Coexistence of Wi-Fi 6e with Lte-U/Laa in the 5 Ghz Frequency Band

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COEXISTENCE OF WI-FI 6E WITH LTE-U/LAA IN THE 5 GHZ FREQUENCY BAND

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Abstract. This work is how to achieve high user throughput with high performance in congested areas by amending the existing coexistence methods and enhancing the performance metrics by updating some input metrics such as duty cycle period, energy detection threshold, data transfer period, etc. The simple topology will verify the basic concept of LTE-U/LAA coexistence with Wi-Fi. Then the indoor crowded coexistence scenarios of LTE-LAA/U and Wi-Fi 6E in the 5 GHz will be the main idea of this study using the enhanced CAT-4 LBT algorithm design. The proposed model evaluated the coexistence performance based on CDF of throughput and latency. The transport layer of wireless communication will play a worthy role. When using the TCP protocol, the Wi-Fi throughput and latency will be more effective than the LAA operator. When using the UDP protocol, the LTE-LAA network has better throughput and latency than the Wi-Fi network. The throughput and latency for LTE-U and Wi-Fi operators are roughly identical using the FTP protocol. Overall, the throughput improved by 20%, and an approximately 2 ms delay time of the handover compared to the previous research results.

Keywords: Wi-Fi networks, LTE cellular systems, coexistence methods, fair resource sharing, unlicensed spectrum.

1 Introduction

A physical layer in WLAN work as a peer-to-peer bit rate to reach more than 1 Gbps throughput. Wi-Fi employs Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as a channel access method. The Clear Channel Assessment (CCA) method is a contention-based protocol that can direct a Wi-Fi node to listen to the shared medium to determine its status [1].

When Transmission opportunity (TXOP) is up, it should contend for the wireless medium. The countdown stops when another station starts sending. When a station contains frames to send, the station will wait for some time, equal to Arbitration Inter-Frame Spacing (AIFS), which prioritizes one Access Category over the other. It will wait until its Network Allocation Vector reaches zero, and then it will wait for the Contention Window (CW) to complete.

On the other hand, Long Term Evolution (LTE) is an entirely different technology from its predecessor. It is controlled by a single network operator scheduling all the transmissions and does not have the distributed coexistence function that Wi-Fi inherently has. When allocating these two technologies, overlapping each other, Wi-Fi will hear LTE talking and essentially shut down [2]. However, LTE-License-Assisted Access (LTE-LAA) is on track to adopt Wi-Fi-like coexistence features. The FCC has looked to the industry to develop collaborative solutions within a flexible regulatory framework. The unlicensed spectrum can split into numerous carriers with a bandwidth of 20 MHz each [3].

LTE-U uses a Carrier Sense Adaptive Transmission (CSAT) approach that relies on the adaptive duty cycle that senses channel utilization to set the duty cycle parameters. If the LTE-U UEs' traffic demands can be fulfilled using only the primary carrier, the secondary carrier can be turned off to relieve the strain. If two Wi-Fi nodes are next to each other and replace one with LTE-U, the gain will increase from both LTE-U and Wi-Fi spectrum efficiency and improve the Wi-Fi performance. CSAT schedules transmissions depending on the intended duty cycle [4].

Furthermore, LTE-LAA uses LBT-based techniques to detect channel availability. Transmissions between Wi-Fi and LTE could happen in a matter of seconds. ED can detect signals as low as -62 dBm in Wi-Fi and LTE transmitters [5]. Preamble detection can only be used by Wi-Fi devices to identify signals from other Wi-Fi transmitters greater than -82 dBm. The Wi-Fi stations would be notified to begin a transmission via LAA devices.

Our contribution to this work is to improve the handover mechanism of Wi-Fi and cellular communications by improving the data rate and reducing time latency in real-time applications. The various bandwidth split options are defined when resources are allocated to many users equally. Also, this paper focuses on reducing Media Access Control overhead and improving transmission flexibility and the physical layer during the session transfer between Wi-Fi and LTE networks. The radio frame structure and a physical layer in cellular technologies have a primary role in coexistence with other Wi-Fi systems [6].

The scope of this study is summarized as follows:

1. This study focuses on updating the existing coexistence mechanism between IEEE 802.11ax and cellular technology, such as LTE. Therefore, other wireless technologies such as Bluetooth and Zigbee are out of scope.
2. This study focuses on enhancing the throughput and reducing the coexistence time delay of Wi-Fi and LTE cellular communications via a simulation program. Thus, it does not test real-time condition experiments.

The rest of the papers are structured as follows; Section 2 discusses the most related work to this study. Section 3 outlines the methods used. The first scenario is a simple design then the second scenario is an indoor dense scenario experiment. Section 4 analyzes the results using the ns-3 open-source network simulator to comprehend how LTE and Wi-Fi share channel access. Section 5 evaluates the results and explains the difference between each finding. Finally, Section 6 concludes the paper.

2 Related Work

The research community is becoming more interested in the coexistence of Wi-Fi and cellular networks in the unlicensed shared spectrum. A discrepancy in TXOP transmission time and energy detection (ED) reduces the coexistence throughput shown in [7]. However, their method cannot modify parameters like TXOP duration or preamble detection during the coexistence method. Also, [8] compared Wi-Fi performance and delay to other systems using three Markov chain models. A channel is examined for DIFS time to see if it is idle. However, this LBT approach has a longer delay time and lower channel utilization.

UL transmissions use Single-Carrier Frequency Division Multiple Access (SC-FDMA) explained in [5]. License-anchored systems (LTE-U, LTE-LAA) that the anchor is the principal carrier and operates on a licensed spectrum. But it does not include any experiments to examine their theories. Also, a new Contention Window (CW) approach was used for LAA to enable the coexistence of LTE and Wi-Fi, according to [9]. The proposed system is used when there are more traffic demands. Static muting, LBT, and RTS/CTS are just a few coexisting strategies available. But it incurs a significant delay in transmission.

Before transmission, the LBT technique LAA device can calculate the medium and confirm the measured energy, as proposed in [10]. The LAA LBT procedure's energy detection (ED) threshold and Freeze Period (FP) can impact LAA's channel access opportunities. But this method decreases the average user data rate when the served traffic increases because of interference and delays. Also, [11] suggested a Duet as a solution for LTE-U and Wi-Fi coexistence in unlicensed bands. Wi-Fi employs a dispersed MAC system, whereas LTE-U uses a centralized MAC protocol. But this mechanism costs additional energy and inaccurate duty cycle periods.

Wi-Fi and LTE-A are not interfered with using the Almost Blank Subframe (ABS) method, as explained in [12, 13]. The spectrum sensing method can only evaluate the quality of the user channel using a BS statistical estimate because it cannot determine which cells are communicating. Moreover, UEs can convert from Wi-Fi to cellular via the core network's gateway, as shown in [13]. The Wi-Fi APs may recognize the channel and communicate via LTE broadcasts during the random ABS. However, this solution has the disadvantage of requiring synchronization of Wi-Fi and LTE.

Also, [14] used a secondary carrier via various RAN technologies. The network topology contains management resource that is shared network operations and spectral resources that cost high power resources. Moreover, Wi-Fi broadcasts are slotted with a random duration between idle and busy phases, as proposed in [15]. Modifying the duty cycle percentage from 50% to 41% to lower the overhead for LTE-U to use the Wi-Fi channel is an excellent option for coexistence. However, sometimes, the Markov chain model is incompatible with the MAC protocol of Wi-Fi.

Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) scheduling mechanisms are used in cellular systems, according to [6]. Wi-Fi used in the same preamble might result in better spectral usage for coexistence. However, this method has a dilemma arising in a fair backoff NR-U and Wi-Fi coexistence in the 6 GHz band. On the other hand, some devices used the CTS-to-self variation to secure transmissions in mixed-mode situations, as proposed [16]. Because it can achieve larger throughputs, CTS-to-self is better than RTS/CTS. However, it is unable to address the hidden nodes issue. AP identifies considerable activity from surrounding BSSs.

MAC time-sharing methods and channel selection methods (spectrum sharing in frequency) were the two categories of spectrum sharing methods, as explained in [17]. However, in other circumstances, time-sharing MAC approaches are irrelevant. Also, [18] implemented the simulation using two Communication Channels (CCs) operating on non-overlapping frequency channels to transmit data simultaneously. However, it does not feature the traditional Wi-Fi inter-system interference simulation.

Certain RBs have been set aside to control traffic in specialized channels with user traffic, according to [1]. However, it employed complicated techniques and CCE overflow timeslots to handle requests from several networks. Moreover, [4] suggested a new approach based on Sense Before Transmit (SBT) that assigns secondary carriers in the uplink and downlink directions in the unlicensed spectrum to carry traffic using reciprocity theory based on Channel State Information (CSI). But when the channel estimate error increases, the LTE-U user's performance suffers.

On the other hand, [2] introduced that LTE-U used the Almost-Blank Subframes (ABS) capability to blank a section of LTE transmission to increase Wi-Fi throughput. However, it did not concentrate on the coexistence of unlicensed multi-band frequencies in a dense environment. Also, [19] researched the difficulties of communicating low-band and high-band signals and established a detection threshold in wireless technology. However, the coexistence with LBE/LBT devices still requires channel access parameters optimization used by the LBT-based MAC protocols in NR-U and Wi-Fi.

Furthermore, [20] created two LAA transmission rules, Orthogonal Random LBT Unlicensed Access (ORLA) and Optimal Orthogonal LAA Access (OLAA), to increase LAA throughput in asynchronous and synchronous applications. However, the suggested transmission policies increase LBT throughput by 200% without increasing the Wi-Fi throughput. Moreover, [3] proposed a carrier that detects radio signal interference using Dynamic Frequency Selection (DFS). However, their technique reveals that when utilizing the licensed PCell, UE uses more power and lower frequencies.

In addition, for coexistence between LTE-U and Wi-Fi, [21] analyzed power consumption for all nodes in the testbed scenario in the srsLTE software. Also, [22] put their planned coexistence scenario to the test on a testbed. srsLTE software was used to implement LTE eNB on the USRP b-210 platform. But the proposed scenarios' throughput has limitations on each category in real-life conditions.

3 Simulation Setup

This section explained the simulation setup of our work. We are using the NS3.26 program installed in Ubuntu VM with installed libraries such as Gnuplot, libxml2, python-kiwi, python3, etc. We investigate the two scenarios; one design is verification of our design via a simple setup, and the second design is via the indoor scenario. The cellular parameters are channel access manager, packet data flow, transmission duty cycle, and sensing threshold. The Wi-Fi parameters are CW update rule, TXOP, cyclic prefix duration, different detection thresholds, etc.

3.1 Data Collection

The data is gathered from the MAC and physical layers of Wi-Fi 6E, the physical and logical layer of LTE-U/LAA frame designs from the academic surveys and professional papers. The simulation model will handle the radio waves of different wireless communication systems and compare the signals interference when working in the shared wireless spectrum. The radio waves can combine, causing an increase in wave amplitude to reach a seamless integration method.

3.2 Simulation Design Procedures

The first design: Implement a simple model between Wi-Fi 6E and LTE-U/LAA in the 5 GHz band. It contains two operators. This is to verify our working solution is indeed a working one. Operator A contains either LTE-U or LTE-LAA network architecture, including one eNB and one UE. Operator B has a Wi-Fi 6E infrastructure network containing one AP and one STA, close to operator A's area.

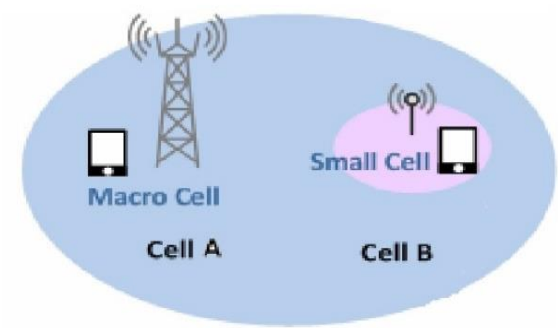

Fig. 1. Simple Wi-Fi 6E Coexistence Design with LTE-U/LAA

Figure 1 shows the two cells whose radio coverage overlaps. Two operators in the same region with transmissions may impact mechanisms such as clear channel assessment, adaptive modulation, and coding. Either LTE-U or LTE-LAA operates on

5.180 GHz, and Wi-Fi 802.11ax works on channel 36 (5.180 GHz). The application data rate is 20 Mbps, which saturates the Wi-Fi link but can be handled by the LTE link.

The second design: Implement a dense deployment scenario between Wi-Fi 6E network and LTE-LAA/U cellular networks in the 5 GHz band. It contains two operators. Operator A contains either LAA or LTE-U network architecture, including eNBs and UEs located at different distances. Operator B has a Wi-Fi 6E infrastructure network containing APs and STAs in the same coverage zone, as shown in figure 2.

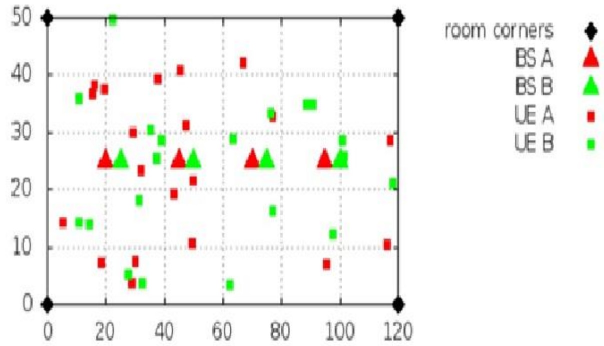

Fig. 2. Wi-Fi 6E Coexistence with LTE-LAA/U (Indoor Scenario)

Figure 2 depicts two different wireless network operators in the program, each with four cells and five UEs. Each operator has four BS and twenty UEs. The BS's positions are established (offset from one another by default of 5 meters). The bounding box of a simulation is 120 x 50 m. The small cells of each operator are centered along the shorter dimension of the building. There is a random distance between the two operators' closest nodes. UEs (STAs) travel at a 3 km/h speed within the bounding box. Each operator uses a 75 Mbps constant bit rate UDP flow as a simulation data rate. UDP transmissions are employed from the backhaul to the BSs. On the other hand, the TCP segment contains 1440 bytes, and the initial CW of TCP consists of 10 segments. Also, FTP is used to control and manage traffic.

4 Simulation Results

4.1 Wi-Fi 6E Coexistence with LTE-U

Our first simulation setups are shown in table 1. The parameters used in this simple scenario are d1 and d2 distances, channel access manager, packet data flow, number of BS and users, the duty cycle attributes, minimum threshold multi-user value (ThresholdMuLow), and the maximum threshold value (ThresholdMuHigh).

Table 1. Simulation parameters of simple scenario (LTE-U with Wi-Fi 6E)

Parameters	***Settings***	***Details***
Center frequency	5.180 GHz	Frequency band
LTE-U band	252	-
LTE-U/Wi-Fi bandwidth	20 MHz	-
Wi-Fi Channel	36	-
Cell Config A	LTE-U	Cell A vendor (Operator A)
Cell Config B	Wi-Fi 6E	Cell B vendor (Operator B)
Number of eNB/AP (carrier)	2	One/Operator
Number of UE/STA	2	One/BS
Intra-cell distance	10 meters	Distance between UE and BS
Inter-cell distance	50, 100 meters	Distance between two Base Stations
Channel Access Manager	CSAT	Channel access category
CSAT Duty Cycle	0.5	Portion of ON time in CSAT Cycle
CSAT Cycle Duration	160	Duration of CSAT cycle in several subframes
MU1	0.1, 0.2, 0.3	Threshold MU Low (CSAT adaptation)
MU2	0.3, 0.4, 0.5	Threshold MU High (CSAT adaptation)
ftp Lambda	3.5	Packet arrival rate
Transport protocol	UDP	Transport type

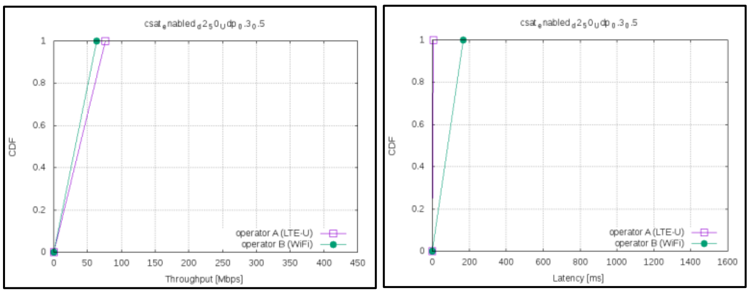

Fig. 3. First Performance Simulation Outcome (Wi-Fi 6E/LTE-U)

Figure 3 depicts that when enabling CSAT, d2 equals 50 meters, ThresholdMuLow equals 0.3, and ThresholdMuHigh equals 0.5. Moreover, CDF measures the average throughput and latency as performance analysis metrics. The throughput and latency of the LTE-U network are better than the Wi-Fi network. The LTE-U will utilize more radio spectrum resources than the Wi-Fi network.

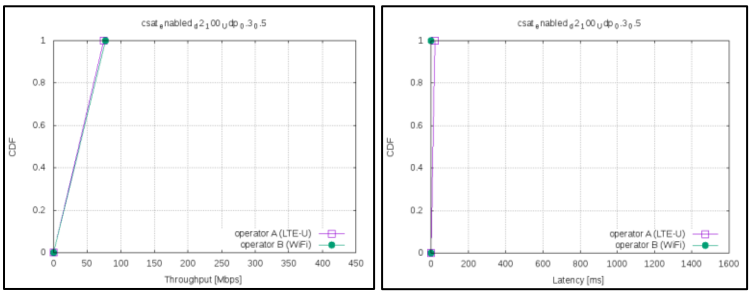

Fig. 4. Second Performance Simulation Outcome (Wi-Fi 6E/LTE-U)

Figure 4 displays that when enabling CSAT, d2 to equal 100 meters, ThresholdMuLow equals 0.3, and ThresholdMuHigh equals 0.5. The throughput and latency of the LTE-U operator are approximately equal to the Wi-Fi operator.

4.2 Wi-Fi 6E Coexistence with LTE-LAA

Table 2 shows the simulation settings for the parameters in the second scenario, such as d1 and d2 distances, channel access manager, packet data flow, energy detection threshold, contention window, and LBT TXOP. The LBT is different than in LTE-U attributes such as TXOP, User reservation signal, and CW update rule.

Table 2. Simulation parameters of simple scenario (LAA with Wi-Fi 6E)

Parameters	***Settings***	***Details***
Center frequency	5.180 GHz	Frequency band
LTE-LAA band	252	-
LTE-LAA/Wi-Fi bandwidth	20 MHz	-
Wi-Fi Channel	36	-
Cell Config A	LTE-LAA	Cell A vendor (Operator A)
Cell Config B	Wi-Fi 6E	Cell B vendor (Operator B)
Number of eNB/AP (carrier)	2	One/Operator
Number of UE/STA	2	One/BS
Intra-cell distance	10 meters	Distance between UE and BS
Inter-cell distance	50, 65 meters	Distance between two Base Stations
Channel Access Manager	LBT	Channel access category
LAA Ed Threshold	-72 dBm	CCA-ED threshold for channel access manager
ftp Lambda	1.5	Packet arrival rate
LBT TXOP	8 ms	TXOP for LBT devices
CW Update Rule	80 %	Rule to update contention window of LAA
Transport protocol	UDP	Transport type

LAA prevents Wi-Fi from using the channel when d2 equals 50 meters. The default result of the code shows operator A (LTE-LAA) has a throughput of 65.3 Mbps and the lowest latency of 34.1 ms. However, operator B (Wi-Fi 6E) has no throughput without latency. The LTE-LAA will take all the radio resources of the channel to send its data to the users. However, when d2 equals 65 meters, the result shows operator A (LTE-LAA) has a throughput of 65.3 Mbps and a latency of 34.1 ms. However, operator B (Wi-Fi 6E) has acquired a throughput of 76.8 Mbps and lower latency of around 0.8 ms.

4.3 Wi-Fi 6E Coexistence with LTE-LAA using UDP/TCP protocol

The evaluation of performance metrics of these output flows:

1. Cumulative Distribution Function (CDF) of Throughput: throughput is the amount of data received on a flow divided by the time between the first and last packet.
2. CDF Latency: Time from packet arrival in the MAC buffer of devices (eNB, AP, UE, STA) to packet transmission success.

Table 3 displays some parameters used in the indoor coexistence example, such as channel access manager, packet arrival rate, energy detection threshold, LBT TXOP, BS spacing distance, MU1, MU2, data transfer duration, and transport protocol.

Table 3. Simulation parameters of indoor scenario (LTE-LAA/U with Wi-Fi 6E)

Parameters	***Settings***	***Details***
Cell Config A	LTE-LAA/U	Cell A vendor (Operator A)
Cell Config B	Wi-Fi 6E	Cell B vendor (Operator B)
Number of carriers	4	Four carriers/operator
Number of UEs	5	Five user equipment or base stations/carrier
Intra cell distance	10 meters	Intra cell separation
Inter cell distance	10 meters	Inter cell separation
Bs Spacing	5 meters	Spacing between the two BSs of different operators
Channel Access Manager	LBT or CSAT	Channel access category
LAA Ed Threshold	-62, -72, -82 dBm	CCA-ED threshold for channel access manager
ftp Lambda	0.5, 1.5, 2.5	Packet arrival rate
LBT TXOP	8 ms	TXOP for LBT devices
CW Update Rule	80 %	Rule to update contention window of LAA
CSAT Cycle Duration	160	Duration of CSAT cycle in number of subframes
MU1	0.1, 0.2, 0.3	Threshold MU Low (CSAT adaptation)
MU2	0.3, 0.4, 0.5	Threshold MU High (CSAT adaptation)
Transport protocol	UDP/TCP/FTP	Transport type
Data Transfer Duration	48, 80, 240 ms	Data transfer duration for the packet in LAA

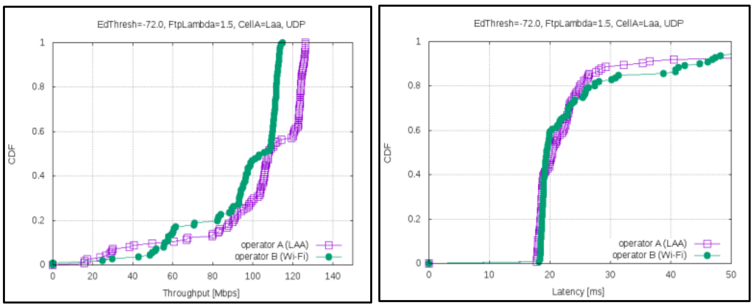

Fig. 5. Indoor Coexistence Performance (Wi-Fi 6E/LAA) with UDP

Figure 5 shows the left-hand side diagram that the LAA operator has a slightly higher throughput than the Wi-Fi operator. The right-hand side diagram shows both operators have latency values that are approximately equivalent to each other. Using UDP-based file transfer applications, customers experience the best throughput in the LAA network compared to a Wi-Fi network in the unlicensed carrier.

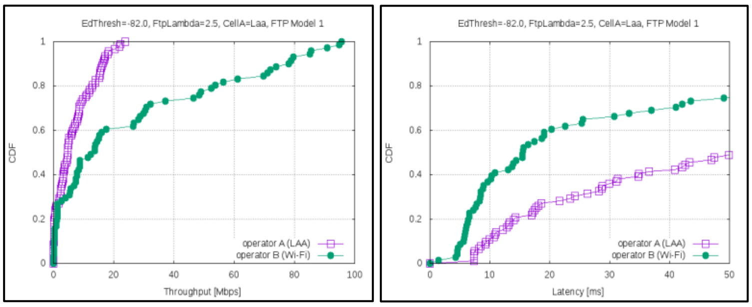

Fig. 6. Indoor Coexistence Performance (Wi-Fi 6E/LAA) with TCP

Figure 6 represents the left-hand side diagram showing the Wi-Fi operator has a significantly higher throughput than the LAA operator. The right-hand side diagram shows the Wi-Fi operator has lower latency than the LAA network. Using Wi-Fi and TCP-based file transfer applications, Wi-Fi users will get higher throughput than in the LAA network.

4.4 Wi-Fi 6E Coexistence with LTE-U using FTP protocol

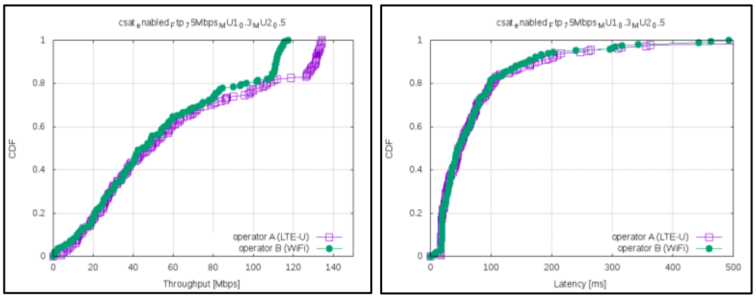

Fig. 7. Indoor Coexistence Performance (Wi-Fi 6E/LTE-U) with FTP

Figure 7 illustrates the left-hand side diagram that the LTE-U operator has a higher throughput than the Wi-Fi operator in some values. The right-hand side diagram shows the Wi-Fi operator has approximately the same latency as the LTE-U network. The coexistence outcome will get a higher performance rate for both networks when using LTE-U with FTP protocol in the indoor coexistence with the Wi-Fi networks.

5 Discussion

5.1 Wi-Fi 6E Simple Coexistence scenario with LTE-U/LAA

When the distance between two stations is high in the first scenario, the Wi-Fi operator will acquire chances to use the same radio resources as LTE-U. But, in the second scenario, Wi-Fi will get more radio resources than LAA, which is better than the previous Wi-Fi 6E coexistence with the LTE-U scenario because it avoids interference inside the carrier sense range. However, in some cases, the performance of LTE-U coexistence with Wi-Fi degrades because flows affected by LTE-U OFF periods have significant delays, and the number of possible collisions has grown because of the duty cycle modification. On the other side, Wi-Fi networks get a low throughput and lower medium resources in some cases in LAA coexistence due to the influence of reservation and control transmission signals, and the hidden terminals incur collisions.

5.2 Wi-Fi 6E Indoor Coexistence scenario with LTE-LAA/LAA

The proposed technique compares the mean and Cumulative Distribution Function (CDF) of delay and throughput under different signal/energy detection thresholds utilized to conclude fairness. The built-in Flow Monitor tool tracks per-flow statistics at the IP layer to determine throughput and latency. CDF is calculated because the nodes' locations are randomly allocated. The CDFs are then created by post-processing these results. CDF of throughput and latency is calculated for every node as an average value in the indoor-crowded scenario.

In UDP, the throughput and latency of the LTE-LAA network are better than the Wi-Fi network because there is no guarantee of connection delivery between the sender and the receiver. When the energy detection threshold value increases, the LTE-LAA throughput has a higher value, and the Wi-Fi network gets a lower latency time. However, in TCP, the Wi-Fi throughput and latency will be more efficient than the LAA operator because there are more details for LTE-LAA than the Wi-Fi network structures. The LAA curve is skewed significantly to the right, indicating low throughput compared to the Wi-Fi network because of the LTE's high latency.

The throughput and latency of both operators change when increasing values of Ed Threshold and FTP Lambda. When the energy detection threshold value increases, the LTE-LAA throughput has a higher rate, and the Wi-Fi network gets a lower latency time when using UDP. However, in TCP, the LAA curve is skewed significantly to the right, indicating low throughput compared to a Wi-Fi network because of the LTE system's high latency, particularly the round-trip time, which fluctuates between 10 and 30 ms because of the delay in scheduling and sending the TCP ACK upstream. The LAA average latency ranges from 4 to 48 ms and a median of 11 ms. But Wi-Fi latency is between 2 and 5 ms.

By increasing the parameter values (energy detection threshold and packet arrival rate) in UDP data flow, Wi-Fi throughput increases from (110 to 118 Mbps). However, LAA throughput remains at (130 Mbps) in all cases, and latency fluctuates in values similar in both wireless systems with a little higher value for LAA than in the Wi-Fi network. On the other hand, when increasing the parameter values (energy detection threshold and packet arrival rate) in TCP data flow, Wi-Fi throughput remains at (100 Mbps). However, LAA throughput remains low in the range (20 - 25 Mbps), and latency remains fluctuations the same value approximately in some cases in each system, with a little higher value for Wi-Fi than LAA network.

However, in FTP, the throughput and latency for LTE-U and Wi-Fi operators are nearly similar, indicating low transmission time delay with a high data rate for low latency and high-bandwidth applications. The throughput and latency for LTE-U and

Wi-Fi operators are nearly similar, indicating a high coexistence performance indicator and a fair manner of sharing radio resources. When increasing ThresholdMu values in FTP, the outcome of LTE-U coexistence with Wi-Fi displays fair radio resource sharing at a throughput of 110 Mbps.

The Wi-Fi/LTE latency needs to transfer buffer status reports upstream, receive Downlink Control Information (DCI) message on the downlink channel, and then schedule the ACK for transmission on the next subframe. Also, throughput decreases due to the higher Channel Occupancy Time (COT). There will be less congestion in the LAA network when TCP (13%) and UDP (5%) are utilized. FTP is used to flow the packets between nodes in the LTE-U network to reduce signal interference and prevent signal jamming.

Moreover, each flow consists of 354 packets with 1448 bytes of 1476 bytes payload. It contains 1000 TXOPs at the Wi-Fi layer, each with best-effort traffic and a PPDU consisting of aggregated-MPDUs of up to 4 ms a piece. Because most flows are less congested than other flows, the transfer occurs without channel congestion, and the 0.5 MB file is transferred as quickly as possible. The coexistence curves may converge in some places while diverging in other sections of the simulation outcomes.

The main important LBT scheme features, such as contention windows and defer periods, should be customizable to allow for fair coexistence with other unlicensed spectrum technologies. The results reveal that by modifying parameters like the energy detection threshold, flow packet rate, threshold MU, and data transfer duration time, the proposed techniques can acquire a shared radio spectrum between the Wi-Fi 6E network and the LTE cellular system. The IEEE 802.11ax model was employed for the small cells in the indoor environment. The channel access structure, at least for downlink data transmissions, consists of a category 4 LBT system with random backoff and variable contention windows based on experimental results. Moreover, while LTE SINR distribution is unaffected by decoding, Wi-Fi user SINR distribution depends on preamble decoding.

6 Conclusion

The two simple scenarios have proved that LTE-LAA surpasses LTE-U in the coexistence with the Wi-Fi 6E networks based on data rate and delay with higher wireless connectivity reliability when sharing the bandwidth. However, according to indoor coexistence scenarios, the Cumulative Distribution Function (CDF) of throughput and latency were compared using UDP/TCP/FTP protocols. Co-channel allocation decision-making defines parameters to decide whether to choose another AP or other LTE BSs to get higher spectrum utilization efficiency. The analytical and simulation comparisons yielded accepted results by achieving a higher data rate and lower latency with low power consumption. When the performance of the Wi-Fi network is more elevated than LTE, we can utilize some user applications, such as web browsing, email, etc., over the Wi-Fi networks. However, when the LTE performance is higher, we can use applications such as VOIP, video streaming, etc., over the LTE network. The future work will tend to coexist with the next generation of cellular communication and the new wireless technology, for instance, NR-U, ORAN, and Wi-Fi 7, in IoT and cloud applications as wireless infrastructure. Moreover, future fairness research will focus on generalizing a new model framework by including second-order stochastic dominance notions to allow fairness to be determined even when non-monotonic curves intersect to avoid any loss in the packet transfer.

Acknowledgment

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