Coexistence of Wi-Fi and LAA-LTE: Experimental Evaluation, Analysis and Insights

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***Abstract*—LTE-A as a cellular technology has gained tremendous importance in recent years due to its high data-rates and improved data access for mobile devices. Recently, utilizing the unlicensed band as a supplementary band for LTE-A is being considered to expand the capacity of mobile systems. License-assisted access using LTE (LAA-LTE) will thus operate in the unlicensed band, and will operate in a spectrum that overlaps with Wi-Fi, another popular unlicensed-band technology. The concern is that LAA-LTE and Wi-Fi are unlikely to have mechanisms to directly coordinate with each other to address channel-sharing issues. In this paper, we study the interference impact of LAA-LTE on Wi-Fi under various network conditions using purely experimental analysis in indoor environments. The following three questions are specifically considered in this paper: (1) What are the implications of LAA-LTE usage on Wi-Fi? (2) How should LAA-LTE or Wi-Fi be configured for Wi-Fi to be less impacted? (3) How should the LAA-LTE MAC protocol be designed to be gracefully co-exist with Wi-Fi? To answer the above questions, we present comprehensive experimental results and give insights based on the results.**

Keywords: LAA-LTE, LTE-A, Wi-Fi, coexistence, experimental performance evaluation

I. Introduction

Innovations in communication technology and densely deployed networks have brought about ubiquitous high-speed broadband access. Such broadband access makes our daily lives increasingly dependent on the Internet for a wide variety of content and services. Internet users constitute over 78% of the population in North America [1], and the mobile service revenue is estimated to become $270 billion in 2016 [2]. In order to sustain the possible growth in mobile services, Licensed-Assisted Access-Long Term Evolution (LAA-LTE)[1] [3] is emerging as a candidate technology for telecommunication companies to utilize unlicensed spectrum for wireless data traffic offloading. Using carrier aggregation [10] combining licensed and unlicensed bands, LAA-LTE delivers cellular services to mobile users in the 5-GHz unlicensed band.

In the past, telecommunication companies have introduced technologies in the unlicensed band such as carrier Wi-Fi that were integrated with their licensed wireless/wireline infrastructure for wireless traffic offloading. Unlike carrier Wi-Fi, which uses the same MAC/PHY protocols as other Wi-Fi networks provided by cable companies (cable-co Wi-Fi), LAA-LTE uses the same technology as LTE-Advanced (LTE-A). From the viewpoint of telecommunication companies, LAA-LTE provides a tighter integration with licensed LTE-A as an extension of the 3G/4G/LTE-A network with unified mobility, authentication, security, and management. This allows telecommunication companies to utilize the unlicensed spectrum more efficiently and seamlessly than the integration of carrier Wi-Fi and LTE-A services. Besides, by sharing the same core network, backhaul, and deployment plan, LAA-LTE can co-exist with carrier Wi-Fi as friendly neighbors and even provide a small cell as a service (SCaaS) for cloud mobile network users [4].

Though the coordination between LAA-LTE and carrier Wi-Fi can be anticipated, the cooperation of LAA-LTE and cable-co Wi-Fi is hard to achieve, considering the different core networks, the random user-deployments, and the unpredictable performance of Wi-Fi networks. Given the tremendous popularity and high density of Wi-Fi networks that already operate in the unlicensed band (IEEE 802.11a/n/ac all operate in the 5-GHz spectrum), coexistence issues between LAA-LTE and Wi-Fi are unavoidable.

In order to anticipate possible problems due to this coexistence, a quantified study of how LAA-LTE and Wi-Fi signals may affect each other can be an important preliminary step. A detailed study and analysis of the impact of LAA-LTE interference on Wi-Fi networks can reveal potential issues in the upcoming coexistence scenario, and results from such a study can also trigger the design of possible cooperation policies/mechanisms for LAA-LTE and Wi-Fi networks.

In this paper, we study the problems that are likely to arise due to the coexistence of LAA-LTE and Wi-Fi in indoor environments using *experimental evaluation*. We use a customer implementation of the LTE-A PHY layer on the National Instruments PCI eXtensions for Instrumentation (NI PXI) platform ([13]) to represent LAA-LTE nodes. For Wi-Fi networks, both off-the-shelf Wi-Fi routers and the software-defined Wireless Open-Access Research Platform (WARP [12]), are used as Wi-Fi nodes. While off-the-shelf Wi-Fi routers can represent typical Wi-Fi nodes, WARP radios provide ways to gain detailed information and evaluation. We identify critical PHY layer parameters and design **five** experiments that explore how LAA-LTE interference impacts Wi-Fi performance.

The main contributions of the paper are the following: 1) an

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[1]LTE-U is another term used for the same technology.

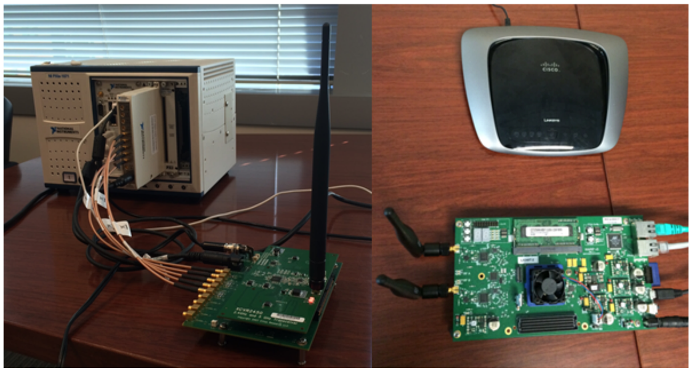


Fig. 1: Left: LAA-LTE platform; Right: Wi-Fi platform (WARP and Router)

experimental evaluation of the LAA-LTE interference effects on Wi-Fi performance under various network conditions along with insights; 2)suggestions for better coexistence of LAA-LTE and Wi-Fi networks.

The rest of the paper is organized as follows: In Section II, we introduce related works. In Section III, we describe the experiment platforms, environments, parameter settings, and the five experiments we used to study the LAA-LTE interference effects on Wi-Fi performance. Experimental evaluation results are presented in Section IV. We present our perspectives on an appropriate MAC design for LAA-LTE in Section V and present our conclusions in Section VI.

II. Related work

Little research has been done on the co-existence of LAA-LTE and Wi-Fi networks in the 5GHz band. In [9], several LAA-LTE MAC mechanisms for coexistence of LAA-LTE and Wi-Fi networks are proposed. Simulation results show that LAA-LTE gains high throughput performance without harming Wi-Fi performance with the proposed MAC mechanism. However, this conclusion only holds when the coexisting channel model can accurately simulate the interfering condition between LAA-LTE and Wi-Fi transmissions. There are several works that consider the coexistence of LTE[2] and Wi-Fi networks ([5]-[8]). In [5], coexistence of LTE and Wi-Fi has been studied in the TV White Space band. Simulation results indicate that LTE interference can degrade Wi-Fi throughout significantly even when LTE and Wi-Fi nodes are randomly deployed. In [6-8], several approaches that solve the coexistence problems of LTE and Wi-Fi networks have been proposed. [6] proposed coexistence mechanism utilizing LTE pico-cells. With the proposed mechanism, simulation results show that LTE can deliver significant throughput even when coexisting with Wi-Fi networks. In [7], a physical layer framework is presented for the coexistence of LTE and Wi-Fi networks. Simulation results indicate that the proposed framework can protect Wi-Fi performance from severe degradation in the presence of LTE interference. An approach using LTE uplink power control to solve the coexistence issue of LTE and Wi-Fi networks is proposed in [8]. Simulation results show that the proposed power control mechanism can improve the performance of both types of networks.

All of the above related works use simulations to study the coexistence of LAA-LTE (or, LTE) and Wi-Fi networks. However, without a robust representation of the PHY layer properties and accurate simulation models, simulation results can be somewhat suspect. Our work uses experimental evaluations to study the coexistence problem of LAA-LTE and Wi-Fi networks under various network conditions. To the best of our knowledge, this is the first work that studies the impact of LAA-LTE interference on Wi-Fi performance using experimental evaluation.

[2]LTE is an earlier version of LTE-A

TABLE I: EXPERIMENTAL TESTBED FOR LAA-LTE

Equipment	Model	Specification
Chassis	PXIe-1071	
Controller (Host)	PXIe-8133RT	1.73GHz Quad Core
FPGA	7965R FlexRIO	Virtex 5; 512MB DRAM; P2P streaming with other modules
Baseband Transceiver	NI-5781	ADC; 14bit DAC; 40 MHz BW
RF Frontend	XCVR 2450	2.4-2.5GHz & 4.9-5.9GHz

III. Experimental Setup

A. Evaluation platform

In this section, we describe the experiment platforms that are used to evaluate the impact of LAA-LTE interference on Wi-Fi performance.

1) LAA-LTE platform: The NI PXI testing system [13] was used as LAA-LTE testbed as shown in Fig. 1. The standard-based PHY of LTE-A (release 10) is implemented on the NI PXI system. The equipment details are listed in Table I. The system is able to provide many advanced and user-defined operability on signal transmission and reception, such as subcarrier modulation scheme, OFDM parameters, carrier frequency offset, and timing offset estimation.

2) Wi-Fi platform: The Cisco-Linksys WRT320N router and Wireless open-Access Research Platform (WARP [12]) v3 are used for the Wi-Fi testbed (see Fig. 1). The off-the-shelf Wi-Fi routers, supporting both 802.11a and 802.11n in 5GHz band, can represent typical commercial Wi-Fi nodes. On the other hand, since WARP supports modification and monitoring of parameters and functions in both the MAC and PHY layer of Wi-Fi, it provides ways to gain detailed information and evaluation. WARP is capable of communicating with off-the-shelf Wi-Fi nodes, but only 802.11a in 5GHz band is implemented in WARP.

B. Evaluation Environment and parameters

All experiments are carried out in a typical indoor office with size 8x5x2.7m^3. Table II lists the default settings of LAA-LTE and Wi-Fi parameters. We mainly use throughput of

TABLE II: DEFAULT EXPERIMENTAL SETTINGS

Parameters	Default settings
Center frequency	5.18 GHz
Wi-Fi bandwidth	20MHz
Wi-Fi standard	802.11a/n
Wi-Fi ARC	On
Wi-Fi transport protocol	UDP
LAA-LTE bandwidth	20MHz
LAA-LTE modulation scheme	16-QAM
LAA-LTE transmission PSD	-108/-106/-104/-102/-99.5dBm/Hz
Antenna gain	3dBi
Antenna type	Isotropic
Number of Tx/Rx antenna	1/1
Distance between two links	4m
Distance between Wi-Fi Tx/Rx	2m
Wi-Fi throughput testing tool	Iperf

Wi-Fi as a metric to evaluate the impact of LAA-LTE's interference on Wi-Fi performance. Other metrics, such as number of packets transmitted in the PHY layer, can also be collected using WARP, for cases that requires detailed evaluation. In our experiments, the LAA-LTE Tx always transmits, which is similar to the transmission of LTE-A in licensed bands. Also, the LAA-LTE transmission Power Spectral Density (PSD) is chosen such that LAA-LTE interference power is around Clear Channel Assessment (CCA) threshold [11] of Wi-Fi communications.

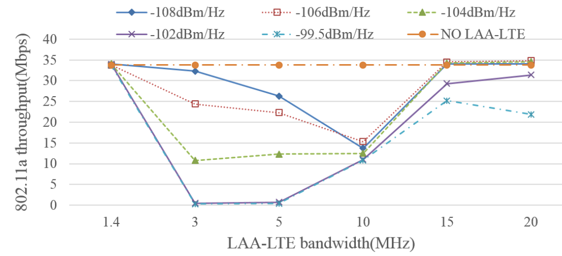
C. Methodology

We design **five** experiments to explore LAA-LTE interference effects on Wi-Fi performance:

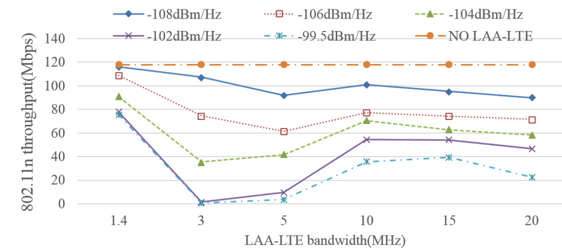
1) *LAA-LTE bandwidth*: LTE-A supports different bandwidths for Dynamic Bandwidth Adaptation (DBA) and spectral efficiency in license bands. Since LAA-LTE uses the same technology as LTE-A, it is possible that LAA-LTE also supports different bandwidths. While most Wi-Fi nodes use bandwidth of 20MHz, possible bandwidths of LAA-LTE can be 1.4/3/5/10/15/20MHz. The bandwidth change can affect the crosstalk interference. Thus, we would like to explore how LAA-LTE interference with different bandwidth affects Wi-Fi performance.

2) *LAA-LTE center frequency*: Since LAA-LTE supports smaller bandwidth than Wi-Fi, it is possible for an LAA-LTE channel to use different center frequencies and overlap with different portion of a Wi-Fi channel. Since different subcarriers in a Wi-Fi channel has different functionalities (some with pilot signals, and no signal is transmitted on the center carrier [11]), overlapping with different portion of the channel can have different effects. Thus, we would like to know how Wi-Fi performance changes when different portions of its channel overlaps with an LAA-LTE channel.

3) *CCA threshold*: In Wi-Fi networks, nodes perform clear channel assessment (CCA) before transmissions. If CCA indicates channel busy, nodes do not transmit. It is possible for LAA-LTE interference to trigger channel busy indication during CCA and make Wi-Fi nodes not transmit, which causes throughput degradation. Thus, we would like to explore how LAA-LTE interference impacts Wi-Fi CCA under different situations.



(a) 802.11a throughput vs. LAA-LTE bandwidth



(b) 802.11n throughput vs. LAA-LTE bandwidth

Fig. 2: LAA-LTE bandwidths impact on Wi-Fi throughput

4) *Wi-Fi MIMO*: Since MIMO has become an important element in Wi-Fi network, it is important to understand how LAA-LTE interference affects MIMO transmissions of Wi-Fi. Since LAA-LTE is a competitive technology with relatively large bandwidth and power, the impact can be much severe compared to other unlicensed technologies. Thus, we would like to examine the impact of LAA-LTE on Wi-Fi with and without MIMO.

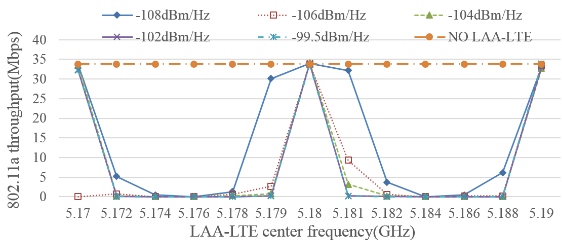
5) *Distance and Obstacles*: Distance between two networks changes the impact of interference. In open space, the interference effect decreases as distance increases. However, this property does not always hold in indoor environment due to heavy multipath fading. Other than distance, existence of obstacles can also change the signal propagation and interference condition. Thus, we study the impact of distance and existence of obstacles between LAA-LTE and Wi-Fi networks on Wi-Fi performance.

IV. EVALUATION RESULTS AND INSIGHTS

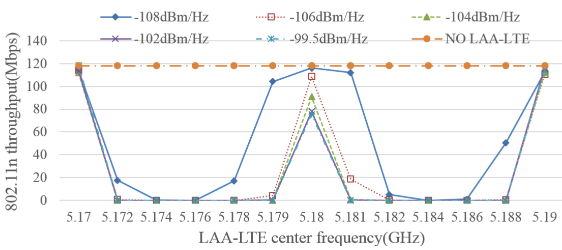
In this section, we present results of the five experiments described in Section III-C. The experiment configurations are presented in Section III-B. Each experiment is performed for a duration of 20s and repeated 3 times.

A. LAA-LTE bandwidth

Since it is possible for LAA-LTE to support different bandwidths, we investigate the impact of LAA-LTE bandwidth on Wi-Fi performance. In this experiment, we set up an LAA-LTE transmission using the same center frequency as a Wi-Fi transmission, and change the bandwidth of the LAA-LTE transmission. Fig. 2 (a) and (b) show the Wi-Fi throughput vs. LAA-LTE bandwidth when the Wi-Fi transmission operates 802.11a and 802.11n respectively with different LAA-LTE transmission PSD.



(a) 802.11a throughput vs. LAA-LTE center frequency



(b) 802.11n throughput vs. LAA-LTE center frequency

Fig. 3: LAA-LTE center frequency impact on Wi-Fi throughput

Results in Fig. 2 indicate that different LAA-LTE bandwidths have different impacts on Wi-Fi throughput. *Surprisingly, the impact is NOT proportional to LAA-LTE bandwidth.* There is almost no impact when the bandwidth is 1.4MHz. When the bandwidth is 15/20MHz, Wi-Fi throughput gradually decreases as LAA-LTE transmission PSD increases. When the bandwidth is 3/5/10MHz, the impact is surprisingly much larger than that of 15/20MHz. When the LAA-LTE transmission PSD grows to -102dBm/Hz, there is almost no throughput for 3/5MHz.

The unexpected degradation of Wi-Fi throughput when the interfering LAA-LTE bandwidth is 3/5/10MHz (especially 3/5MHz) is consistently observed in all the experiments. Later in the 3rd experiment, Wi-Fi CCA, we will be able to see more insights into this phenomenon with help from an instrumented WARP platform.

Comparing Fig. 2(a) and 2(b), one can observe that the throughput of 802.11a and 802.11n have a similar trend, and LAA-LTE interference has larger impact on 802.11n. A more detailed evaluation of the difference in impact between 802.11a and 802.11n will be presented later in the 4th experiment, Wi-Fi MIMO.

We conclude results from this experiment with the following insight:

> *Wi-Fi throughput can be heavily degraded by LAA-LTE transmissions with 3/5/10MHz bandwidth (especially 3/5MHz)*

B. LAA-LTE center frequency

Since different sub-carriers in a Wi-Fi channel have different functionalities (some with pilot signals, and no signal is transmitted on the center carrier [11]), we investigate the impact of an LAA-LTE channel overlapping with different portions of a Wi-Fi channel. In this experiment, we set up an LAA-LTE transmission with 1.4MHz (we use the smallest bandwidth for the best resolution) and change its center frequency to overlap with different channel portion of a Wi-Fi transmission. The LAA-LTE center frequency is varied from 5.17 to 5.19GHz and the Wi-Fi channel is located in 5.17∼5.19GHz. The measured Wi-Fi throughput vs. LAA-LTE center frequency is shown in Fig. 3(a) and 3(b) when the Wi-Fi transmission operates 802.11a and 802.11n respectively with different LAA-LTE transmission PSD.

Results in Fig. 3 indicate that overlapping in different channel portion does have different impact on Wi-Fi throughput. There is almost no impact when the 1.4MHz LAA-LTE channel is located in the guard band of the Wi-Fi channel. The impact is much smaller when the LAA-LTE channel is located in the center frequency of the Wi-Fi channel, where no Wi-Fi signal is transmitted ([11]), compared to that of other channel portions. The Wi-Fi throughput is almost zero when the LAA-LTE channel allocates around middle part of each sideband (5.174∼5.176GHz, and 5.184∼5.186GHz), even when the transmission PSD of LAA-LTE is relatively small (-108dBm/Hz).

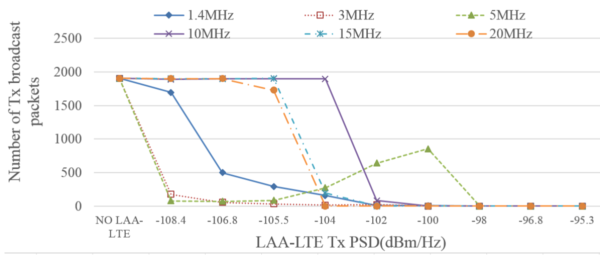
Again, comparing Fig. 3(a) and 3(b), similar trend of the throughput of 802.11a and 802.11n can be observed.

We conclude results from this experiment with the following insight:

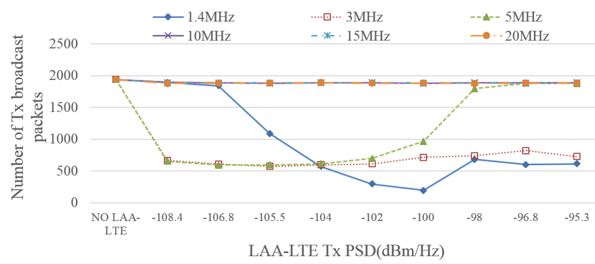
> *LAA-LTE transmissions can have small impact on Wi-Fi throughput when using a 1.4MHz channel with center frequencies located on the guard bands or the center frequencies of Wi-Fi channels.*

C. Wi-Fi CCA

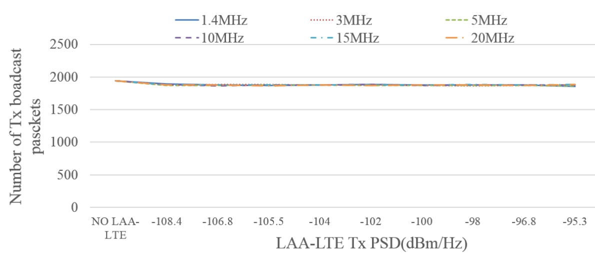
To figure out the cause of throughput degradation in the previous two experiments, we investigate the impact of LAA-LTE bandwidth on Wi-Fi CCA. CCA indicates channel busy in the following two conditions: 1) Carrier Sense/CCA (CS/CCA): the PHY layer detects a Wi-Fi preamble successfully; 2) CCA threshold: the PHY layer detects signal power above a predefined CCA threshold [11]. In this experiment, we set up an LAA-LTE transmission using the same center frequency as a Wi-Fi transmission, and change the bandwidth of the LAA-LTE transmission. Two WARP v3 nodes carry out the Wi-Fi transmissions. In order to prevent the ACK timeout from increasing the backoff contention window (CW), we make the Wi-Fi Tx transmit broadcast packets, which does not trigger ACK transmissions. The application layer of the Wi-Fi Tx sends down to the MAC layer 100 broadcast packets per second with packet size of 168Bytes. The total number of packets transmitted by the PHY layer of Wi-Fi vs. LAA-LTE transmission PSD is shown in Fig. 4 with different LAA-LTE bandwidth. Fig. 4(a), 4(b), and 4(c) shows the results when Wi-Fi CCA works normally, when the CCA threshold (-62dBm) is disabled (only CS/CCA is functioning), and when CCA is totally disabled respectively.



(a) Number of transmitted broadcast packets vs. LAA-LTE Tx PSD (CCA works normally)

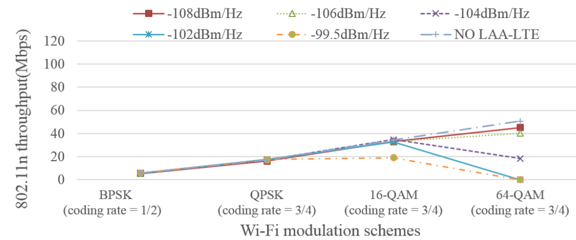


(b) Number of transmitted broadcast packets vs. LAA-LTE Tx PSD (Only CS/CCA is functioning)

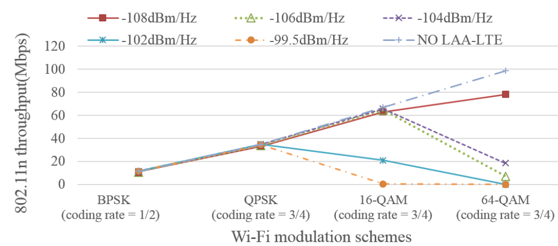


(c) Number of transmitted broadcast packet vs. LAA-LTE Tx PSD when CCA is totally disabled

Fig. 4: LAA-LTE impact on Wi-Fi CCA



(a) 802.11n throughput vs. MCSs without MIMO



(b) 802.11n throughput vs. MCSs with MIMO

Fig. 5: LAA-LTE impact on Wi-Fi MIMO

Results in Fig. 4(a) indicate that different LAA-LTE bandwidths have different impacts on Wi-Fi CCA. The impact is severe when LAA-LTE bandwidth is small, such as 1.4/3/5MHz. This indicates that the LAA-LTE interference impact on Wi-Fi CCA is an essential cause of the throughput degradation in previous experiments.

Comparing Fig. 4(a) and 4(b), one can clearly observe that the LAA-LTE interference impacts on Wi-Fi CS/CCA. Theoretically, LAA-LTE interference should not trigger channel busy indication when only CS/CCA is functioning. In Fig. 4(b), when the LAA-LTE bandwidth is 10/15/20MHz, the channel busy indication is not triggered, and the number of transmission keeps the same; we can infer that the decrease in Fig. 4(a) when the LAA-LTE Tx PSD is around -103dBm/Hz is caused by CCA threshold. However, surprisingly, the number of transmitted packets decreases severely when the LAA-LTE bandwidth is 1.4/3/5MHz in Fig. 4(b). When the bandwidth is 5MHz, this anomalous condition occurs only when the LAA-LTE Tx PSD is smaller than -98dBm/Hz; and we can infer that the second decrease of 5MHz bandwidth in Fig. 4(a) around -98dBm/Hz is due to CCA threshold. The anomalous situation when the LAA-LTE bandwidth is 1.4/3/5MHz indicates that LAA-LTE can trigger CS/CCA of Wi-Fi and cause throughput degradation. However, since WARP implements cross-correlation in CS/CCA for preamble detection, the probability of false alarm is expected to be very small. Currently, we cannot explain this specific anomaly and our ongoing work is exploring potential reasons.

In Fig. 4(c), when CCA is totally disabled, LAA-LTE interference cannot impact the transmission of Wi-Fi, and thus the number of transmitted packets remains the same. Comparing Fig. 4(b) and 4(c), we can further confirm that the impact on the number of transmitted packets in Fig. 4(b) is caused by CS/CCA.

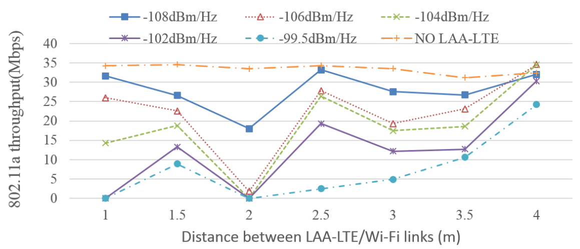
We conclude results from this experiment with the following insight:

> *LAA-LTE transmissions with 1.4/3/5MHz bandwidth can trigger Wi-Fi CS/CCA and thus heavily impact Wi-Fi performance.*

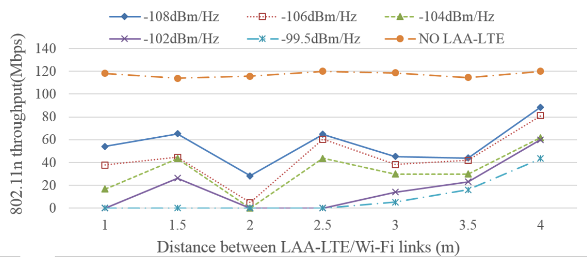
D. *Wi-Fi MIMO*

Since MIMO has become an essential element of Wi-Fi standards, we examine the impact of LAA-LTE interference on MIMO transmissions of Wi-Fi nodes. In this experiment, Cisco-Linksys WRT320N routers are used as Wi-Fi nodes. We set up a LAA-LTE transmission using the same center frequency and bandwidth as a Wi-Fi transmission, and change the modulation and coding schemes (MCSs) of the Wi-Fi transmission. Fig. 5(a) and 5(b) shows Wi-Fi throughput vs. Wi-Fi MCSs when the Wi-Fi transmission operates without and with MIMO respectively with different LAA-LTE transmission PSD.

As shown in Fig. 5 (a) and (b), Wi-Fi throughput degrades faster for higher modulation rates as the LAA-LTE interference

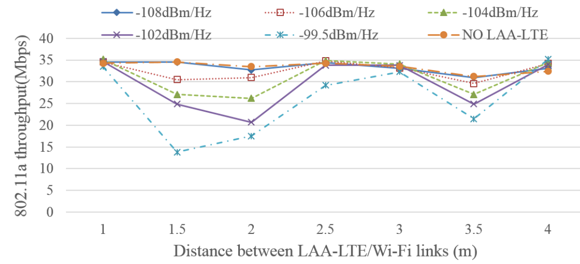


(a) 802.11a throughput vs. distance

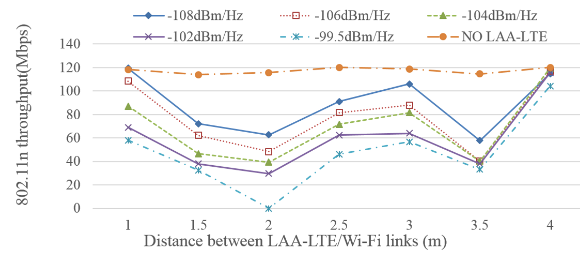


(b) 802.11n throughput vs. distance

Fig. 6: Impact of distance between LAA-LTE and Wi-Fi



(a) 802.11a throughput vs. distance with obstacle



(b) 802.11n throughput vs. distance with obstacle

Fig. 7: Impact of a obstacle between LAA-LTE and Wi-Fi

power increases. This indicates that higher modulation rates are more sensitive to interference.

Comparing the results in Fig. 5(a) and 5(b), one can observe that 802.11n throughput with MIMO is even lower than the throughput without MIMO when the LAA-LTE interference power is high and the modulation rate is high. This implies that MIMO is more vulnerable to interference, and may degrade the performance of Wi-Fi when interference is strong. Although this throughput degradation can also be caused by other unlicensed wireless transmission (e.g. 802.15), LAA-LTE has relatively large bandwidth and transmission power, which makes it easier to cause severe impact to MIMO transmissions of Wi-Fi.

We conclude results from this experiment with the following insight:

Wi-Fi with MIMO can perform worse than Wi-Fi without MIMO when LAA-LTE interference is strong.

E. Distance and Obstacles

Distance and obstacles between two networks changes the impact of interference. In this experiment, we set up an LAA-LTE transmission using the same center frequency and bandwidth as a Wi-Fi transmission, and move the Wi-Fi link to change the distance between the LAA-LTE and the Wi-Fi link. The distance is varied between 1m to 4m in step of 0.5m. Figure 6(a) and 6(b) shows the Wi-Fi throughput vs. distance for 802.11a and 802.11n respectively. To test the effect of obstacles, a 1.07x0.57x1.04m^3 metal desk is placed in the line of sight (LOS) of the 2 links. The Wi-Fi throughput with the obstacle vs. distance is shown in Fig. 7(a) and 7(b) for 802.11a and 802.11n respectively.

As shown in Fig. 6 and Fig. 7, Wi-Fi throughput is not inversely proportional to the distance between the LAA-LTE and the Wi-Fi link. This is due to heavy multipath fading in indoor environment. Even when there is no interference from LAA-LTE, Wi-Fi throughput slightly changes with distance due to different multipath condition in different location.

Comparing Fig. 6(a) and 7(a) or Fig. 6(b) and 7(b) respectively, one can observe that as LOS between LAA-LTE and Wi-Fi is blocked by obstacles, throughput of Wi-Fi increases.

We conclude results from this experiment with the following insight:

Increasing distance between LAA-LTE and Wi-Fi links does not necessarily decrease the impact of interference in indoor environment. On the other hand, blocking LOS between LAA-LTE and Wi-Fi links can effectively help decrease the impact of interference.

V. PERSPECTIVES ON LAA-LTE MAC DESIGN

Since the medium access control (MAC) protocol for LAA-LTE is still under development, we present below a few perspectives based on our experimental results that could guide the design of the MAC protocol: 1) In the *LAA-LTE bandwidth* experiment, we concluded that LAA-LTE with smaller bandwidths can cause severe performance degradation of Wi-Fi. Special care is thus required when simulating the coexisting channel model and designing mechanisms for channel/bandwidth selection. 2) As shown in the *LAA-LTE center frequency* experiment, LAA-LTE with a 1.4MHz bandwidth does not have a big impact on Wi-Fi transmissions when the center frequency is set to the center or guard bands of Wi-Fi channels. This observation can be utilized for the design of coexisting mechanisms. 3) Indicated by the *Wi-Fi CCA* experiment, Wi-Fi nodes may interpret LAA-LTE signals as Wi-Fi signals and become too conservative when contending for transmission. When designing LAA-LTE MAC, this situation needs to be considered, so that LAA-LTE and Wi-Fi networks can fairly share the unlicensed band.

VI. CONCLUSIONS

In this paper, we have conducted the experimental evaluation to study the impact of LAA-LTE interference on Wi-Fi performance in indoor office environments. We study how Wi-Fi performance is impacted by LAA-LTE interference in five different scenarios and provide analysis and insights. Based on the analysis and insights, we also provide perspectives for LAA-LTE MAC designs to deal with coexistence issues between LAA-LTE and Wi-Fi networks. Based on the experimental observations, we get two surprising results: 1) Small bandwidth of LAA-LTE(1.4/3/5/10MHz) has large impact on Wi-Fi performance. 2) LAA-LTE signals with LAA-LTE can trigger channel busy indication of CS/CCA in Wi-Fi. We will explore potential reasons of these anomaly as future works.

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