Result Highlights of Early 6G Enablers

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Motivation

- Discussion on 6G started as early as ~2018
- Projects in 5G PPP used the term to promote the “next” thing in mobile networks
- E.g. proposals made in 2019-2020 timeframe as a contribution to “Smart Connectivity beyond 5G”
- When the landscape matured, Europe launched the Smart Networks and Service Joint Undertaking
  - European Union
  - 6G Infrastructure (Industry) Association

6G-BRAINS

Bring Reinforcement-learning Into Radio Light Network for Massive Connections

Objectives

The aim of 6G BRAINS project is to design, develop and exhibit:

- An AI-driven D2D cell free network architecture for highly dynamic and ultra-dense connectivity
- AI-based End-to-End (E2E) Directional network slicing with guaranteed QoS over highly dynamic network
- AI-driven data fusion for the 3D indoor position map through heterogeneous location methods enabling 1cm location position accuracy and 1° orientation accuracy
- Enhanced new spectrum links: OWC and THz
- International Standardisation and Demonstration to Industry

6G BRAINS Use Cases and KPIs

- Identification of application sectors, user stories and use cases with focus on primary features (communication) and secondary features (ranging, sensing ISAC/JCAS, imaging, etc.).
- Analysis and comparison of the user requirements and technology KPIs; comparison to 3GPP and HEXA-X, derivation of input for 3GPP, 5G PPP, 5GAA, 5G-ACIA, etc.
- Shaping the directions of research to best meet best the user requirements; increase the attractiveness and sustainability of the future technology.
- Gap analysis between user requirements and KPIs
- Findings from gap analysis (e.g., “direction accuracy” KPI), innovative use cases based on features (sensing, etc.)

	Offloading of the PLC Control Function to the Edge	Smart Transportation Vehicles		Maintenance Video Guides	Advanced Network Slicing	Animal Tracking in Indoor Farming Scenarios	Airports Service and Baggage Handling Robots
		Localization	Video Processing Offloading				
Round Trip Time (sensor to controller to actuator)	**< 10 ms (250 µs - 10 ms)**	**100 ms**	**100 ms**	**>50ms**	**5-15ms**	**>50ms to sec.**	**10 ms**
Reliability	**10^{-8}**	**10^{-6}**	[illegible]	**10^{-2}**	**10^{-6}**	**10^{-5}**	**10^{-6}**
Data Rate	**kbit/s- Mbit/s**	**kbit/s- Mbit/s**	**Mbit/s- Gbit/s**	**kbit/s- Mbit/s**	**kbit/s- Mbit/s;10 +Gbps at backbone**	**kbit/s**	**Mbit/s- Gbit/s**
Packet Size	**up to 1500 Byte**	**20-50 Byte**	**1500 Byte**	**<300 Byte**	**<300 Byte**	**<80 Byte**	**>200 Byte**
Covered distance (from an Access Point)	**<100m**	**within the facility**	**within the facility**	**<200m**	**within the facility**	**100m-1km**	**<100m**
Movement speed of the user	**< 1 m/s**	**<10 m/s**	**<10 m/s**	**<40 m/s**	**< 10 m/s**	**< 10 m/s**	**< 3m/s**
Time critical handover support	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**No**	**No**
User Equipment Density	**0.33-3 per m^2**	**0.1 per m^2**	**0.1 per m^2**	**0.1 per m^2**	**0.1 per m^2**	**10000 per plant**	**0.03-0.02 per m^2**
Energy Efficiency	**n/a**	**n/a**	**n/a**	**n/a**	**< 8h**	**1 years**	**1 day**
Location detection accuracy	**<50cm**	**1 cm**	**n/a**	**<1cm**	**<5cm**	**from 1mm to <10cm**	**< 1cm**
Service Availability	**99.999 %**	**99.999 %**	**99.999 %**		**99.999 %**		

Key innovations

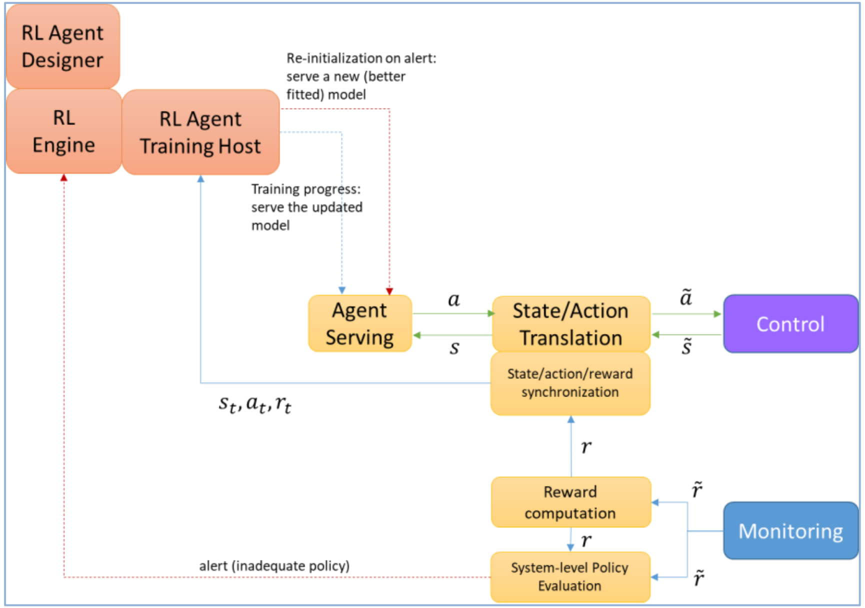
- Multi-agent Deep Reinforcement Learning Scheme Specifications, Workflows and how to apply to:
  - General modelling of the mobile network
  - RAN Scheduler
  - Joint-Slicing Scheduler
  - AI driven cell-free Scheduler with IAB
  - D2D Clustering Control
- 3D Laser measurement at a factory with 3D cloud scanner and 3D hand scanner
  - Obtained a raytracing model that allows simulations with spatial consistency over different bands, providing an accurate geometrical representation of the environment from the propagation properties for precise localization applications.
- Specifications and Upgrade of Multiband Channel Sounder for Quad-Band Measurements at Sub-6 GHz + mmWave + THz + OWC in Industry Scenarios
  - Used for validation and calibration of the obtained ray tracing model

Key innovations

- Design of an Artificial Intelligence (AI) based scheduler for Cell-Free (CF) Networks with Integrated Access and Backhaul (IAB) and intelligent beam steering
  - ultra-dense dynamic CF Network includes a cluster of Device to Device (D2D) User terminals (UE) and human-centric control interfaces
- E2E Network Slicing Control Enablers
  - Design and prototyping of enabling technologies for E2E network slicing across RAN and Core network segments
  - Algorithm design of AI-based radio link control and RAN slice scheduler
  - Integration aspects of Management-Orchestration and Cognitive Plane
- Prototype platform for DRL
- Enablers for 3D localisation
  - 3D Localisation and Mapping
  - Sensor fusion operations using Location Database (LD) Location Server (LS) and a Deep Reinforcement Learning (DRL) application to improve location accuracy
  - Integration of Blockchain Location Ledger technologies for sharing position data

Multi-agent Deep Reinforcement Learning

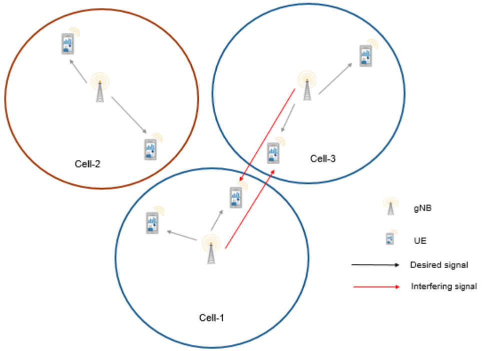
- Introduction to Reinforcement Learning, its formalism and technical challenges, and how it should be implemented in 6G
- Application cases of RL, from the networking domain modelling perspective and the RL problem formulation perspective
- Specification of key components of the MA-DRL scheme, their generic interfaces, and how they interact through RL training and inference workflows.
- Extensible foundation to describe applications cases of RL in 6G and enable implementing RL in the 6G network
- Projection of the RL processes onto the 6G architecture logical planes
- Formalisation of 6G resource allocation and scheduling cases as RL problems.

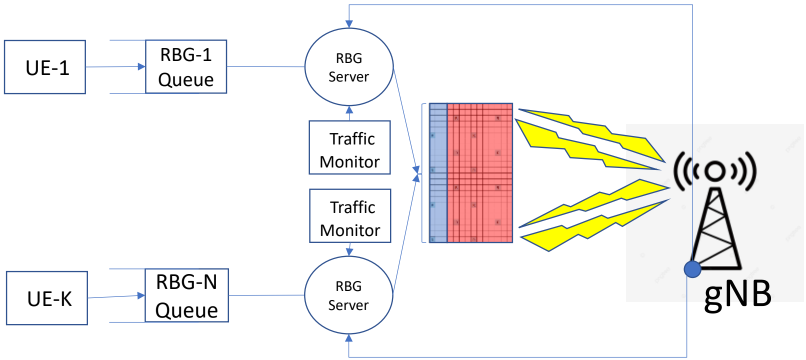


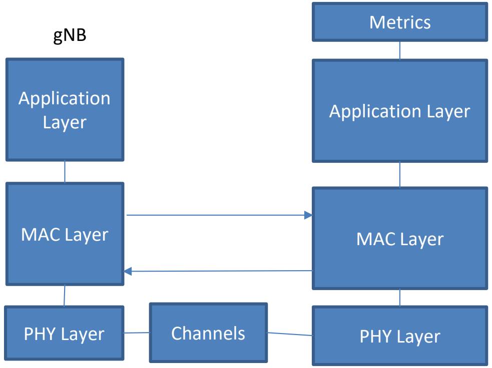
Functional breakdown of a RL training loop

Radio Link Control using RL

- Simulation study based on a NR Intercell Interference Downlink Model as a cell free network.
- Used RL to choose the best Modulation and Coding Scheme (MCS) from Channel Quality Indicator (CQI).
- Enhance the 5G network model radio link control using RL and Industry 4.0 Traffic Models
- Obtain comparative performance results

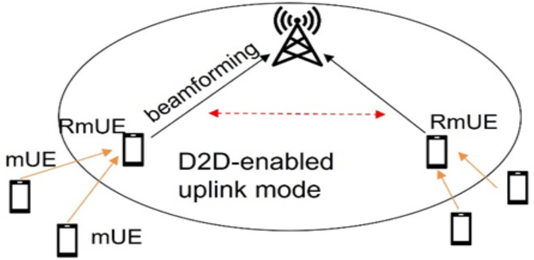




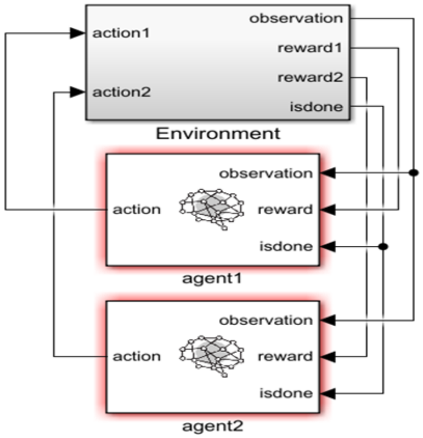


D2D-enabled coop. network for cell-free access

- Improve communication performance of the far cell-edge users by using D2D relays between them and an integrated access and backhaul (IAB) node
- Dynamic allocation of transmission power levels for far users and D2D relay, and decoding individual users by beamforming and successive interference cancellation
- Improve communication quality of cell-edge users with poor channel conditions, thereby expanding cell coverage
- Application of MA-DRL for optimising user rate



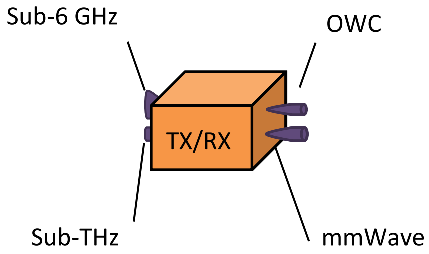
D2D enabled cooperative network model



MA-DRL model for power allocation

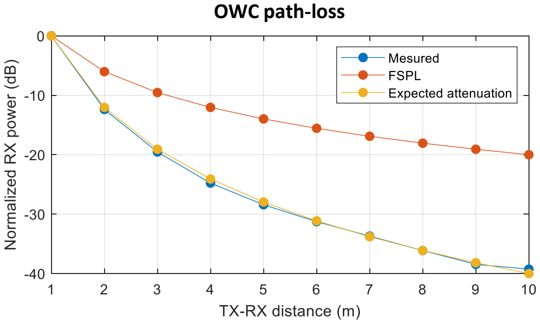
Quad-band channel sounder

- The RF sub-6 GHz and mm-wave channel sounder has been extended with sub-THz and OWC interfaces to cover four different bands simultaneously. This channel sounder has been tested verified and validated with measurements in the lab.
- The extended channel sounder allows to fairly compare propagation in the different bands of interest and extend the validation of the RT to the sub-THz and OWC bands
- Unique channel sounder covering simultaneously the four bands of interest.

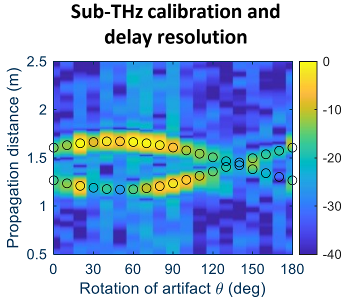


Schematic of the quad-band channel sounder

Picture of the quad-band channel sounder



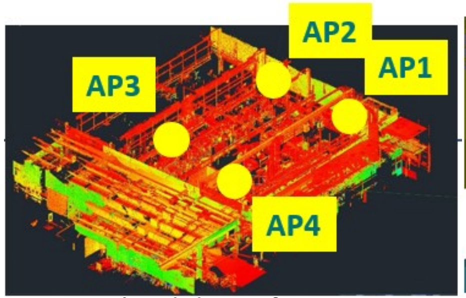
Measured and estimated path-loss for OWC



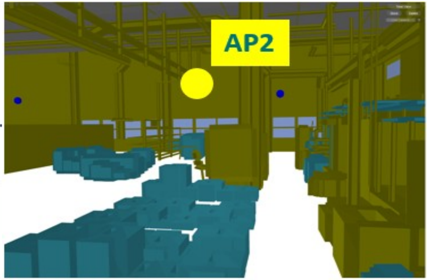
Measured and estimated delay of arrival for validation of the sub-THz sounder

Communication and Sensing Localisation

- ❑ A 3D laser scan of a real factory creates a detailed point cloud data set. This is turned into a "digital twin" model
- ❑ Uses a deterministic method based on the geometrical theory of propagation (GTP) to predict radio propagation at different frequencies
- ❑ Considers factors like environmental geometry and propagation attributes such as time of flight (ToF), direction of arrival (DoA), and direction of departure (DoD)
- ❑ Laboratory SLAM (Simultaneous Localisation and Mapping) system for combining multiple localization and mapping technologies
- ❑ Indoor location of < 1 cm accuracy and 99.9999% reliability can be obtained using 6G



Point cloud data of Factory
Source: Bosch Plant



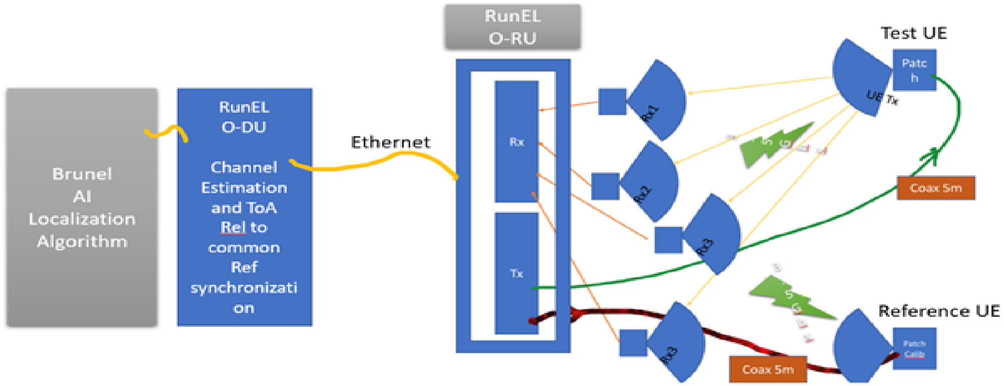
Ray Tracing Map of Factory
Source: Bosch Plant

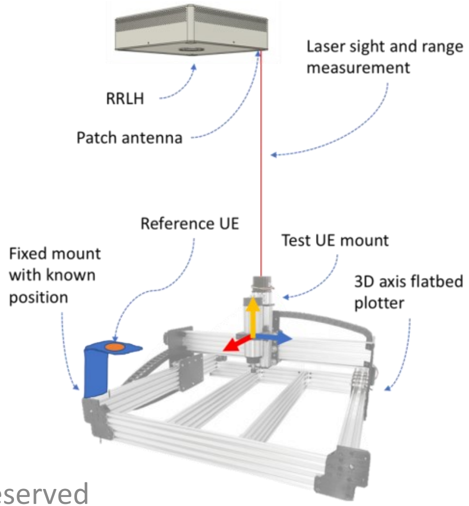

Video of Lidar Sensing Emulator

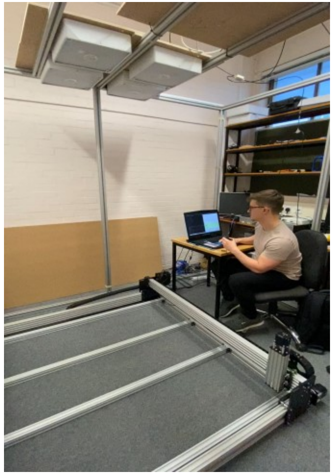

Lidar Sensing Emulator

1 cm sub-6GHz ToA Localisation

- Time Difference of Arrival experiment on 5G indoor network to measure and store distances with 1cm accuracy using Zadoff-Chu Pseudo Random Noise sequences generated at user equipment and picosecond resolution time delay measurements on the sub-6GHz RAN (3.5GHz)
- Very high 1 cm indoor distance/location estimation accuracy for stationary and moving objects
- FPGA signal processing for timing resolution with 30ps accuracy integrated into experimental setup
- 1 cm accuracy for indoor location can be obtained







Towards an AI-Native, User-Centric Air Interface for 6G Networks

What is CENTRIC?

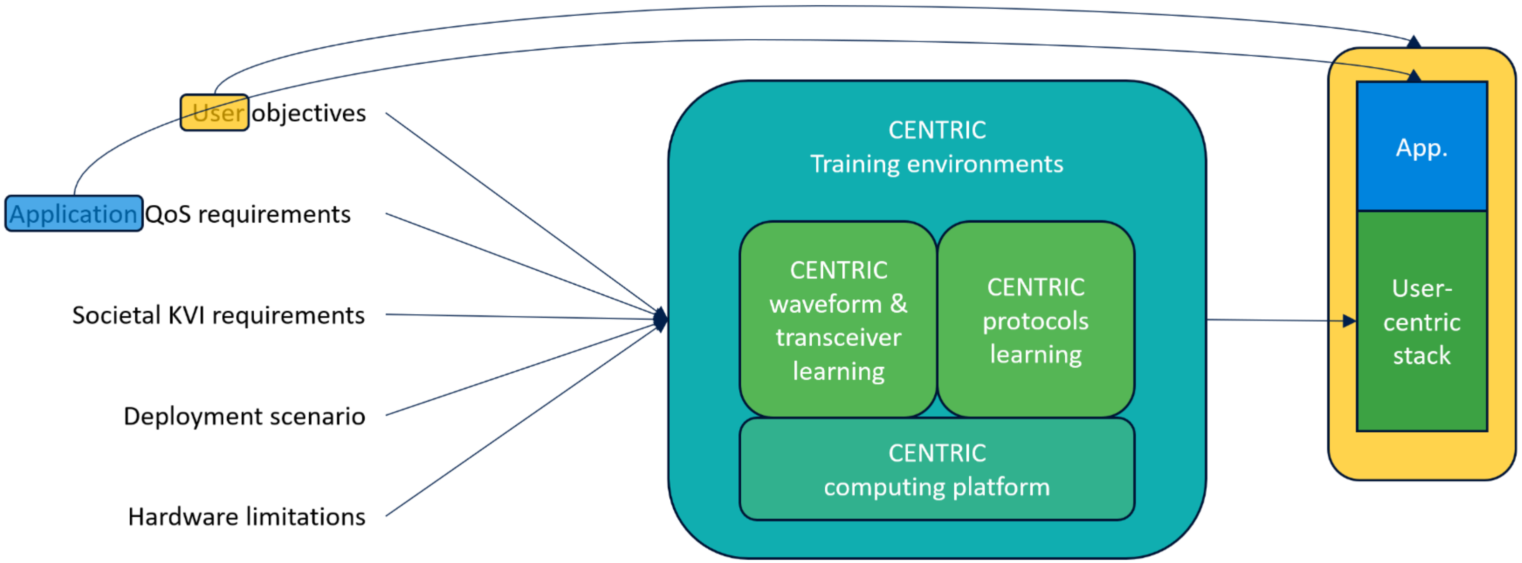
CENTRIC is a co-funded R&D&I European project who proposes to leverage AI techniques through a top-down, modular approach to wireless connectivity that puts the users' communication needs and environmental constraints at the centre of the network stack design.

The results of CENTRIC will be validated and demonstrated in laboratory prototypes and its breakthroughs will enable future 6G use cases, such as self-driving vehicles, the internet of nano bio-things, or multi-sensory holographic communications.

CENTRIC

Vision & Goal

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



CENTRIC research topics

- AI methods for the discovery of
  - novel and efficient waveforms
  - novel and efficient transceivers
  - customized lightweight
  - communication protocols
- Novel end-to-end hardware co-design solutions for energy-efficient AI-native transceivers
- Training and monitoring for AI Air Interface deployments
- Validate user-centric solutions

Thank you for your attention

https://6g-brains.eu/
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