Implementation of Wi-Fi NSTR MLO Coexisting with LTE-LAA via ns-3

Suhwan Jung, Seokwoo Choi
Dept. of Electrical Engineering
UNIST
Ulsan, Republic of Korea
{fydnrltlzl,csw2055}@unist.ac.kr

Youngkeun Yoon, Ho-kyung Son
Radio Research Division
ETRI
Daejeon, Republic of Korea
{ykyoon,hgson}@etri.re.kr

Hyoil Kim
Dept. of Electrical Engineering
UNIST
Ulsan, Republic of Korea
hkim@unist.ac.kr

***Abstract*—The coexistence between Wi-Fi and the cellular technology in the unlicensed spectrum has been a significant research topic for several years. To investigate their coexistence performance, ns-3, one of the most popular network simulators, introduced the LTE-LAA project in 2016 [1], but its modules have not been updated in later versions of ns-3. Moreover, ns-3 does not yet support Wi-Fi 7's NSTR(Non-Simultaneous Transmit and Receive) MLO(Multi-Link Operation) features. Therefore, there is an urgent need to update both LTE-LAA and Wi-Fi modules of ns-3 accordingly. This paper presents a methodology to modify ns-3 to address the aforementioned need, so as to enable the ns-3 simulator to accurately evaluate coexistence scenarios between Wi-Fi MLO and LTE-LAA.**

***Index Terms*—WLAN, MLO, LTE-LAA, NR-U, Coexistence**

I. Introduction

In response to the surge in data traffic, the 802.11 standard introduced Multi-Link Operation (MLO) in its latest amendment, 802.11be [2], aiming to improve its throughput and latency performance concurrently. Nevertheless, introduction of MLO could adversely affect the performance of other wireless technologies (e.g., legacy Wi-Fi devices, Bluetooth, Zigbee) operating in the same bands. Therefore, it is essential to analyze the impact of MLO on the performance of coexisting technologies, among which unlicensed cellular communications like LTE-LAA and NR-U [3] possess commercial significance due to their wide-band operation and potentially-high traffic demands.

Unfortunately, however, there has been no simulator that can investigate the mutual impact between MLO and LTE-LAA in their coexistence scenarios. To address the issue, we have modified the ns-3 simulator to enable such simulation by implementing MLO's NSTR operations in Wi-Fi modules and by updating the obsolete LTE-LAA project accordingly.

II. System Model

This section introduces the system model of this paper.

Hyoil Kim is the corresponding author.

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government (MSIT) [RS-2023-00217885, Development of integrated interference analysis technology for improving frequency utilization efficiency].

A. Coexistence setup

To investigate the mutual impact of MLO and LTE-LAA on each other's performance, we consider two types of devices: Wi-Fi and LTE devices. For Wi-Fi devices, we assume that each of them supports the IEEE 802.11be standard including its MLO mechanisms. For LTE devices, we assume that all of them support the LTE-LAA standard. In addition, we assume that Wi-Fi and LTE-LAA devices operate on the same unlicensed band, thereby interfering with each other's transmission.

B. Wi-Fi devices

We consider a WLAN consisting of an AP MLD (Multi-Link Device) and multiple non-AP MLDs. Each MLD includes multiple STAs each of which can access a different channel simultaneously. Moreover, the MLDs are assumed to support both STR (Simultaneous Transmit and Receive) and NSTR (Non-STR) MLO mechanisms.

For NSTR MLO in DL transmissions, the end-times of PPDUs should be aligned (called end-time alignment) to avoid the IDC(In-Device Coexistence) interference problem, which is caused by ACK transmission intefering with other frame receptions on NSTR paired links [4]. In addition, when an MLD performs UL transmission, it must align not only the end-times but also the start-times of PPDUs, because UL transmission on one link may interfere with the Clear Channel Assessment (CCA) on another link due to the IDC interference and thus the MLD may not be able to properly perform its MAC operations based solely on its observed channel state without start-time alignment.

C. LTE devices

We consider a LTE network consisting of an eNB (eNodeB) and multiple UEs (User Equipments). With LTE-LAA, LTE devices can utilize unlicensed spectrum, which may cause collision with other devices operating in the same channel and hence degrade their performance. To avoid it, LTE devices should listen to the channel before commencing their transmission using CCA, adopting the concept of Listen-Before-Talk (LBT).

Specifically, in order to transmit data, the LTE devices should first wait for the 'CCA defer' period [5]. After that, the

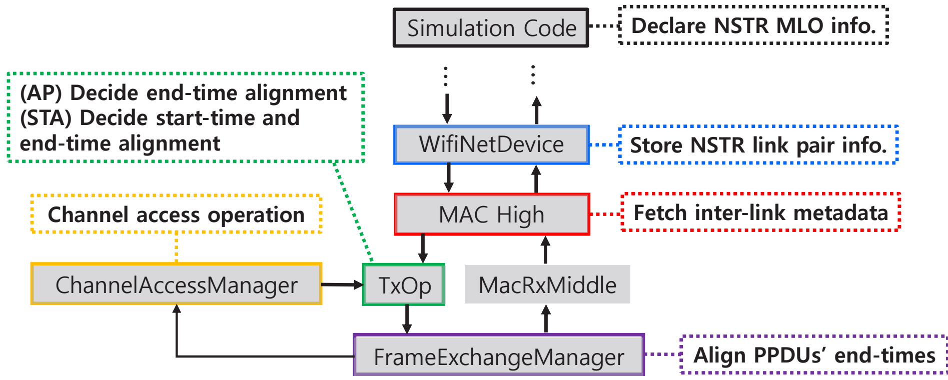

Fig. 1. NSTR MLO functions implemented in the ns-3 Wi-Fi modules

LTE devices initiate their random backoff procedure similar to Wi-Fi, called 'extended CCA'. That is, the LTE devices can transmit data only if its backoff counter reaches zero.

III. Modification of ns-3 to Support Coexistence between MLO-based Wi-Fi and LTE-LAA

As mentioned in Section I, there exists no ns-3 project capable of simulating the coexistence between MLO-based Wi-Fi and LTE-LAA, since ns-3's LTE-LAA modules have not been updated since its introduction to be inter-operable with any recent Wi-Fi standards. Hence, we modified the outdated LTE-LAA modules to be compatible with both latest versions of ns-3 and IEEE 802.11be. Moreover, we implemented all necessary NSTR MLO functionalities into the ns-3 Wi-Fi modules as well. The details of the aforementioned updates are as follows.

A. Updating LTE-LAA Modules for Compatibility with ns-3.42

Since previous LTE-LLA modules were developed on ns-3.24, they should be revised to operate correctly on ns-3.42, the recent ns-3 version supporting limited 802.11be features such as STR MLO. Specifically, the `LbtAccessManager` in ns-3 is the core responsible for the LBT functionality of LTE-LAA, and there are three types of ns-3 modules for `LbtAccessManager`: `Lbt-access-manager`, `Basic-lbt-access-manager`, and `Duty-cycle-access-manager`. Therefore, these modules have been updated to ensure their compatibility with ns-3.42.

B. Revising LTE modules related to LTE-LAA

Next, we should revise the LTE modules in ns-3.42 that interact with LTE-LAA modules so that they can interoperate seamlessly. Among them, `Lte-enb-phy` and `Lte-enb-mac` (which are core LTE modules responsible for channel access, resource allocation, and transmission decisions) require a structure that allows the `LbtAccessManager` module to be hooked into themselves to incorporate LBT functionalities. In addition, the `Lte-spectrum-value-helper` module needs to be revised since there has been a change in the configuration of LTE spectrum in ns-3.42. Moreover, we needed to revise the `Channel-access-manager` module for the connection with the `LbtAccessManager` module.

C. Modifying Wi-Fi related modules

We also needed to adapt the Wi-Fi related functions in the LTE-LAA modules, originally implemented in ns-3.24, to be compatible with ns-3.42. In the earlier version, there was a function called *NotifyMaybeCcaBusyStart* within the Wi-Fi module to notify external components of the channel status, in order to detect Wi-Fi signals. However, in ns-3.42, a function called *NotifyCcaBusyStart* takes over such a role, and hence the previously function must be replaced with the current one. Additionally, several other functions used by the `LbtAccessManager` module to detect Wi-Fi state changes (e.g., *NotifyRxStart*, *NotifyTxStart*, *NotifySleep* and *NotifyWakeup*) needed to be updated to their corresponding implementations in ns-3.42.

In addition, since recent ns-3 versions do not support NSTR MLO yet (while only supporting STR MLO), we implemented NSTR functionalities in the Wi-Fi modules as shown in Fig. 1. The followings are the description of each module.

- The `Simulation Code` part, serving as the scenario-level configuration script, declares the NSTR operation and NSTR link pairs.
- The `WifiNetDevice` module stores and retrieves NSTR link pair information.
- The `MAC High` module fetches inter-link status and metadata as needed.
- In the `TxOp` module, an AP determines the necessity of end-time alignment based on the transmission status and the destination of each link, while a non-AP STA performs start-time and end-time alignments only when all the links have access to the channel.
- The `ChannelAccessManager` module grants, defers, or rejects channel access based on start-time and end-time alignment conditions.
- The `FrameExchangeManager` module synchronizes TXOP termination across links when an MLD performs end-time alignment.

IV. Conclusion

In this paper, we have presented a methodology to modify the ns-3 simulator to enable coexistence simulations between MLO based Wi-Fi and LTE-LAA. We identified incompatibilities between the previous LTE-LAA modules and the recent versions of ns-3 supporting STR MLO, and also recognized that NSTR MLO is not yet implemented in ns-3. Therefore, we proposed detailed modifications to resolve the issues. As a result, our enhanced ns-3 simulator is now capable of simulating the MLO-LAA coexistence in the unlicensed spectrum and evaluating their interactions, thus laying the groundwork for future studies to optimize their coexistence strategies.

References

[1] ns-3 project, “LTE LBT Wi-Fi Coexistence Module Documentation,” Feb. 2016.

[2] *IEEE Approved Draft Standard for Information technology–Telecommunications and information exchange between systems Local and metropolitan area networks–Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment: Enhancements for Extremely High Throughput (EHT)*, Std., Rev. IEEE 802.11be-2024.

[3] M. Shanahan and K. Bahia, “The state of mobile internet connectivity 2024,” GSMA, Tech. Rep., Oct. 2024.

[4] S. Jung, S. Choi, H. Kim, Y. Yoon, and H.-K. Son, “Modeling the Coexistence Performance between Wi-Fi 7 and legacy Wi-Fi,” in *Proc. NOMS*, 2024.

[5] B. Bojović, L. Giupponi, Z. Ali, and M. Miozzo, “Evaluating Unlicensed LTE Technologies: LAA vs LTE-U,” *IEEE Access*, vol. 7, pp. 89 714–89 751, 2019.