# Fair and Efficient Channel observation-based Listen-Before Talk (CoLBT) for LAA-WiFi Coexistence in Unlicensed LTE

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***Abstract*— License Assisted Access-WiFi (LAA-WiFi) coexistence allows the operations on the unlicensed spectrum for Long Term Evolution (LTE) along with existing unlicensed wireless local area networks (WLANs). The current spectrum access process of legacy WLANs uses clear channel assessment (CCA) and carrier sense multiple access with collision avoidance (CSMA/CA), where the spectrum is sensed before use and a random binary exponential backoff (BEB) mechanism is employed for collision avoidance. While LAA uses a listen-before-talk (LBT) mechanism, moderately similar to the CCA CSMA/CA for channel access. However, there is a fairness issue when these two technologies coexist. In this paper, we propose a channel observation-based LBT (CoLBT) mechanism for fairness in LAA-Wi-Fi coexistence scenarios. Specifically, we introduce a more realistic practical channel observation-based collision probability observed by the LAA evolved Node B (eNB) to adaptively scale-up and scale-down the backoff contention window for channel contention, to reduce the waste of resources and improve LAA-WiFi coexistence performance. Simulation results validate that the proposed CoLBT mechanism is effective in LAA-WiFi coexistence scenario and can improve fairness performance, compared with the current mechanism of LBT.**

***Index Terms*—Wi-Fi; Unlicensed band; LAA; LAA-WiFi coexistence; listen before talk.**

## I. INTRODUCTION

5th generation (5G) wireless networks will support 1,000-fold gains in capacity, connections for at least 100 billion devices, and a 10 Gb/s individual user experience capable of extremely low latency [1]. To support capabilities for supporting massive capacity and massive connectivity, 3rd generation partnership project (3GPP) have been working to extend LTE/LTE-Advanced cellular system to the unlicensed bands [2], mainly 5 GHz band. In LTE Release 13, License assisted access (LAA) of 5 GHz Wi-Fi band is being studied for this purpose. However, these bands are already occupied by wireless local area networks (WLANs). Thus, WLAN will be facing a huge challenge in term of interference to access this band due to a massive increase in contention as shown in Fig. 1. Currently, WLAN medium access control (MAC) protocols mainly focus on maximizing the communication channel utilization using fair MAC layer resource allocation (MAC-RA) [5] using a carrier sense multiple access with collision avoidance (CSMA/CA) scheme of distributed coordination function (DCF) for the Wi-Fi stations (STAs) competing to access the channel, while LTE uses continuous traffic generation with minimum time gaps. From this operational structure in both networks, WLAN is likely to have minimal chances to access the medium than LTE in coexistence scenarios, resulting 70% to 100% performance degradation for WLAN [3]. To withstand this challenge and coexist fairly, there has been an increasing amount of research going on LTE in an unlicensed band. One of the methods, Listen-Before-Talk (LBT) in LAA method [4] in which LAA performs CSMA/CA like channel access method to access the unlicensed band [6].

In general, terms, LBT is a procedure that uses clear channel assessment (CCA), that is, it determines the energy level on the communication channel before attempting to transmit data frames. LBT is also more closely resembles Wi-Fi CSMA/CA, and it seems spontaneous that utilizing channel access schemes with similar as disparate to differing mechanics for the two radio access technologies (RATs) might yield better coexistence performance. Since the availability of the communication channels cannot always be guaranteed, thus limits on the maximum duration of a transmission opportunity (TXOP) is imposed, usually < 10ms [7].

In WLAN, detection of a collision is performed using an acknowledgment control response (ACK) frame. While, in LTE, no such frame exists, so the collision detection is based on the hybrid automatic repeat request (HARQ) feedback [8]. HARQ contains a number of negative ACKs (NACKs) for the transmitted frames in a single TXOP. According to 3GPP, in LBT the backoff contention window (CW) size is proposed to be increased if 80% of the HARQ feedbacks of the most recent TXOP are NACKs [8]. Since LTE is capable of scheduling multiple Nodes in a single sub-frame, the 80% threshold is

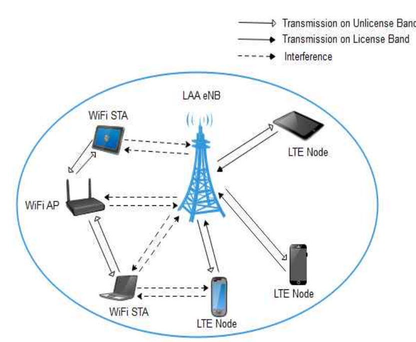


Fig. 1. LAA-WiFi coexistence deployment and interference scenario for LAA evolved Node B (eNB) with LAA users (Nodes) and Wi-Fi AP with Wi-Fi stations (STAs).

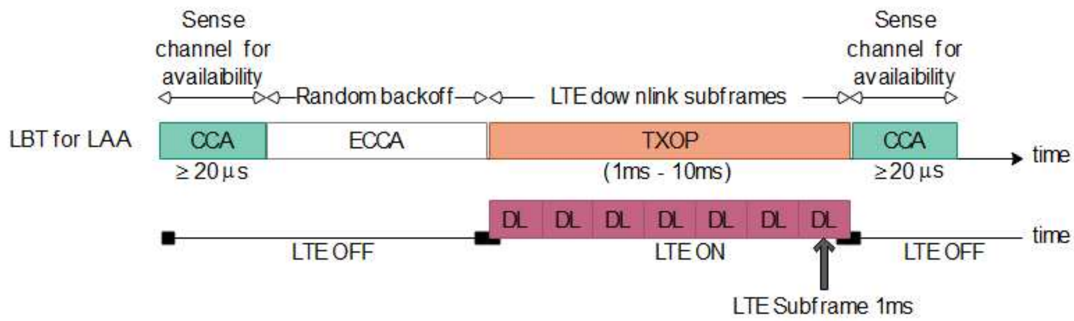


Fig. 2. Listen before talk (LBT) mechanism of License Assisted Access (LAA)

usually hard to meet. Even if a collision happens, that is, less than 80% of the scheduled data frames suffer from the collision, the LAA evolved Node B (eNB, similar as Wi-Fi Access Point that is AP) will not increase its backoff CW and collision will remain unsolved. Moreover, due to the integral latencies introduced by the LTE continues transmission protocol stack, the HARQ feedback associated with a certain sub-frame is received at least 4ms after its transmission time. Therefore, 3GPP proposes to consider only the collisions detected during the first sub-frame of a TXOP, in order to update the CW with a minimum delay. As a result, the collisions from the rest of the sub-frames are ignored.

However, in spite of adopting LBT by LAA, the performance of Wi-Fi when coexisting with LAA is highly dependent on how the LBT parameters are configured. The fairness for accessing the communication channel is one of the important aspects when implanting LBT. In this paper, we propose a channel observation-based unsuccessful (collision) probability to allow the LAA eNB scale the CW size ($W$) and bring fairness while sharing the resources with WLANs. Instead of waiting for HARQ feedbacks to be more than 80%, the proposed channel observation-based LBT (CoLBT) scales-up/scales-down the size $W$. Furthermore, the exponential increase, and reset to the minimum procedure of standard LBT is replaced with a more realistic and adaptive channel observation-based scaled backoff (COSB) mechanism for scaling-up $W$ (unsuccessful probability) and scaling-down the $W$ (successful probability). In particular, the proposed CoLBT scheme learn from the observation, through a channel sensing approach, how many NACKs per sub-frame of a TXOP are received along with busy time observed during the ECCA period ($B$) before TXOP.

The rest of this paper is organized as follows. In the next section, we describe the currently implemented LBT mechanism of LAA. In section III, we discuss proposed CoLBT using COSB. We then evaluate the performance of proposed mechanism using an event-driven NS3 simulator with a densely deployed LAA-WiFi coexistence scenario proposed by the 3GPP [8] for indoor deployments. Finally, we make conclusions and present our future research.

## II. Listen-Before-Talk (LBT)

3GPP evaluated different preferences for LBT, and the eventual algorithm selected was the one that allows most similarity to how Wi-Fi networks implement MAC-RA, that is binary exponential backoff (BEB) mechanism. Specifically, BEB is a Distributed Coordination Function (DCF), which aims to resolve channel contention among competing STAs by implementing a random backoff with exponentially increasing maximum CW and by imposing limits on the transmission opportunity (TXOP) before contention resolution occurs again. In LAA's CCA-based LBT mechanism, LTE users (in this paper we refer Wi-Fi users as STAs and LAA users as Nodes) wishing to transmit must observe a CCA for an initial deferral period, if the channel is found to be clear (idle), a deferral-based extended CCA (ECCA) process is performed until the channel is idle as shown in Fig. 2. In an ECCA, the communication channel is observed for the duration of a random backoff factor $B$ multiplied by the CCA slot-time ($\sigma$) duration. $B$ defines the number of observed idle slots that need to be sensed before TXOP. The value of $B$ is randomly selected as $B \in [1, W_u]$ every time an ECCA is required and the value is stored in a counter. The value of $W_u$ is the upper bound of the contention window ($W$), which varies according to an exponential backoff stage. The size of $W$ is exponentially increased upon collision detection, and reset to the minimum $W_{min}$ upon the absence of collision detection.

## III. Channel Observation-based LBT (CoLBT)

In this section, we propose a replacement to the standard HARQ-based $W$ size scaling with a more realistic channel observation-based mechanism. The proposed mechanism has two-fold changes to the standard one. Firstly, it replaces the HARQ-based scaling for backoff window $W$ with a practical channel observation-based collision probability ($p_{obs}$). Secondly, instead of an exponential increase of $W$ and reset back to minimum $W_{min}$ as of BEB, the backoff window size $W$ is scaled-up and scaled-down based on $p_{obs}$.

### *A. Channel Observation-Based Collision Probability* ($p_{obs}$)

In the proposed CoLBT mechanism, after the communication medium has been idle for a CCA, eNB competing for a channel proceed to the ECCA procedure by selecting a random backoff value $B$. The time immediately following an idle CCA is slotted into observation time slots ($\alpha$). The duration of $\alpha$ is either a constant slot-time ($\sigma$) during an idle period or a variable busy (successful or collided transmission by other device in the network) period. While the wireless channel is sensed to be clear during $\sigma$, $B$ decrements by one. A TXOP is availed only at the beginning of the slot time when B reaches zero. In addition, if the channel is sensed to be busy, the eNB freezes $B$ and continues sensing the channel. If the channel is

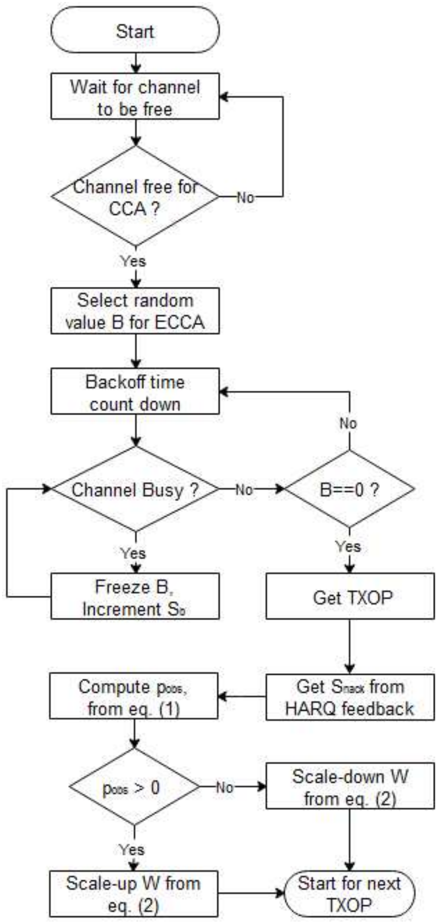


Fig. 3. CoLBT process for LAA eNB

again sensed to be clear for CCA, $B$ is resumed. Each eNB can proficiently measure channel observation-based conditional collision probability $p_{obs}$. This happens if other devices in the network transmit during the same slot time. It might seem that the exact estimation of $p_{obs}$ requires each eNB to observe and count the number of failed transmissions (NACKs) and divide it by the total number of transmission attempts. However, a more realistic observation for $p_{obs}$ can be achieved if busy slots during the ECCA procedure are also counted, since a transmission would have collided if the tagged eNB transmit in the same busy slot time. Thus, we update $p_{obs}$ at every ECCA backoff contention stage by counting number of NACKs ($S_{nack}$) in recent TXOP and the number of busy slots ($S_b$) during observed slot times ($\alpha$) in order to consider dynamic changes in the traffic load.

We discretize the time in $B_{obs}$, where the value of $B_{obs}$ is the total number of $\alpha$ (idle or busy, that is $B_{obs} = B + S_b$) between two consecutive ECCA backoff stages. A tagged eNB updates $p_{obs}$ from $B_{obs}$ of ECCA backoff stage as follows:

$$p_{obs} = \frac{S_b + S_{nack}}{S_{nack} + B_{obs}}, \tag{1}$$

where, $S_b = \sum_{k=0}^{B_{obs}-1} S_k$, and for an observation time slot $k$, $S_k = 0$ if α is empty (idle), while $S_k = 1$ if $\alpha$ is busy due to other device transmission. Following example explains the formulation of $p_{obs}$, suppose an eNB selects its ECCA backoff value $B = 10$ (from $W_{min} = 15$, and $W_{max} = 63$). If the tagged eNB observes three busy periods during the observation of $B$ idle slots ($B_{obs} = 10 + 3 = 13$), and the number of NACKs from the most recent TXOP experience are two (that is, $S_{nack} = 2$). Thus $p_{obs}$ is updated as $\frac{3+2}{13+2} = \frac{5}{15} = 0.33$ for next ECCA contention window stage.

The formulation of channel observation-based practical collision probability has a prominence to the LBT mechanism. The contention window update based on the observed practical collision probability leads to more adaptive contention procedure for LAA Nodes according to the all contenders (LAA and Wi-Fi devices) in the network, thus brings fair share between the two coexisting technologies.

## *B. Channel Observation-based scaled ECCA window*

In HARQ feedback-based mechanism, scaling is based on observed NACKs from the recent TXOP, the idea here is that a NACK may be indicative that the receiving Node is experiencing high interference. Moreover, experienced NACKs do not specify the available number of contenders in the network. For this purpose, first, we replace the HARQ feedback-based scaling mechanism with a method based on channel observation-based practical collision probability $p_{obs}$ formulated in the previous section. A tagged eNB can scale current ECCA contention window size if it finds $p_{obs} > 0$, which means even if there is no NACK received in the feedback, still contention window can be scaled due to busy slots during observation. Second, unlike the existing exponential increase for unsuccessful and resetting back to a minimum value of $W$ in LBT, the CoLBT operates as, scaling-up and scaling-down of the $W$. In the scaling-up, the $W$ is scaled-up if $p_{obs} > 0$ (that is, there exists busy slots or/and NACKs), and the $W$ is scaled-down, if $p_{obs} = 0$ (that is no busy slots and NACKs). The scaling-up and scaling-down of the ECCA contention window operates as follows:

$$W_{cur} = \begin{cases} min\left[2 \times W_{pre} \times \omega^{p_{obs}}, W_{max}\right], \text{if} & p_{obs} > 0 \\ max\left[W_{pre} \times \omega^{p_{obs}}/2, W_{min}\right], \text{ if} & p_{obs} = 0 \end{cases}, \tag{2}$$

where $W_{cur}$ is current scaled-up/scaled-down ECCA contention window from a previous $W_{pre}$. The $\omega$ is a constant design parameter to control the adaptive size of the ECCA contention window and is expressed as $\omega = W_{min}$. The Fig. 3 explains the CoLBT algorithm procedure to utilize COSB to scale-up and scale-down their backoff contention window.

## IV. Performance Evaluation

In this section we evaluate the performance of our proposed CoLBT mechanism using an event-driven simulator NS3 [10] with an available LAA-WiFi coexistence model [11]. Specifically, we consider two imaginary operators; operator-A (LAA), and operator-B (Wi-Fi), using the same 20 MHz channel. We evaluate performance in terms of the cumulative

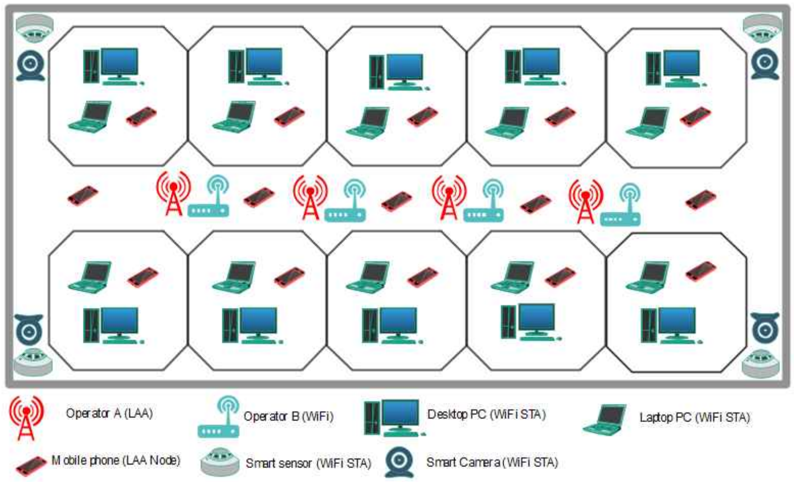


Fig. 4. LAA-WiFi coexistence indoor scenario for simulation

distribution function (CDF) of both operators with system throughput (Mbps) and latency (ms).

The operators deploy their networks according to the indoor scenario as designed and recommended for evaluation of LAA-Wi-Fi coexistence by 3GPP [8]. Fig. 4 provides an overview of the LAA Nodes and Wi-Fi STAs layout. The two operators deploy four small cells in an office floor with 10 cubical divisions as shown in Fig. 4. The four base stations (LAA eNBs, and Wi-Fi APs) for each operator are equally spaced (Fixed locations and offset from one another by a default of 5 meters). The Nodes and STAs are randomly distributed in the rectangular region, with some of the fixed Wi-Fi STAs (that is, sensors, cameras and desktop PCs). We performed simulations for two set of densities; five Nodes/STAs (*N*) per cell (that is, cell/operator = 4, *N* = 5, operators = 2, total *N* = 4 * 2 * 5 = 40), and ten Nodes/STAs (*N*) per cell (that is, cell/operator = 4, *N* = 10, operators = 2, total *N* = 4 * 2 * 10 = 80). Table 1 presents the details of the simulation scenarios for both operators. The current scenarios do not use user mobility.

### A. *Simulation Models*

#### *1)* Wi-Fi Model

We consider a 20 MHz 802.11n channel for operator B (Wi-Fi), with an EDCA for QoS considerations. The energy detection-based (ED) CCA for detection of other RATs is set to -72dBm. Although the Wi-Fi has -62dBm since LTE has -72dBm so we set same for both operators, which does not cause much effect on the access mechanism [11]. Simulations described herein use data rates up to Modulation and Coding Scheme (MCS) 15 with no short guard interval. The Wi-Fi APs use BEB mechanism to update the *W* with $W_{min} = 15$, and $W_{max} = 1023$.

#### *2)* LAA Model

LAA implements an LBT and CoLBT protocols. All LBT parameters were approved in 3GPP RAN Plenary meeting in December 2015 [8]. The initial CCA time is 43µs, and the LAA CCA slot time ($\sigma$) is 9µs. LAA ED threshold is set to -72dBm. The maximum length of TXOP is configurable and it defaults to 8ms. The update of the *W* for LBT is implemented following an HARQ feedback based approach, as agreed in [8]. For LBT, the upper bound of the contention window varies according to BEB between {15, 31, 63}, while for CoLBT it varies between {15-63} depending upon the network density (that is, $p_{obs}$ ).

#### *3)* Traffic Model

The overall offered load is the same for both coexisting networks. In experiments, we have implemented the File Transfer Protocol (FTP), and evaluated it on a downlink only scenario, as one of the recommended options in [9]. This model simulates file transfers arriving according to a Poisson process with arrival rate $\lambda$. The recommended range for $\lambda$ is between 0.5 to 2.5 [9], we have implemented $\lambda$ = 2.5 to use a level of load that allows both LAA and Wi-Fi to always have data available for transmission. To model this, we configured the FTP application to operate over UDP. We used simulation time of 244 seconds for $\lambda$ = 2.5, because lower traffic intensities do not occupy the link enough to show interesting performance differences.

#### *4) Performance Metrics*

The main performance metrics described in TR 36.889 [9] are 'user perceived throughput (Mbps)' and 'latency (ms)'. In NS3, we are calculating these metrics by using the built-in

TABLE I. PARAMETERS USED IN SIMULATIONS

| Parameter | Value |
|---|---|
| Network Scenario | Office Floor (Indoor) |
| Number of cells/operator | 4 |
| Number of devices/cell | 5, 10 |
| Traffic Model | FTP over UDP |
| Packet arrival rate (λ) | 2.5 |
| Operating Frequency | 5 GHz |
| Bandwidth | 20 MHz |
| Physical rate of the channel | MCS 15 (130Mbps) |
| Data frame payload | 1000 bytes |
| $W_{min}$(LAA/WiFi) | 15/15 |
| $W_{max}$(LAA/WiFi) | 63/1023 |
| ED threshold (LAA/WiFi) | -72 dBm |
| SIFS | 16 $\mu$s |
| DIFS/CCA | 60/43 $\mu s$ |
| Slot-time $\sigma$ (LAA/WiFi) | 9 $\mu s$ |
| TXOP (LAA) | 8 ms |
| NACKs feedback (LAA) | 80% |
| Scaling design factor ($\omega$) | 32 |
| Simulation time | 250 s |

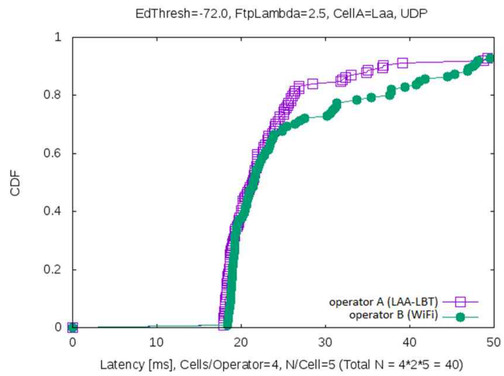


Fig. 5. Latency (ms) performance of LAA-WiFi coexistence with LAA LBT: FTP (arrival rate λ= 2.5) over UDP with 5 Nodes/STAs per cell/operator.

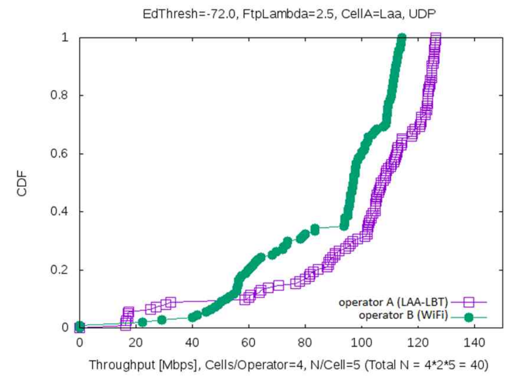


Fig. 7. Throughput (Mbos) performance of LAA-WiFi coexistence with LAA LBT: FTP (arrival rate λ= 2.5) over UDP with 5 Nodes/STAs per cell/operator.

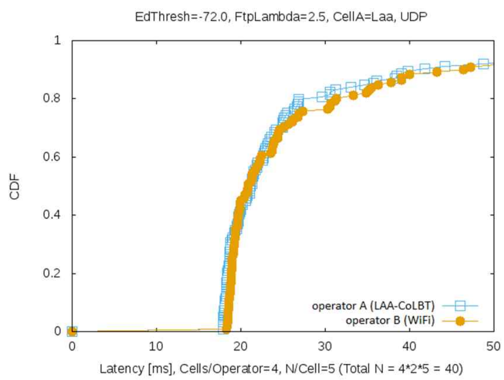


Fig. 6. Latency (ms) performance of LAA-WiFi coexistence with proposed LAA CoLBT: FTP (arrival rate λ= 2.5) over UDP with 5 Nodes/STAs per cell/operator.

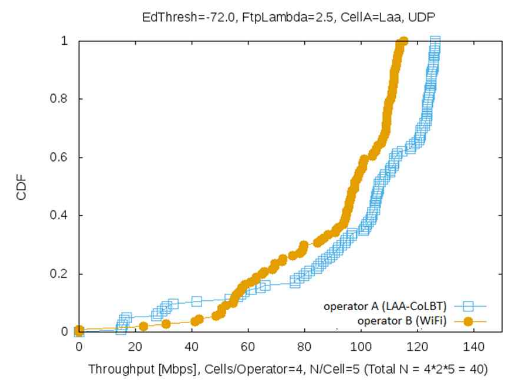


Fig. 8. Throughput (Mbps) performance of LAA-WiFi coexistence with LAA CoLBT: FTP (arrival rate λ= 2.5) over UDP with 5 Nodes/STAs per cell/operator.

FlowMonitor tool that tracks per-flow statistics at the IP layer including throughput and latency. Later we post-process these flow results to obtain CDFs for 'user perceived throughput (Mbps)' and 'latency (ms)'.

### *B. Results and Discussions*

Fig. 5 and Fig. 6 show latency impact of the LAA-WiFi coexistence when using LAA LBT and LAA CoLBT, respectively. The figures show that the ratio of Wi-Fi STAs suffers high latency coexisting with LAA LBT scheme and it decreases with LAA CoLBT scheme. Moreover, the Fig. 6 shows that both operators (LAA and Wi-Fi) fairly share the channel and have a similar latency performance. The throughput impact on the Wi-Fi networks is shown in Fig. 7 and Fig. 8 for both schemes. The Fig. 7 shows that there exists a prominent amount of throughput degradation for the Wi-Fi STAs, while the performance degradation of Wi-Fi network is comparatively smaller for the LAA CoLBT replaced network, as shown in Fig. 8.

The fairness between the LAA and Wi-Fi becomes more noticeable when the number of Nodes/STAs (*N*) increases per cell, due to increase in channel occupancy probability and time. This is because current LAA LBT mechanism only considers the HARQ feedback for backoff window update, which is received with much more delay that is after 7ms [9]. The Fig. 9 shows that both operators face a noticeable amount of higher latency as compared to the less number of Nodes/STAs per cell (Fig. 5), and figure shows, Wi-Fi network is the one who suffers more than the LAA. When LAA LBT is replaced with LAA CoLBT, the degradation in latency performance is smaller and both operators follow the similar latency as shown in Fig. 10. Since the LAA CoLBT adjusts the backoff contention window based on the available probability of channel condition, therefore the throughput degradation due to an increase of the number of contenders has a small effect on CoLBT as compared to LBT as shown in Fig. 11 and Fig. 12. The practical channel observation-based channel access of CoLBT enhances the fair channel occupancy for both LAA and Wi-Fi devices in the network.

## V. CONCLUSION

LAA-WiFi coexistence performance is highly sensitive to the factors that affect the channel access (e.g. BEB), that is the parameter choices in LAA LBT and contention window update mechanisms, such as HARQ feedback. Different aspects and LAA parameters affect the coexistence performance. In this paper, we propose a more realistic channel observation-based LBT (CoLBT) to enhance the fairness of LAA-WiFi coexistence. We have tested the impact of the parameters associated with the LBT access protocol and with the backoff

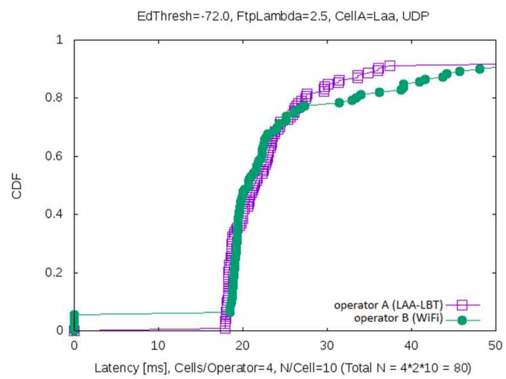


Fig. 9. Latency (ms) performance of LAA-WiFi coexistence with LAA LBT: FTP (arrival rate λ= 2.5) over UDP with 10 Nodes/STAs per cell/operator.

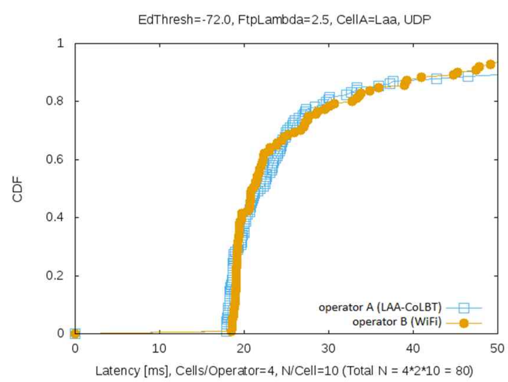


Fig. 10. Latency (ms) performance of LAA-WiFi coexistence with proposed LAA CoLBT: FTP (arrival rate λ= 2.5) over UDP with 10 Nodes/STAs per cell/operator.

algorithm to improve the fairness between LAA and Wi-Fi networks. In particular, we tested the sensitivity to 1) the parameter associated to the HARQ-based rule to update the contention window size, and 2) the BEB mechanism used by LAA for scaling of the contention window. In general, we observed that one of the reasons for coexistence performance degradation is by these parameters. Simulation results show that the proposed adaptive contention window scaling with COSB in CoLBT is effective in LAA-WiFi coexistence scenario and can improve fairness performance, compared with the current mechanism of LBT.

In the future, this research will be extended to include an analytical model to affirm the accuracy of the mechanism. In addition, the proposed algorithm must be validated for employing different QoS traffic applications, such as voice and video applications. Since we have evaluated CoLBT for increased user density only, thus another important aspect has to evaluate is to increase the network density (number of eNB and APs deployment).

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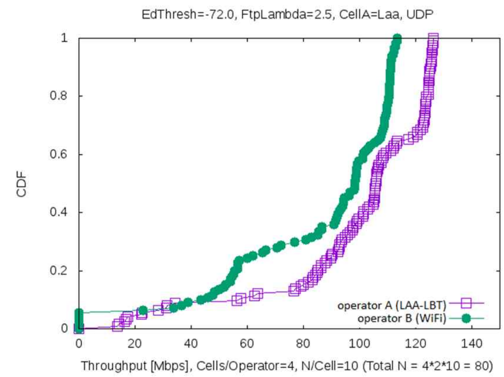


Fig. 11. Throughput (Mbos) performance of LAA-WiFi coexistence with LAA LBT: FTP (arrival rate λ= 2.5) over UDP with 5 Nodes/STAs per cell/operator.

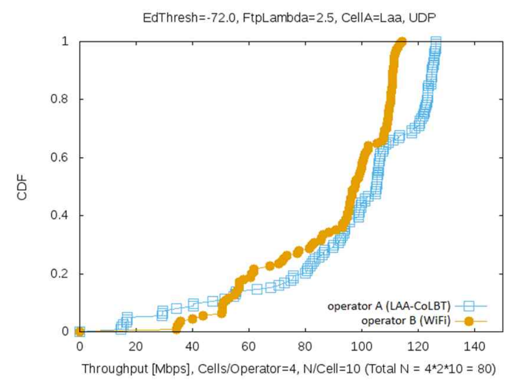


Fig. 12. Throughput (Mbps) performance of LAA-WiFi coexistence with LAA CoLBT: FTP (arrival rate λ= 2.5) over UDP with 10 Nodes/STAs per cell/operator.


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