

TOWARDS NS-3 6G-LENA: EVOLVING RESEARCH & SIMULATIONS THROUGH OPEN-SOURCE COLLABORATIVE DEVELOPMENTS

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ONE6G OPEN LECTURES 2022 – 6G TESTBED/SIMULATION

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AGENDA

- CTTC OpenSim research unit
- 5G-LENA network simulator
 - History
 - Overview
 - Projects
 - Development examples
- Towards 6G-LENA
 - Cross-layer QoS management, XR
 - Disaggregated RAN, distributed ML-decision
 - Security in UAVs
 - Cellular and TSN integration in i4.0
 - New development strategy
- Contributors

CTTC OPENSIM RESEARCH UNIT

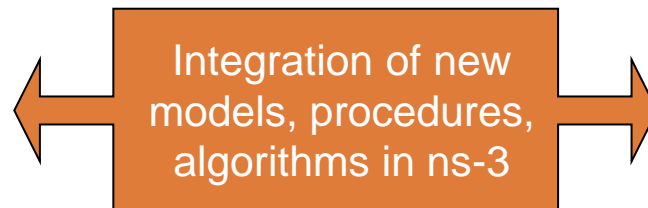
- **Vision:** collaborative research through **open-source code developments**
- **Why?** technology development and standardization should be based on common software platforms and joint efforts, to progress further
- **How?**
 - research based on **ns-3**, an open-source end-to-end network simulator
 - release (open-source) major part of our developments and findings
 - strong commitment with the ns-3 community (ns-3 executive consortium, LTE/NR maintainers)

<https://5g-lena.cttc.es>

- **Research lines:**
 - Spectrum sharing and 3GPP/IEEE tech coexistence/convergence
 - RAN: models, algorithms and architectures
 - RRM and SON in disaggregated RANs

- **Methodological approach:**

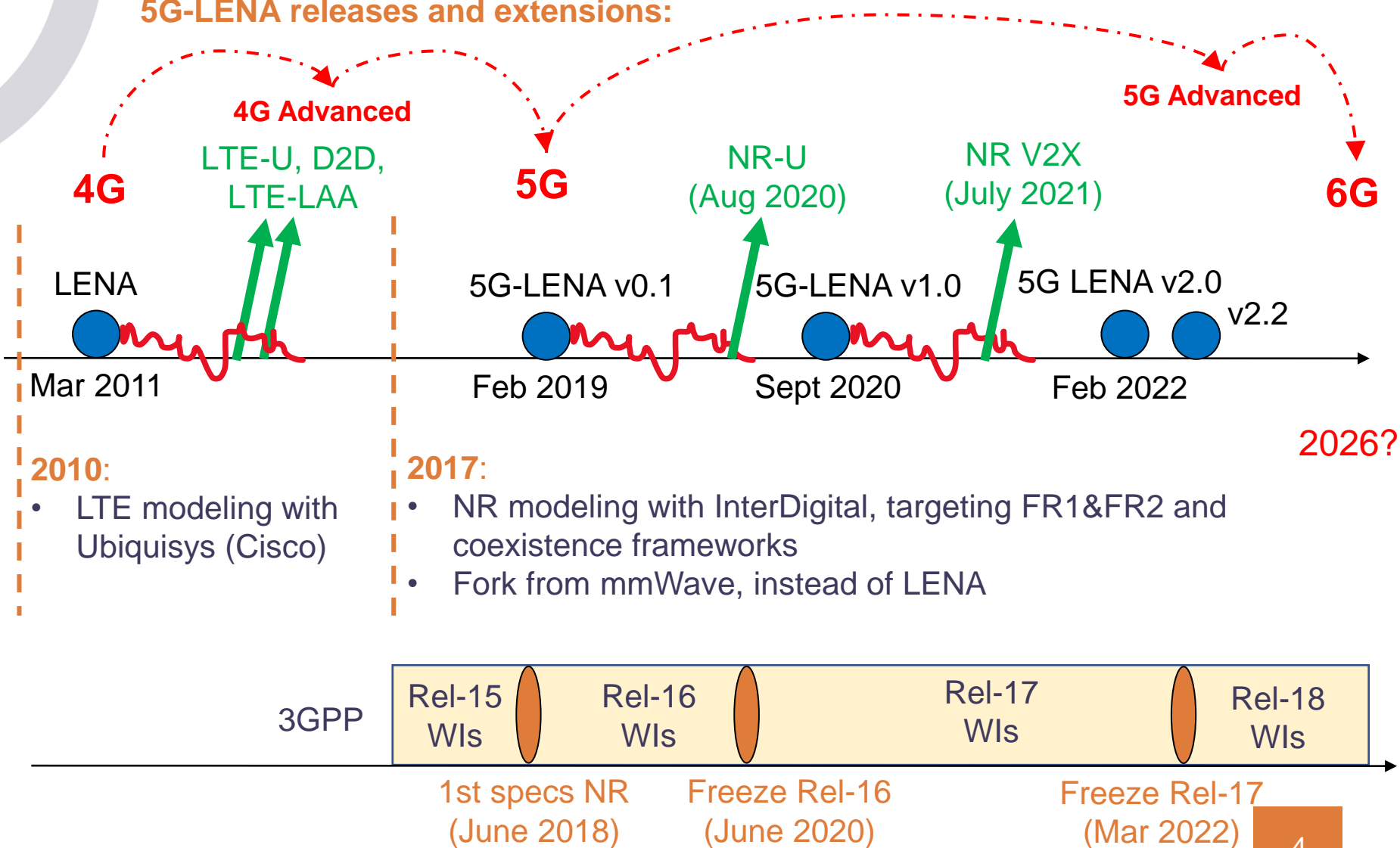
Advances in RRM, arch,
coexistence, SON.
Analytical problem
formulation and solving.



ns-3 5G-LENA
design, development,
validation, calibration,
evaluations

5G-LENA HISTORY

5G-LENA releases and extensions:



2010:

- LTE modeling with Ubiquisys (Cisco)

2017:

- NR modeling with InterDigital, targeting FR1&FR2 and coexistence frameworks
- Fork from mmWave, instead of LENA

2026?

5G-LENA WEBPAGE

<https://5g-lena.cttc.es>

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5G-LENA simulator

ns-3 module to simulate 3GPP 5G networks

5G-LENA is a GPLv2 New Radio (NR) network simulator, designed as a pluggable module to [ns-3](#). Its development, initially funded by InterDigital, is open to the community in order to foster early adoption, contributions by industrial and academic partners, collaborative development and results reproducibility.

The simulator is the natural evolution of [LENA](#), the LTE/EPC Network Simulator, the development started from the [mmWave module](#), and it incorporates fundamental PHY-MAC NR features aligned with NR Release 15 TS 38.300. The first release of the simulator is dated February 2019.

Get the software

along with complete
source code

Join 5G-LENA Group

to discuss, collaborate
and share results

Inherit the strengths of ns-3

[ns-3](#) is an open source discrete-event network simulator/emulator. The ns-3 project is committed to build a solid, well documented, easy to use and debug simulation core, which caters to the needs of the entire simulation workflow, from simulation configuration to trace collection and analysis.

Compared to other open source simulators, ns-3 offers multi-RAT (Radio Access Technology) and multi-band simulation capabilities, with Wi-Fi, WiGig, LTE (LTE-A, LAA, LTE-U), among others, already openly available.

See the 5G-LENA features

Born in academia

5G-LENA is born within the [Mobile Networks group](#) of a public research institute, [CTTC](#) (Centre Tecnològic de Telecomunicacions de Catalunya). The Mobile Networks group maintains a strong commitment with the ns-3 community in the area of LTE, its evolutions in licensed and unlicensed spectrum, and NR.

The outcome of 5G-LENA simulator through an end-to-end performance assessment is analyzed in many peer-reviewed papers, and there is plenty of material to consider for the bibliography of your next paper.

See the papers

... and for industries?

We have successfully collaborated with many industries and agencies like [Ubiquisys](#), [WiFi Alliance \(WFA\)](#), [Spidercloud Wireless](#), [InterDigital](#), [National Institute of Standards and Technologies \(NIST\)](#), [Lawrence Livermore National Lab \(LLNL\)](#), [Google Summer of Code](#) and many EU projects funded in the framework of FP7 and H2020.

For any inquiry, we have a team at your disposal for modeling, design, development, field trials, testing, 3GPP knowledge and 3GPP standard practical implementation. Why don't you consider us for your next proposal?

See the services

- More than 1000 users around the world
- ... Including top telecom industry players

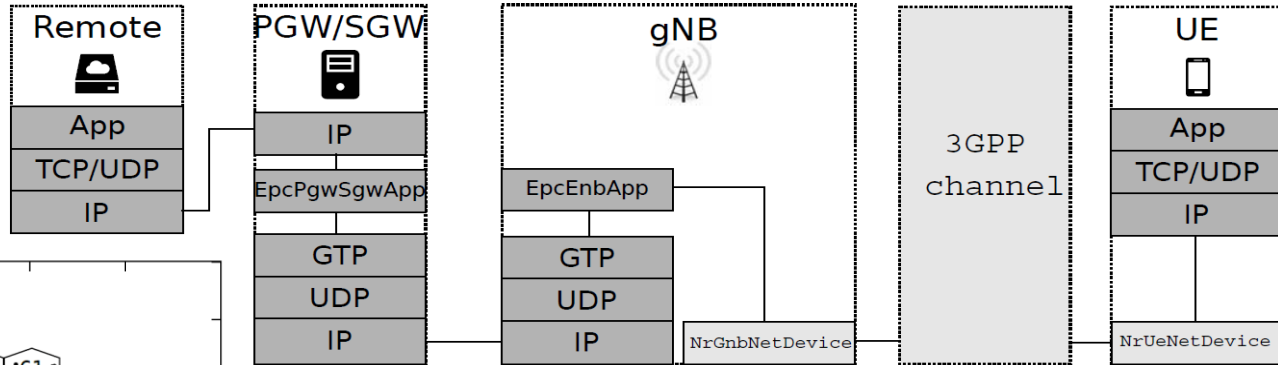
Latest news on our blog »

[NR V2X release v0.1](#)
[WNS3 papers](#)

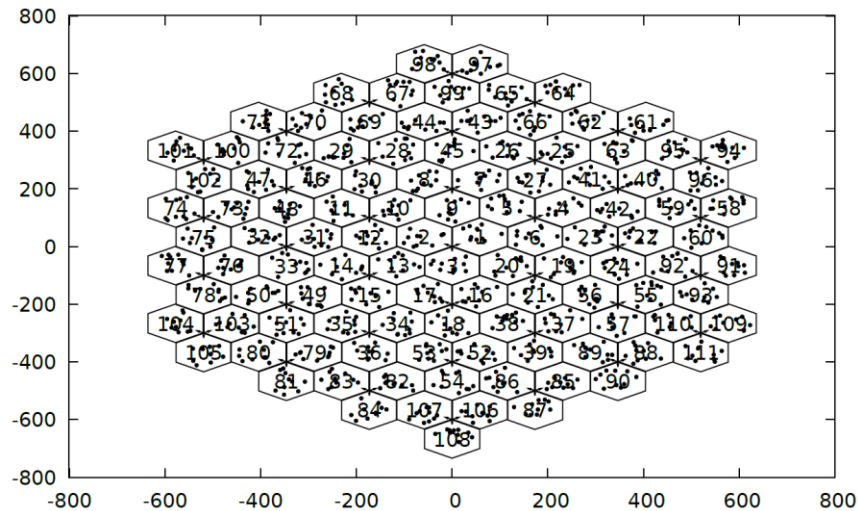
Jul 29, 2021
Jun 12, 2021

5G-LENA OVERVIEW

E2E overview:



- Flexible to work from 400 MHz to 100 GHz, using the 3GPP SCM in TR 38.901
- We have tested NR in FR1 and FR2, and also NR-U in 60 GHz and 5-6 GHz



410MHz 7,125GHz 24,25GHz 52,6GHz 71GHz 114,25GHz

R15

Study R16

R15

R17

Study R18

NR-U in 5/6 GHz in R16

NR-U in 60 GHz in R17

RECENT AND ON-GOING PROJECTS

We developed 5G-LENA and its various extensions (NR-U, NR V2X) in the context of industrial projects:

- **InterDigital** (2017-2019)
 - First release of **5G-LENA**
 - First release of **NR-U module** (extension for unlicensed bands) and NR-U/WiGig coexistence studies at mmWave bands
- **LLNL** Lawrence Livermore National Lab (US dept. Defense) (2019-2021)
 - Spectrum sharing simulator (LTE/NR)
- **NIST** National Institute of Standards and Tech (US dept. Commerce) (2020-2021)
 - First release of **NR V2X module** (mode 2, out-of-coverage)
- **Huawei** (2020-2021)
 - Fronthaul compression control, **O-RAN** architecture
- **Meta** (2021-2022)
 - 5G-LENA improvements for AR/VR use cases
- **6G-BLUR** (2022-2024)
 - Disaggregated RAN architecture and distributed decision-making ML controllers, **O-RAN** architecture

5G-LENA SUPPORTED FEATURES

- **NSA architecture:** 5G RAN and 4G EPC
- 3GPP spatial channel model (0.5-100 GHz) and uniform planar arrays

MAC

- OFDMA and TDMA (variable TTIs)
- Dynamic scheduled-based access
- PF/RR/MR/QoS schedulers
- HARQ CC/IR
- 3GPP-compliant processing times
- Multiple HARQ processes per UE
- AMC
- CC/BWP managers
- CA and TDM of numerologies
- BSR, SR, CQI, RI processing

NR-U extension

- LBT after MAC
- CAMs: AlwaysOn, OnOff, LBT
- LBT Cat2, Cat3, Cat4
- Energy detection (omni)

PHY

- NR frame structure (numerologies)
- TDD and FDD
- Time multiplex of shared and control channels
- LDPC coding, LDPC base graph selection
- MCS table 1 and MCS table 2
- Code block segmentation
- SRS
- Ideal and realistic beamforming (analog)
- Uplink power control
- DP-MIMO and rank adaptation

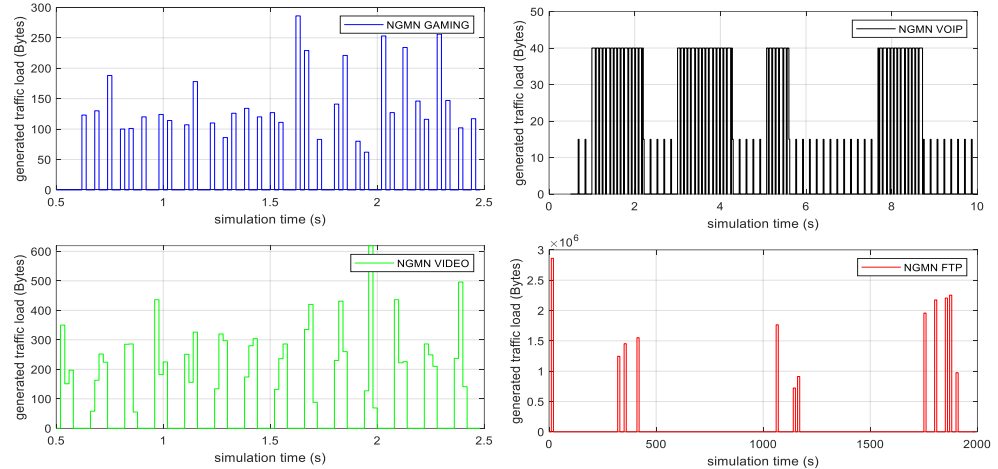
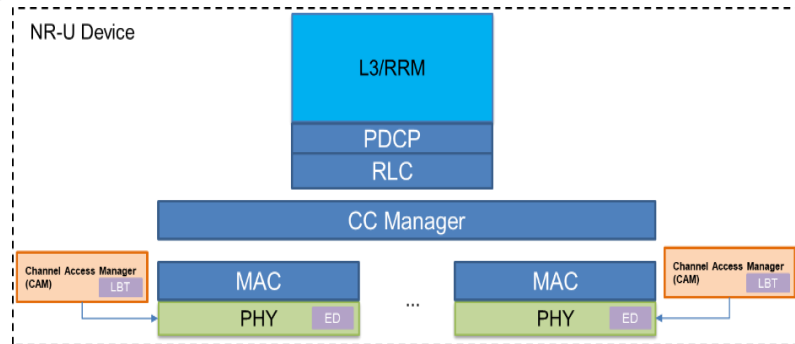
NR V2X extension

- Broadcast
- Out-of-coverage
- Mode 2 resource allocation (UE selected)
- Sensing and random semi-persistent scheduling
- Blind retransmissions, no feedback

KEY RECENT DEVELOPMENTS (EXAMPLES)

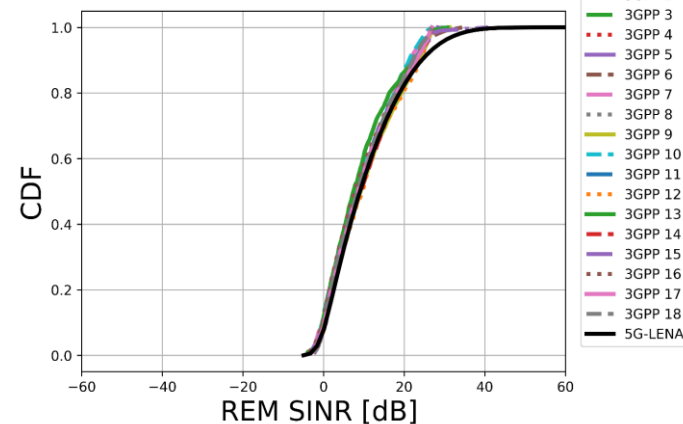
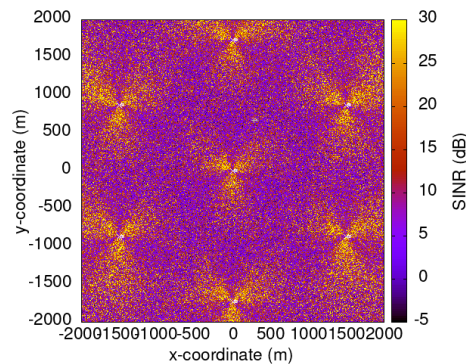
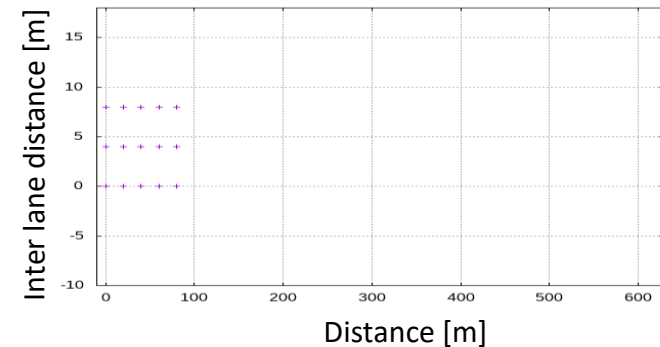
New traffic models (NGMN and 3GPP) to support XR and 5G-Advanced scenarios

NR-U device



Radio Environmental Maps and calibration

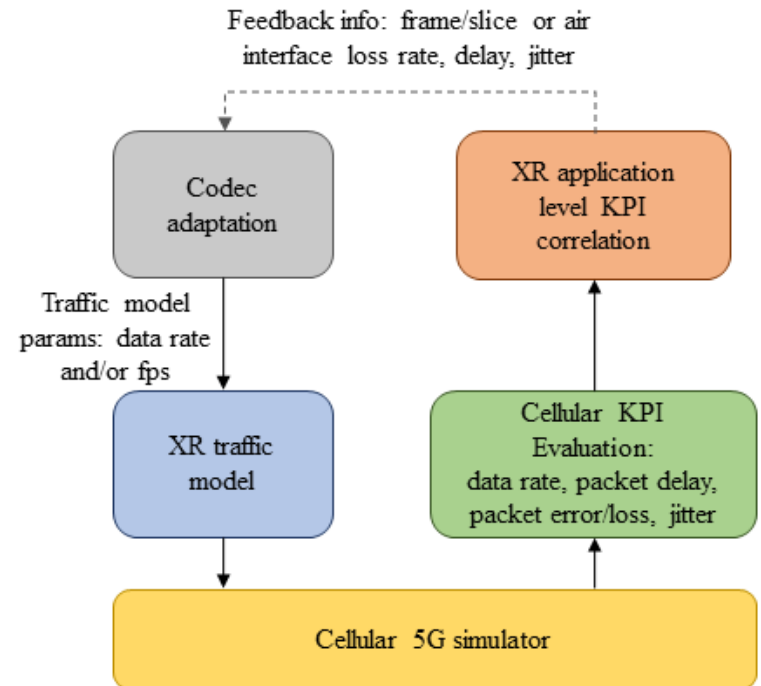
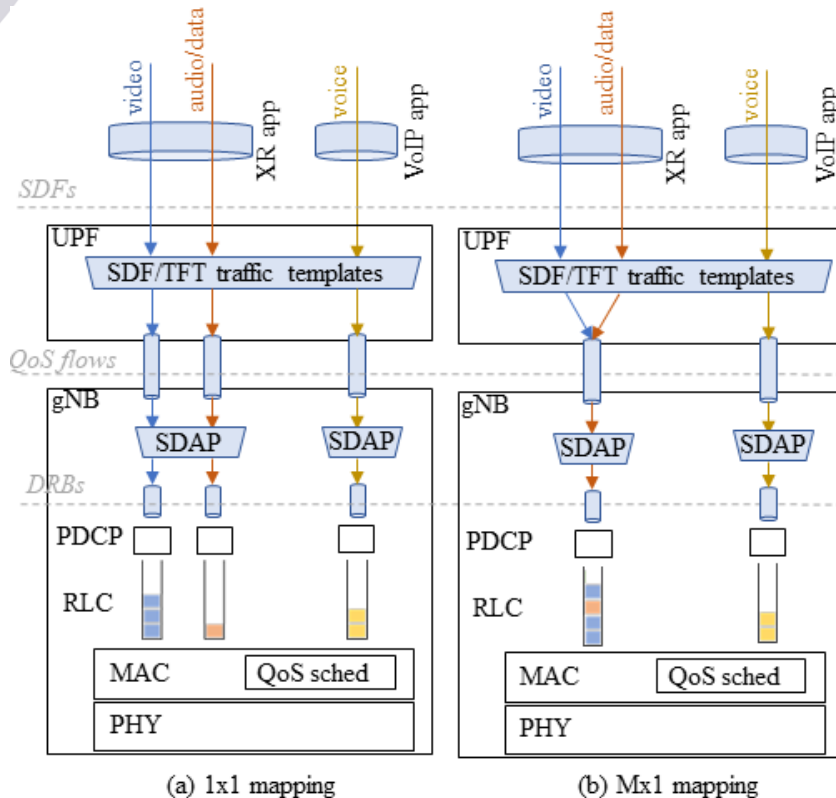
NR V2X simulations



TOWARDS 6G-LENA

- QoS management for mixed XR applications

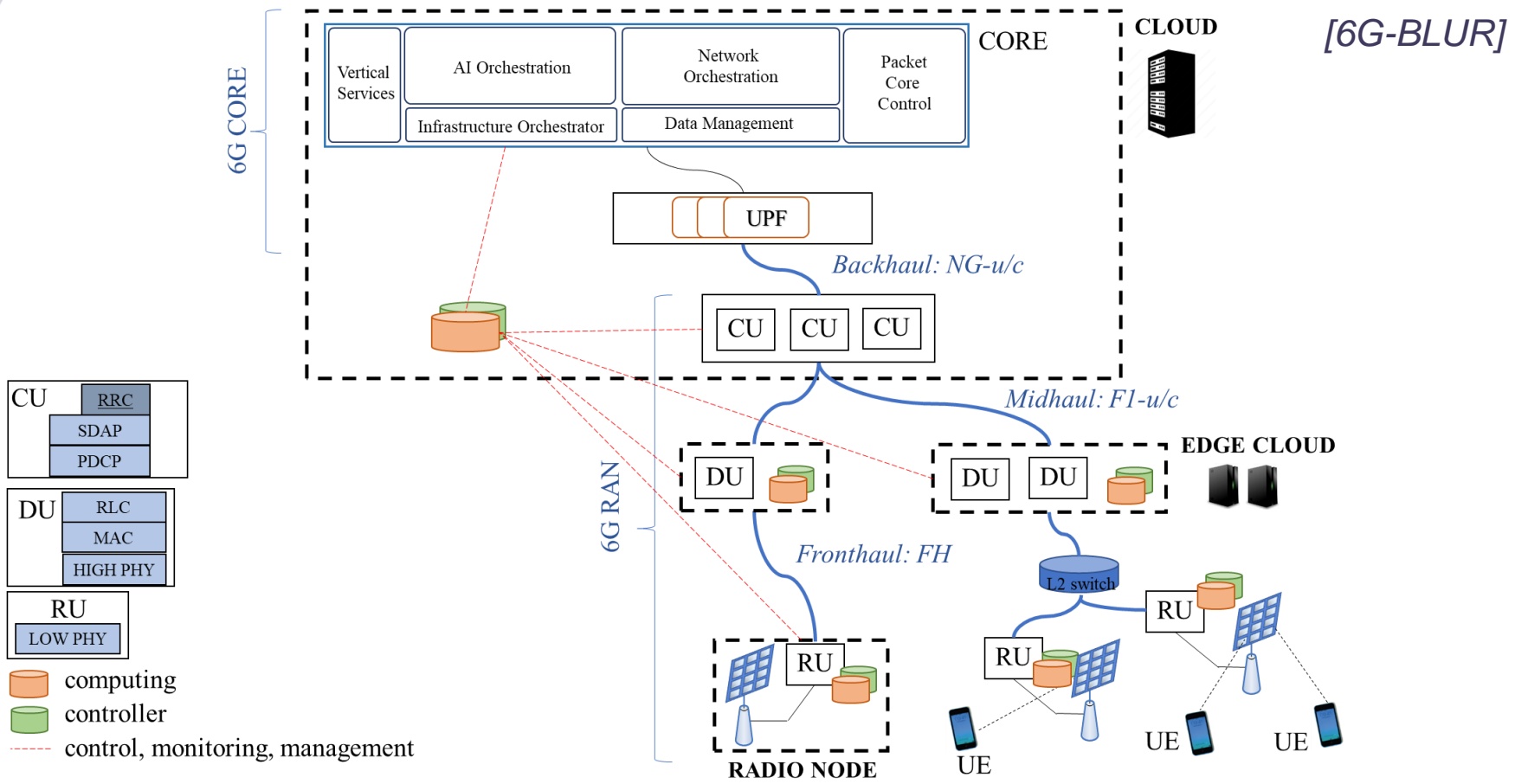
[Meta]



- Multi-layer joint QoS management (APP, SDAP, RLC/PDCP, MAC)
- 1x1 vs Mx1 mapping architectures at UPF (core) and SDAP (RAN)
- XR loopback adaptation algorithms

TOWARDS 6G-LENA

- Disaggregated RAN architecture and distributed decision-making ML controllers

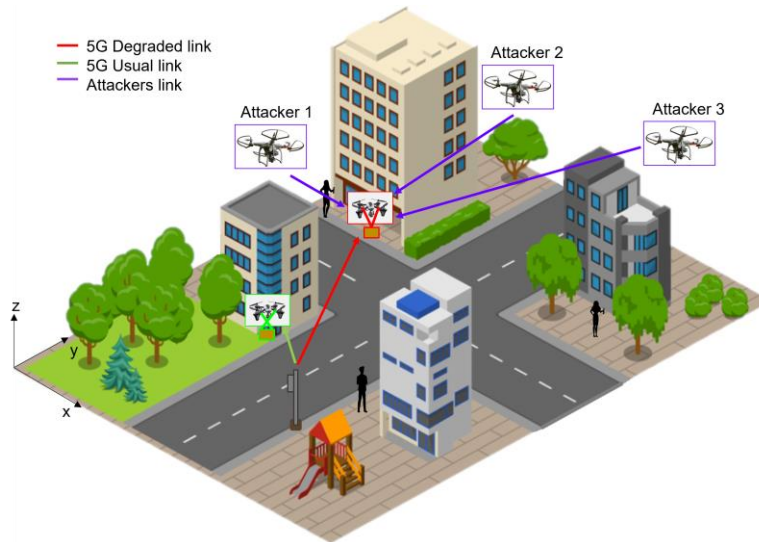


- Joint RAN and transport orchestration/control (incl. FH compression)
- Smart distributed decision-making processes and end-to-end resource management (various time scales, policy definition to scheduling)

TOWARDS 6G-LENA

- ML-based security in UAV networks

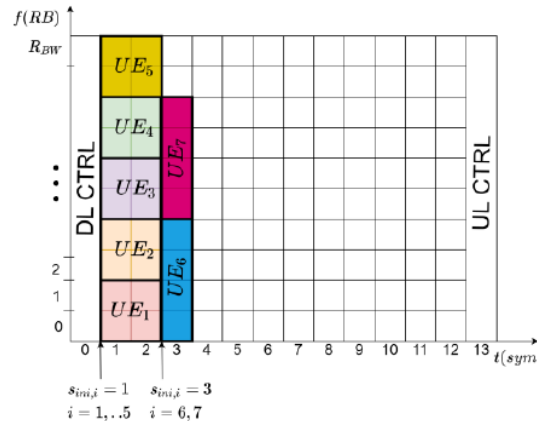
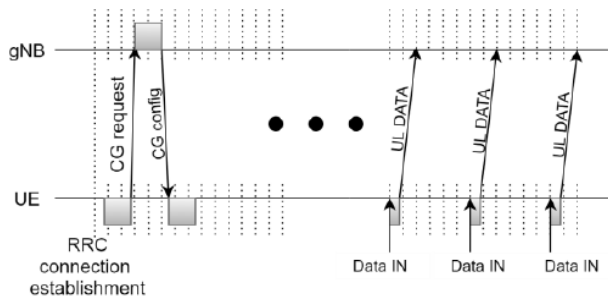
[ISCTE]



- Design of deep learning architectures to identify attacks in authenticated UAVs based on network measurements
- NTN + terrestrial integration
- Air-to-air and air-to-ground channel modeling in ns-3
- Security-based RAN reconfiguration

- 5G and TSN in i4.0 scenarios

[IKERLAN]



- Support for time-critical services
- Flexible scheduling for URLLC
- Cellular and TSN integration

TOWARDS 6G-LENA

- 5G:
 - NR RLC, PDCP, SDAP, RRC layers
 - 5G core network
 - Full MIMO model (PHY, MAC)
 - Simplified channel model (alternative to 3GPP SCM) for large scale simulations
- 5G-Advanced:
 - XR enhancements, QoS management
 - AIML for the air interface
 - sidelink evolution
 - MIMO evolution for DL/UL
 - Enhanced dynamic spectrum access
 - UAVs support and NTN improvements
 - Full duplex
- 6G: Once defined by the standard...
 - Channel modeling for above 100GHz frequency bands
 - 6G RAN modeling: PHY, MAC, RLC, etc.
 - 6G-compliant PHY abstraction model, considering PHY split
 - Decentralized RAN architecture

TOWARDS 6G-LENA: NEW DEVELOPMENT STRATEGY

New development strategy towards 6G-LENA:

- **Why?** There are many new features to be developed towards 5G-Advanced and 6G and many researchers and companies are already using 5G-LENA to implement them, but they are rarely contributing back to 5G-LENA public repository
- **Objective:** encourage contributions to 5G-LENA by researchers/companies
 - collaborative development by researchers and telecom companies from all around the globe can accelerate 5G-LENA development towards 6G
 - more importantly, more users/companies means more testing, validations, calibrations
- **How?**
 - Since 2022, 5G-LENA has fully **open-access**, so that: 1) anyone can access (no need for permission), 2) anyone can create **merge requests** towards NR public repo
 - **more often 5G-LENA releases**, so that all companies/researchers using 5G-LENA can easily upgrade their code and stay up-to date to the latest 5G-LENA → easier contributions
 - new **release strategy**: each 5G-LENA release is linked to a specific ns-3-dev release (previously, we were aligned with ns-3-dev master, and this was creating problems to some researchers/companies)
 - more **tutorials** to help start with 5G-LENA

CONTRIBUTORS

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Advanced research for everyday life



HR EXCELLENCE IN RESEARCH