Centre Tecnològic de Telecomunicacions de Catalunya

OpenSim

1. WHY ns-3 and LENA/5G-LENA?

As for the simulation models, our bet is on the network simulator ns-3 1. The OpenSim RU group actively designs, develops and maintains the open-source ns-3 simulation models of leading 4G and 5G 3GPP technologies, LTE (Long Term Evolution) and NR (New Radio), also known as LENA and 5G-LENA modules.

ns-3 is a research-oriented, discrete-event network simulator, written in C++ with Python bindings. It has been under continuous development since 2005, courtesy of funding from the US NSF, INRIA in France, and several other public and private organizations. ns-3, and its predecessor ns-2 are the most frequently cited tools used in computer network research (based on a recent survey of journal and conference papers published in 2016 in the IEEE and ACM Digital Libraries). Both ns-3 and ns-2 are licensed under the GNU General Purpose License, version 2. This open-source license is used for many software projects, including the Linux kernel. ns-3 is a complex, multiauthor piece of software that has undergone 29 software releases since 2008 and has been used for thousands of research papers and projects.

The LTE and NR models, commonly referred to as LENA and 5G-LENA, are already by one measure (academic citations) the leading packet simulation tools for 3GPP oriented network simulations. For example, Google scholar counts over 11000 publication counts to ns-3 LTE; while other LTE simulators have significantly fewer counts. The access to the 5G LENA NR models is handled directly by the OpenSim RU team at CTTC and has already been granted to over 900+ people and 200+ institutions around the world, in industry, academia and governmental agencies.

LENA and 5G-LENA combine a simulated channel and physical layer model with a full stack implementation of the LTE/NR RAN (Radio Access Network) and EPC (Evolved Packet Core) protocol stack that closely follows 3GPP specifications. Most of the current version of LENA was developed between 2011 and 2013 as part of an industrial project funded by Ubiquisys Ltd. (now part of Cisco) and carried out by CTTC, in particular by the OpenSim group, with the aim of developing an open-source product-oriented LTE/EPC Network Simulator allowing LTE small/macro cell vendors to design and test Self Organized Network (SON) algorithms and Solutions. The work around the NR protocol stack was initiated in 2017 in the framework of a collaboration with Interdigital. The simulators have received funding from different companies and governmental agencies like the WiFi Alliance, Spidercloud Wireless, National Institute of Standards and Technologies (NIST), Lawrence Livermore National Lab (LLNL), Huawei Technologies, among others. Branches for NR-V2X and NR-U, LAA/LTE-U are also available.

The openness and multi-RAT (Radio Access Technology) characteristic of ns-3, which is inherited by LENA and 5G-LENA, make them suitable for studies where high-fidelity simulations are

required for scalable scenarios where multiple technologies coexist, or where reproducible results are needed. High interest is concentrated now in the potential of these simulators in the area of Open RAN where the use cases identified as key target by the alliance in one of their defining white paper, can be already easily supported by 5G-LENA in its openly available version. Examples are handover management in NR/ NR V2X scenarios, traffic steering between NR/NR-U/LTE, RAN slicing, Dynamic Spectrum Sharing, etc.

Finally, LENA and 5G-LENA inherit some ns-3 unique features at higher layers, including a real-time emulation mode, which allows code reuse on testbeds or real networks, and a capability to compile the source code of real applications and the Linux network kernel for direct use in the simulations. This capability dramatically reduces the gap between simulations and prototyping, allowing for code reuse in the area of research, where products are not yet in the market.

The OpenSim RU has high expertise in this software, one of the members (Sandra Lagén) is the coordinator of all the activities around 3GPP oriented developments inside the open-source community, besides a member of the executive board of ns-3 consortium (which was being previously and for a long time carried out by Lorenza Giupponi), and other members (Biljana Bojovic and Katerina Koutlia) are key designers, developers and maintainers of the LENA and 5G-LENA modules. This strong expertise and the intense involvement of the OpenSim RU inside this open-source community are among the reasons for choosing ns-3 as the appropriate simulation tool, but there are more:

- ns-3 is an open-source simulator, with a strong user community behind and trustful and motivated maintainers. It is a reference simulation tool in research and academia, and the adoption of it will favor the practice of results reproducibility and collaborative developments [1].
- ns-3 has a stable LTE module (a.k.a. LENA), intensively used and well maintained by CTTC, which was developed entirely at CTTC in close collaboration with industry. The simulator is characterized by high fidelity implementations of the standard, especially from MAC to APP, and by a PHY layer abstraction [2].
- Differently from other simulators openly available to the community, ns-3 offers full protocol stack and end-to-end implementations.
- Differently from other simulators openly available to the community, ns-3 offers multi-RAT models, with extremely solid implementations of WiFi and LTE. The ns-3 Wi-Fi models have been developed over time by several authors, usually by directly referencing the IEEE standards, starting with initial 802.11a models and later extending to many aspects of the 802.11b/g/p/e/n/ac/ax standards. The models have been funded by Cisco and Intel, and are currently still under development. Parallel branches also include support for .11ad and .11ay.
- The LTE model, developed and maintained by our group, also supports different features in separate branches, like the D2D model developed in collaboration with the National Institute of Standard and Technologies (NIST) during two years in the context of the project "Modeling, Simulation and performance evaluation for Public safety networks" funded by NIST [3][4], or the Licensed Assisted Access (LAA) branch and the LTE-U

branch, designed and developed in collaboration with the WiFi Alliance and Spidercloud Wireless [5][6].

- In February 2019, our group released the first version of the first open source NR simulator, based on an extension of ns-3 [7][8][9]. The model is a fork of LTE and it mainly focused on refactoring the PHY and MAC layers of LTE codes in order to provide a standard-compliant implementation of Rel-15 NR [10] with 3GPP-aligned channel and antenna models [11]. The RRC (Radio Resource Control) and upper layers, still rely, as of today, on the LTE implementation, as much as the EPC (Evolved Packet Core), which makes the proposed NR model an NSA (non-standalone) implementation. This work was funded by Interdigital and new models were released during 2019 and 2020, including support for NR-U and coexistence with IEEE 802.11ad (WiGig) in 60 GHz bands [12][13][14].
- The NR model in the context of S3 (Spectrum Sharing Simulator) project, led by the Lawrence Livermore National Lab, under funding of the US Department of Defense (DoD), has been significantly extended during 2020-2021 in order to include multiple features (such as inter-cell interference coordination, TDD and FDD, realistic beamforming [15], radio environmental maps for beam management [16]), to enable the simulation of mixed 3GPP multi-RAT scenarios, and evaluate spectrum sharing capabilities of 3GPP technologies in realistic deployments in multiple bands subject to shared access rules [17].
- A further extension of the NR module was developed in the context of a collaborative project with the National Institute of Standards and Technology (NIST), under funding of the US Department of Commerce, during 2020-2021, to enable NR V2X (vehicle to everything) communications [18] with 3GPP-compliant vehicular channel models [19]. The activities involved re-adaptation of upper layers, and in particular RRC (Radio Resource Control), and complete redesign of the PHY and MAC layers to account for the new flexible NR frame structure, new resource allocation granularity, novel numerology concepts, and new features introduced in NR V2X to support improved use cases, as compared to C-V2X.
- Also, we have started working on the O-RAN area through efficient compression control strategies, thanks to an industrial collaboration with Huawei-Sweden. In that respect, we extended 5G-LENA to enable the simulation of specific functional splits and model fronthaul compression through modulation compression and SRS handling methods [20][21]. The 6G-BLUR UNICO-5G project intends to further extend the platform towards open disaggregated RANs for beyond 5G and 6G technologies.
- The NR model is being significantly extended in the context of an industrial collaborative project with Meta-Facebook, in order to include multiple features, such as MIMO support and enhanced QoS-based schedulers, to enable simulation and evaluation of Augmented Reality and Virtual Reality (AR/VR) use cases in realistic radio environments.

As a result of all these parallel and synergistic activities, we believe that in the horizon of the upcoming years, ns-3 will support, improve, and extend the ambitious simulator that we need for the research studies that we do in the OpenSim RU. We have already secured significant funding

from the industry, to make the vision of a high fidelity, end-to-end, and full stack 3GPP oriented simulator for LTE/NR technologies, a reality. The open-source community is doing the rest to guarantee valid multi-RAT options also in the IEEE area.

2. REFERENCES

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