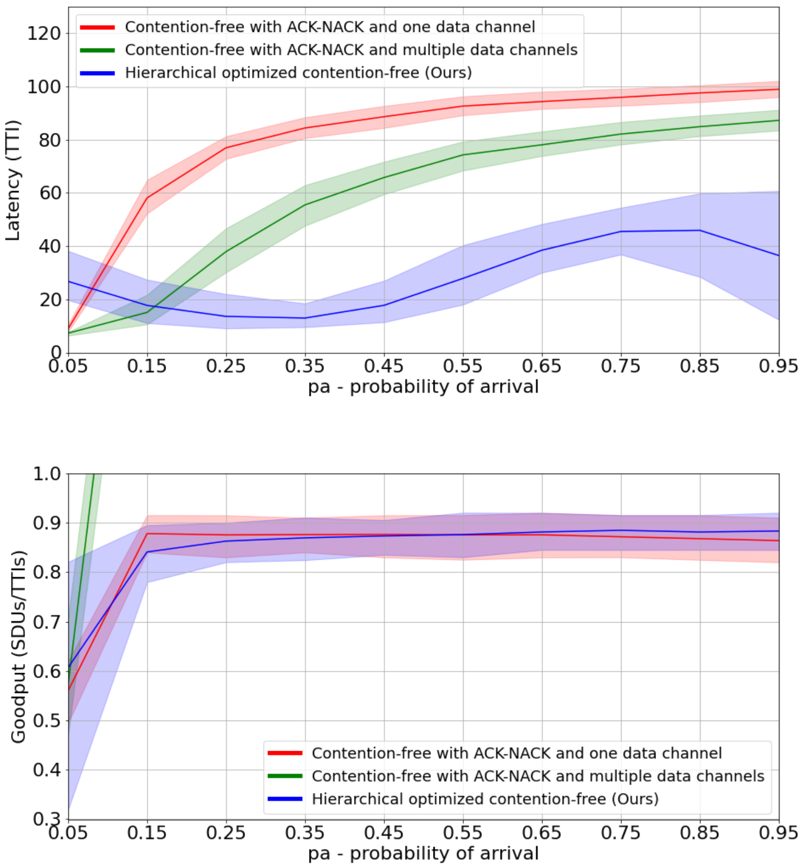
Emerging multiple-access protocols for specialized services

Results:



Scaling to user density



Scaling to traffic density

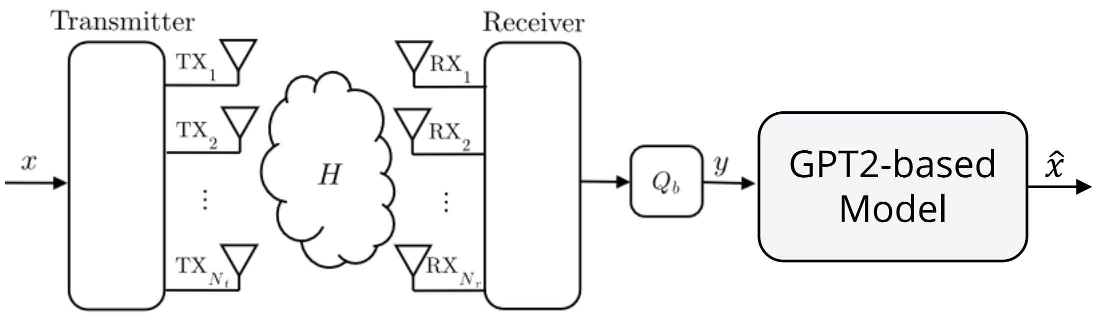
Selected AI-AI Concepts

Hardware Enablers for AI-AI

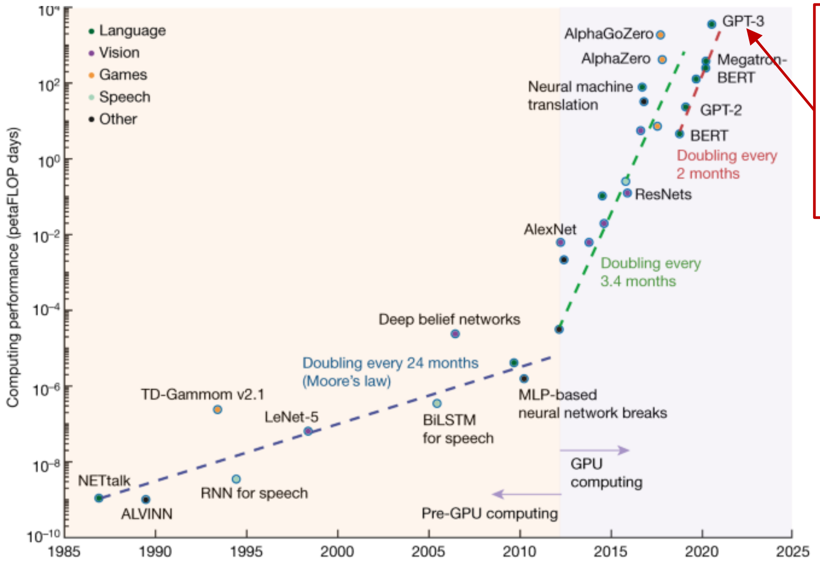
Neuromorphic Hardware Implementation

- **Transformer models** have **in-context learning** capabilities that can be leveraged to quickly adapt AI-AI modules to changing conditions.

- However, the transformer's **high power consumption** limits its applicability for telecom.



Transformer for MIMO equalization

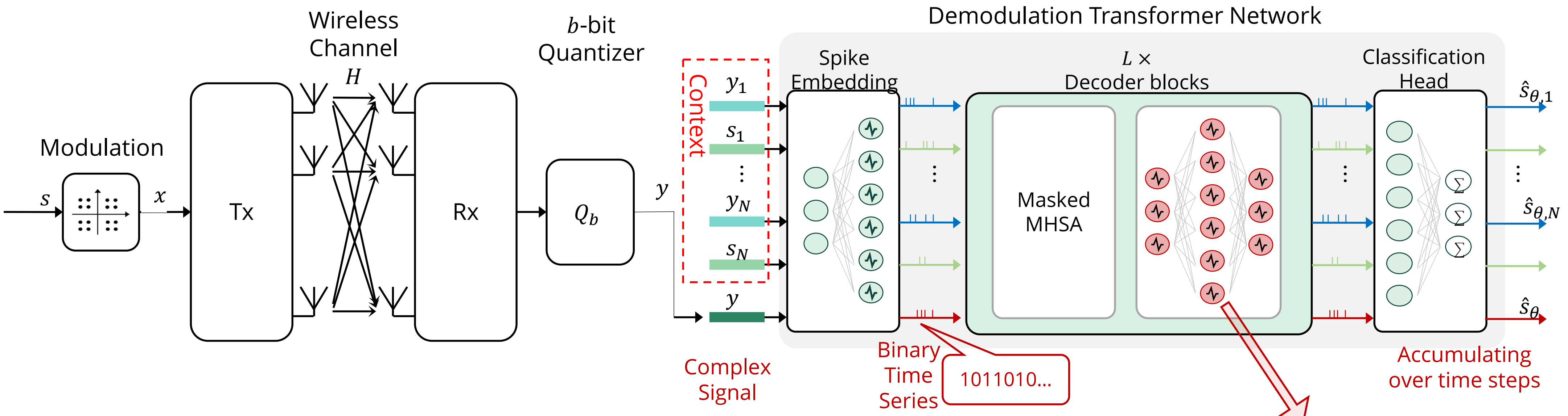


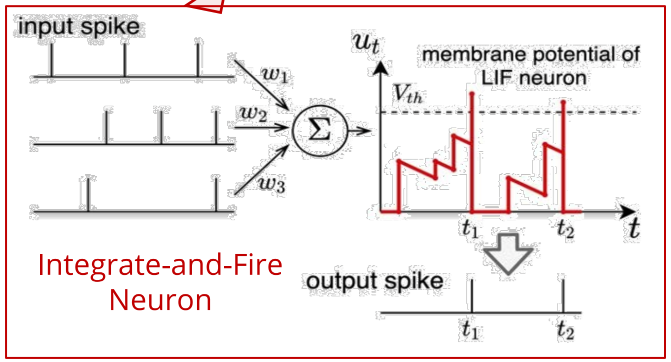
GPT-3
175 billion parameters
113kW
1,300 MWh
502 tons CO2

Computing power demands

- **Goal:** Introduce low-power computing paradigm for Transformer models in AI receivers

Neuromorphic Hardware Implementation

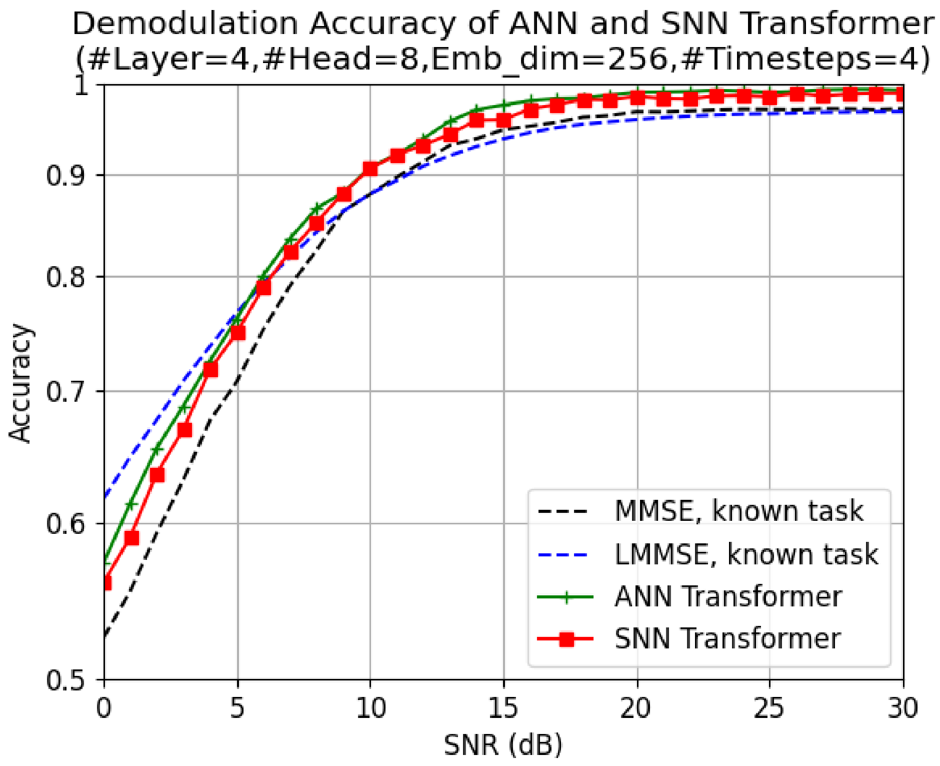


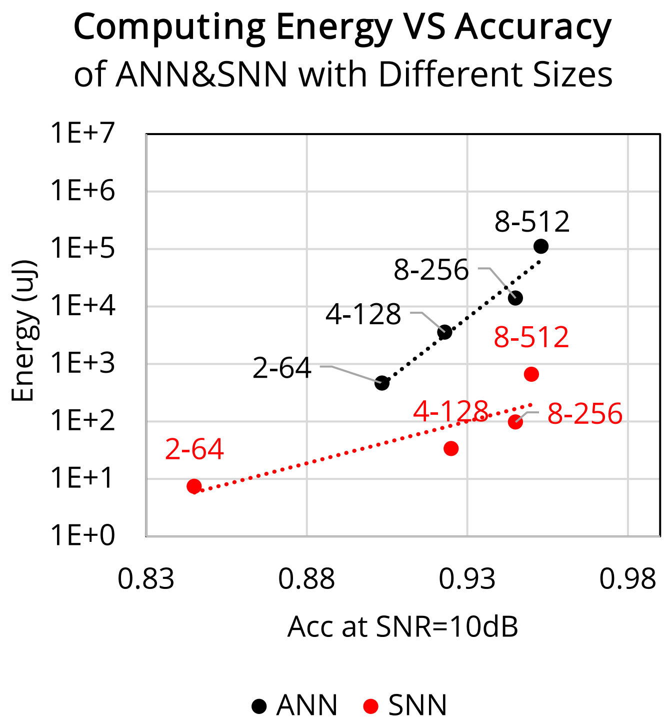


- SNNs **replace multiplication with additions,** significantly reducing power consumption.

Neuromorphic Hardware Implementation

- Energy Evaluation: based on basic energy metrics for 45 nm CMOS technology
- Energy Efficiency: The SNN architecture (with hardware acceleration), achieves up to an order of magnitude higher energy efficiency compared to ANN.



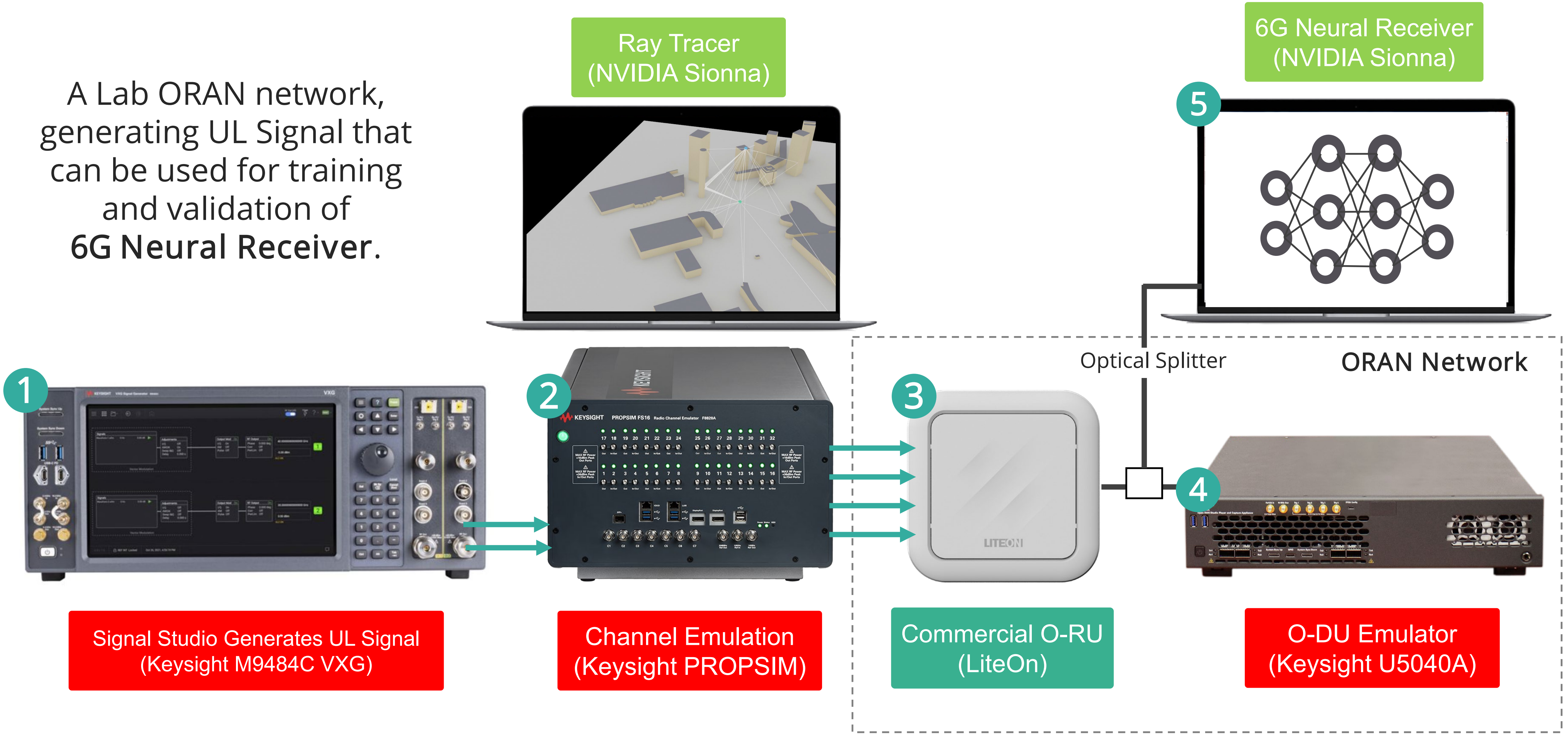


Selected AI-AI Concepts

AI-AI Validation and Testing

PoC: 6G AI MU-MIMO Neural Receiver

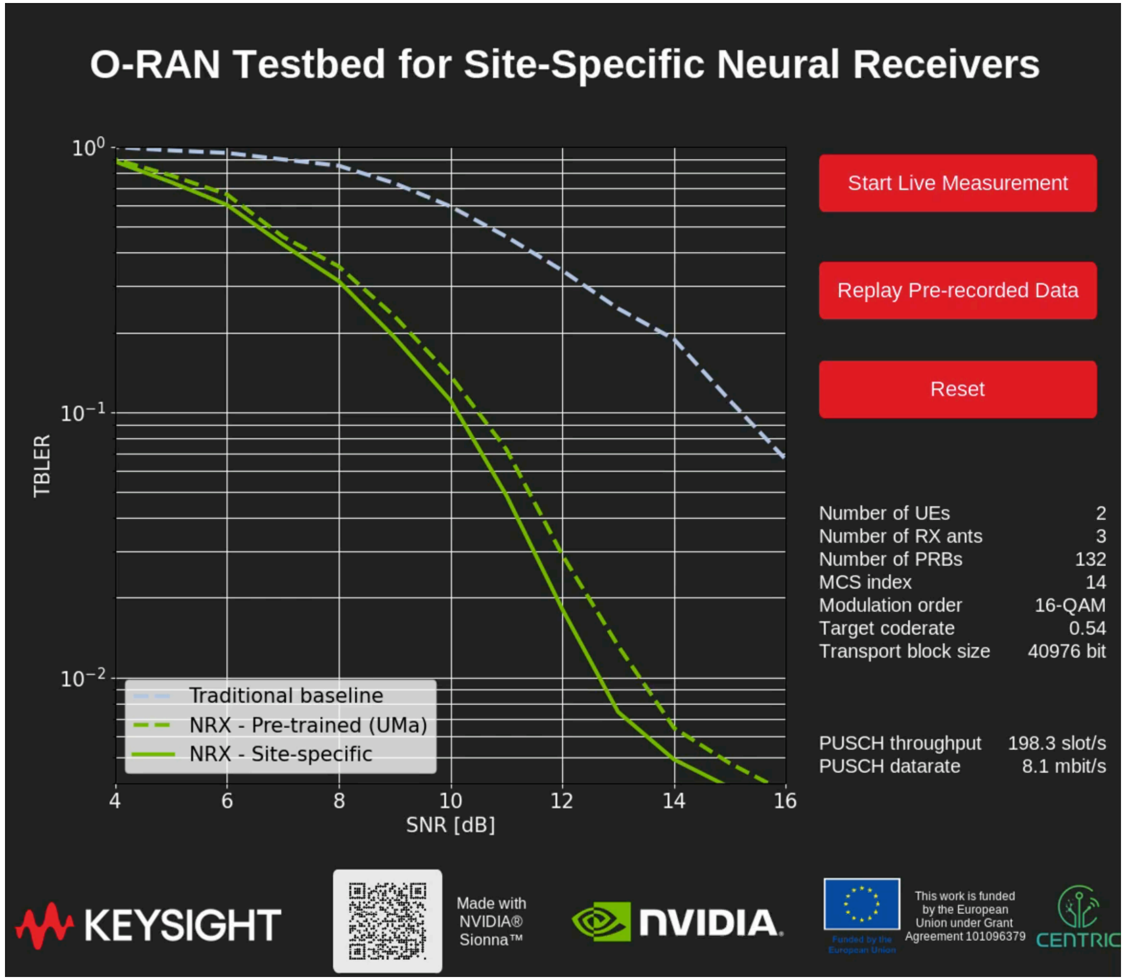
A Lab ORAN network, generating UL Signal that can be used for training and validation of **6G Neural Receiver**.



PoC: 6G AI Neural Receiver Design

NVIDIA Neural Receiver

- Neural Receiver receives live data from ORAN Testbed.
- We can see live results converged to the precomputed curves.
- Clear gains between NRX and the baseline.
- Site-specific training improves performance.
- It works!



Conclusion and Outlook

- CENTRIC has made significant contributions towards actualizing its AI-AI vision.

- Other than those shown in this presentation, CENTRIC is developing:
  - Methods for waveform and modulation learning for sub-THz communication and short packet transmissions.
  - Application- and scenario-specific RRM methods with controlled user EMF exposure.
  - AI-based sensing aided beam management in mmWave ISAC scenarios.
  - Real-time implementation of AI receivers.
  - …. and many more!

- CENTRIC has just had a successful mid-term review, you can expect more interesting results in the second half. Stay tuned!

Many thanks for your attention!

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