# Simulating Network Coexistence of NR-U and IEEE 802.11ax in ns-3

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***Abstract* - In this position paper, CTTC and University of Washington provide a status update regarding new protocol stacks for end-to-end and multi-RAT scenario simulations in the open source network simulator ns-3 (www.nsnam.org). Specifically, the recent advances enable network performance evaluation research in the emergent areas of 5G NR-U and IEEE802.11ax coexistence in unlicensed band. The work relies on previous open contributions of the two partners in the area of NR and IEEE802.11, respectively, among a long track of successful collaborations in the areas of LTE-LAA, and LTE for Public Safety.**

## I. Introduction

Evolution of Wireless Internet 2.0 is being driven by a spate of new applications that in turn will rely on fundamental new changes to end-to-end system (both the Core and Radio Access Network) architecture as well as new wireless access technologies. While prototype deployments will continue to track various aspects of these ongoing developments, a key tool available to researchers and early deployers is use of network simulation for predictive analysis, preferably via open source means. In this work, we (broadly speaking) provide an update on the recent progress in the library modules implemented within the leading open source network simulator ns-3 for 5G wireless network scenario simulation.

Among the milestones introduced by 3GPP Release 16 for New Radio (NR) [1] is their use in unlicensed spectrum. The design of New Radio for Unlicensed (NR-U) started in a study item in Release 16 (2018), and is currently being developed for inclusion in future NR specification [2]. The frequency bands proposed for NR-U include 2.4 GHz, 5 GHz, 6 GHz, and 60 GHz unlicensed bands, as well as 3.5 GHz and 37 GHz bands, which are devoted to shared access in the USA. While the current NR-U work item in NR Release-16 is focusing on sub 7 GHz bands, the extension to unlicensed mmWave bands is expected in later releases.

One of the most critical issues underlying cellular networks operation in unlicensed spectrum is to ensure a fair and harmonious coexistence with other unlicensed systems, such as Wi-Fi in the 5 GHz band (IEEE 802.11a/h/j/n/ac/ax) and directional multi-Gigabit Wi-Fi in the 60 GHz band (IEEE 802.11ad/ay, also known as Wireless Gigabit (WiGig)). Fairness for NR-U operation in the unlicensed bands is defined by 3GPP as the ability that NR-U devices do not impact already deployed Wi-Fi services more than an additional Wi-Fi network would on the same channel. In order to meet the fair coexistence criterion, any RAT that wants to operate in specific unlicensed spectrum must meet the regulatory requirements for the corresponding bands in the region. In the 5 and 60 GHz bands, the regulation mandates the use of Listen-Before-Talk (LBT) in Europe and Japan [23] - a spectrum sharing mechanism by which a device senses the channel using a Clear Channel Assessment (CCA) check before channel access. In principle, LBT applies to different RATs, and has been adopted by LTE-LAA, MulteFire, Wi-Fi and WiGig.

The key challenge to network performance evaluation for these emerging technologies such as IEEE 802.11ax, WiGig IEEE802.11ad and 11ay and 5G NR-U is the lack of available simulation platforms capable of modelling with high fidelity both 3GPP and IEEE technologies. Despite the large body of results presented in [2] by 3GPP, the simulators are not publicly available, and consequently results are not reproducible. Further the system performance results are presented without much detail about the underlying models and assumptions. The unique value proposition of ns-3 [4] - THE leading open source simulator preferred by the network performance evaluation community – is that it already has available solid and high fidelity models for both legacy LTE [6] and WiFi, and has recent models (work-in-progress, yet to be formally released but available upon request) for NR [5] and IEEE 802.11 ax, designed and implemented in close consultation with industry collaborators [11]-[13]. In this work, we present our view for a future coexistence simulator between 5G NR and IEEE802.11ax, relying on current status of 802.11 WLAN and LTE/5G codebase based on previous successful collaborations [7, 8].

## II. Why ns-3?

ns-3 is a research-oriented, discrete-event network simulator, written in C++ with Python bindings. It started as US NSF funded project c. 2005 and has been sustained via subsequent support from other public and private organizations [4]. ns-3 has over 8000 downloads and 2500 citations annually by the networking research community (based on a recent survey of journal and conference papers in the IEEE and ACM Digital Libraries). ns-3 is a complex, multiauthor piece of software (with over 200 credited contributors) that has undergone 30 software releases since 2008. Hence, ns-3 is a powerful tool with significant global adoption for packet-level network simulation tool and with a strong user community behind and motivated maintainers. It is the de-facto reference simulation tool in academic research and its broader adoption would complement and enhance the suite of network performance evaluation methods.

For example, ns-3's base LTE module (a.k.a. LENA), is maintained and intensively used by CTTC for various studies [7,8]; over the years it has received additional funding by industry and US Federal agencies such as National Institute of Standard and Technologies (NIST) [14]and Lawrence Livermore National Lab. (LLNL). The simulator is characterized by high fidelity implementations of the LTE MAC to APP Layers, and PHY layer abstractions [12,13]. ns-3 also offers well-maintained implementations of 802.11 WLAN standard by U. Washington. The ns-3 Wi-Fi library has been developed over time by multiple contributors starting with initial 802.11a models, subsequently extended to include features of the 802.11 n/ac standards and currently, 802.11ax [11]. There are also branches for 60 GHz 802.11ad and initial work on its extension to 802.11ay.

Finally, ns-3 has some unique features including: a real-time emulation mode, which allows code reuse on testbeds or real networks, and a capability to compile the source code for real applications and a Linux network kernel for direct use in the simulations. These capabilities dramatically reduce the gap between simulations and prototyping.

## III. Description of prospective research

In this section we discuss our potential future research plans.

### A. *Status of NR models*

CTTC started working together with Interdigital on an extension of ns-3 targeting NR modelling in 2017. The objective was to build a 5G RAT simulator capable of operating wideband, in both Frequency Ranges 1 (FR1) and FR2. In Feb. 2019, the first version of NR simulator was released as a fork of LTE and mmWave modules [9, 10] and is based on refactoring the LENA layers to provide a standard-compliant implementation of Rel-15 NR. The simulator is a pluggable extension to the LTE LENA stack on which it relies for the MAC (Medium Access Control) and Evolved Packet Core (EPC) layers. As such, NR module offers a non-standalone architecture (NSA) but with new 5G PHY/MAC layers.

As of today, the simulator has gone through 2 official releases [9], and includes the following available features:

1) Flexible and automatic configuration of the NR frame structure through multiple numerologies;

2) Orthogonal Frequency Division Multiple Access (OFDMA) and Time Division Multiple Access-based access with variable Transmission Time Interval (TTI)s;

3) Restructuring and redesign of the MAC layer, including new flexible MAC schedulers that simultaneously consider time and frequency-domain resources (resource blocks and symbols) both for TDMA and OFDMA-based access schemes with variable TTI;

4) Dynamic TDD;

5) Bandwidth Part (BWP) managers to support operation through multiple BWPs;

6) PHY layer abstraction considering LDPC codes;

7) NRU Listen Before Talk Functionalities, considering Cat1-4 LBT in DL and Cat1-2 in UL;

8) Support for Carrier Aggregation and standalone modes.

### B. *IEEE 802.11ax*

In 2018, UW led an effort supported by Cisco Inc. to develop new ns-3 models for the 802.11ax (High Efficiency WLAN) standard, that builds on prior ns-3 802.11 WLAN implementations (Spectrum WifiClass) and Rel. 13 LTE-LAA. The overall goal was to add new features that enable performance evaluation of next-gen WLAN deployments *in dense network scenarios,* hence the effort focussed on adding the following features:

1) Spatial Reuse: BSS Color, dual NAV and adaptive CCA/Transmit power control mechanisms for enabling multiple simultaneous transmissions in overlapping BSS;

2) Dynamic Bandwidth Channel Access & OFDMA: finer granularity in channelization, adapted to user needs provide more knobs for exploring interference management;

3) Multi-User MIMO (11ac Downlink Wave 2) & Random Access OFDMA Uplink (11ax);

4) Het Nets operation: networks with mixed .11n/ac and .11ax clients as well with non-WiFi clients.

### C. *Towards evaluating coexistence of NR-U and 11ax*

The availability of these novel modules paves the way for new coexistence evaluations of the two technologies. Scenario evaluation work on NR-U and 11ax is ongoing at CTTC and UW respectively, and we are currently developing a project plan for perform evaluations of NR-U/802.11ax coexistence.

## IV. Conclusion

This position paper has discussed the current status in ns-3 including 3GPP NR and IEEE 802.11ax capabilities, with a view to prospective multi-RAT simulations.

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