INFORMATION
Volume 20, Number 2(A), pp.827-836

ISSN 1343-4500 eISSN 1344-8994

Impact of Contention based LAA on Wi-Fi Network.

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Abstract

Exponential increase in wireless data demands and limited nature of licensed spectrum for cellular network has motivated the consideration of unlicensed bands for LTE operation, which is referred as Licensed-Assisted Access (LAA). However, unlicensed bands are also occupied by Wireless Local Area Networks (WLAN), specifically IEEE 802.11a/n/ac technologies. Hence, ensuring fair co-existence between LAA and Wi-Fi networks is a main challenge. As the solution, Listen-before-talk (LBT) has been consider by 3rd Generation Partnership Project (3GPP) as one of the fair coexistence mechanisms for LAA. Hence, in this paper, we explore the LBT mechanism and its challenges to the performance of Wi-Fi network. Firstly, we allow LTE to use unlicensed spectrum to study the coexistence with incumbent system with and without LBT scheme. After that, we discuss on the design parameter of LBT LAA system and provide insights into the impact of LBT LAA Contention Window (CW) parameters on the performance and fairness of 802.11n network. Lastly, we suggest the consideration of 802.11-like access parameters and rules to maximize the probability of coexistence.

Key Words: Contention window, Listen before talk, Licensed Assisted Access, Unlicensed spectrum.

1. Introduction

Due to rapid evolution of wireless devices and mobile applications in smartphones, the mobile data usage has grown by 70%-200% per annum [1]. These growth in data usage are not only limited to demand for higher data rates but also for better Quality of Experience (QoE). Hence, to meet such higher data demands and QoE the most common approaches available for operators are densification of small cell networks and improvement of spectrum efficiency, as licensed spectrum is limited and costly. For mobile operators, efficient spectrum utilization is the most essential resource in this pursuit as it offers a significant extension of resources at lower operational costs. Motivated by this, Qualcomm has proposed extending the LTE network operation to the unlicensed frequency bands (LTE-U) [2], namely the 5 GHz band, which is particularly target downlink data traffic and the control traffic is kept in the licensed band for reliability reasons. Following this proposal, 3GPP has already begun initial work towards standardizing LTE Licensed-Assisted Access (LAA) [3], where the 5 GHz (5150-5925 MHz) unlicensed band is used for increasing downlink data rates.

However, due to legacy WLAN (IEEE 802.11a/n/ac) operating in the same spectrum, some issues need to be considered to enable different networks to work in common shared spectrum. One important issue is coordination and interference management between different systems [4]. Wi-Fi uses a Carrier Sense Multiple Access (CSMA) procedure to allow multiple Wi-Fi systems to coexist, while LTE uses continuous traffic generation with minimum time gaps even in the absence of mobile data traffic. From this operational structure in both the networks, Wi-Fi is likely to have minimal chances to access the medium than LTE in coexistence scenario, resulting 70% to 100% performance degradation for Wi-Fi.

Early studies [4 – 10] investigate basic coexistence problems between Wi-Fi and LTE triggered by the dissimilarity in their MAC designs, and develop potential strategies to assist the coexistence. So far, the proposed model was mainly based on Wi-Fi MAC resistance to the LTE always "ON" model, operating in same channel. It includes Discontinuous Transmission [8], Random Back-off [7], Carrier Sensing [8], Clean Channel selection [5] etc. In order to provide single global solution framework allowing compliance with any regional regulatory requirements, LBT is considered to be one of the imperative functionalities required for fair and friendly coexistence in LAA networks [3]. The effectiveness of LBT is evaluated in [4, 6, 9, 10] together with static muting and other sensing based schemes. By analyzing those mechanism, it shows that using such channel sensing schemes achieves a balance between the LAA and Wi-Fi systems. To our best knowledge, there is little literature focusing on the impact of CW parameters on the performance and fairness of coexisting networks. Hence, the main contribution of this work are summarized as follows:

- We provide overview of LBT mechanism and point out difference between LBT (Wi-Fi like access) from Wi-Fi DCF access mechanism.
- We implement the LBT mechanism and show that LBT LAA is viable technology in unlicensed band with much higher throughput performance than existing Wi-Fi solutions.
- We compare the effect of CW parameter for best effort traffic on LBT LAA network and show that LBT LAA is unfair with Wi-Fi in terms of opportunity to access the channel.
- Through simulation, we show that adjustment of CW parameter in LAA helps to maximize the probability of coexistence.

2. LBT Background

The concept of LTE in unlicensed spectrum was first addressed with a focus on LTE usage in TV white spaces at 900 MHz in 2011[11]. Afterwards, several works have been evaluated on the impact of LTE operating in the unlicensed bands and the possible effect of interference in existing unlicensed technologies [3, 5, 11].Then, several approaches [4 -10] that solve the coexistence problems of LTE and Wi-Fi networks have been suggested. Among all, Carrier Sensing and Adaptive Transmission (CSAT) [12] and LBT are two main LTE mechanisms under consideration for ensuring fair co-existence with Wi-Fi. LBT uses carrier sensing and back off rules similar to Wi-Fi whereas CSAT schedules transmissions according to a desired duty-cycle. CSAT mainly targets early deployments and the US market, while LBT is a longer term proposal which required modifications to the LTE specifications but is necessary to meet regulations in Europe and Japan. According to research [12], CSAT is regarded as being more aggressive and less fair than LBT. Hence, LBT is the hot topic for research.

LBT is the carrier sensing mechanism for LTE devices which is used to check the idleness of the channel during the competitions with other LAA or Wi-Fi access schemes. LBT uses energy detection or preamble detection to determine the presence or absence of other signals in a channel which is referred as Clear Channel Assessment (CCA) [7]. There are mainly two categories of LBT mechanism, Frame Based Equipment (FBE) and Load Base Equipment (LBE) [10]. For FBE schemes, the transmission time is fixed (Fixed Frame Period) and it ranges from 1 to 10 *ms*. Fixed Frame Period consists of Channel Occupancy Time and Idle Period as depicted in Figure 1. Before starting transmissions on the medium, the transmitter performs a CCA check towards the end of the Idle Period. If the medium is considered to be free during the CCA slot of at least 20 μs, the transmitter continuously occupy the medium during the next Channel Occupancy Time with a maximum time. Otherwise, there will be no transmission during that fixed frame period. Similar to FBE scheme, LBE transmitter first perform a CCA check before a burst of transmission on the medium. If the medium is found out to be idle during CCA slot (≥ 20 μs), the channel is occupied by the transmitter immediately else an Extended CCA (ECCA) check is performed. In an ECCA, the operating channel is observed for the duration of a random factor N multiplied by the CCA observation

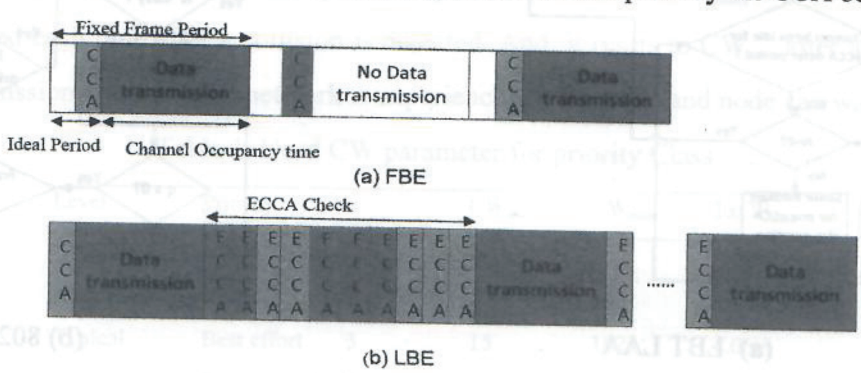


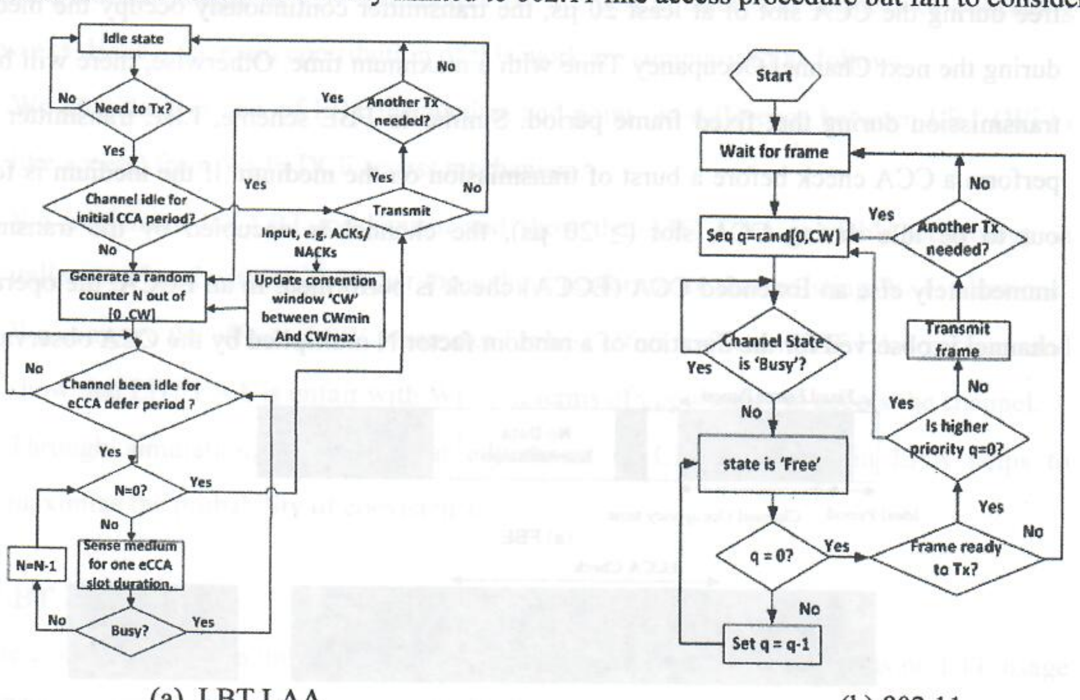
Fig. 1. FBE and LBE based channel sensing mechanism

time. The value of back-off counter N is randomly generated for each ECCA check in the range of 1 to CW, where CW is selected in the range of 4 to 32[4, 10]. The counter N is decremented every time a CCA slot is considered to be unoccupied and transmits when the counter reaches zero with a maximum time of 13/32 × CW *ms*.

LBE take advantage over FBE through channel access opportunity especially in high load scenario. The transmitter can continuously detect the channel if one CCA/ECCA slot fails to capture the channel instead of waiting for a long fixed frame period like FBE does. Additionally, another challenge for FBE-based LBT during channel access is collision. Since the duration of CCA is the same for FBE based schemes, FBE equipment's may find the free channel at the same time if they are synchronized and this leads to the high probability of collisions, as the equipment transmits simultaneously. On the other hand, if equipment's are asynchronous, some of them get definitive access to the channel while others are completely blocked. Therefore, LBE based LBT schemes is preferred over FBE schemes for coexistence scenario and hence we consider only LBE LBT in this paper.

3. Difference between LBT LTE and DCF 802.11 channel access mechanism

LBT mechanism has been recognized as 802.11 like access mechanism for LAA since LBT users contend for shared spectrum. Similar to the 802.11 DCF mechanism, LBT data transmission is followed by carrier sensing and back off on vacant spectrum. However, LBT mechanism consideration are only limited to 802.11 like access procedure but fail to consider



(a) LBT LAA (b) 802.11

Fig. 2. Conceptual flow chart of LBT LAA and 802.11

802.11 like parameters and rules to maximize the probability of coexistence. Figure 2 depicts the conceptual flow diagram of channel access mechanism for LBT LAA and 802.11.This diagram is not intended as details specification but rather a statement of principle. The flow diagram shows that LBT and 802.11 are similar but sufficiently different.

- In 802.11, Quality of service (QoS) is enabled by using Enhanced Distributed Channel Access (EDCA) [13] via four access priority i.e. voice, video, best effort and background. Each priority level is defined by tuple of minimum value of CW (CW_{min}), maximum value of CW (CW_{max}), defer period, Transmit Operation Maximum (TxOP) which are shown in Table 1. However, LBT is unable to guarantee the service fairness of different types of traffic because LBT lacks QoS consideration for LAA which is due to multiple nodes experiencing different situations. With fixed CW size and maximum channel occupancy time of different nodes, these nodes have the same transmission opportunity regardless their traffic demand and channel condition.
- In each technology, the back off procedure is driven by the contention window (CW) parameter which take the values between CW_{min} and CW_{max}. A back off procedure operates by choosing random number N between 0 and CW. A back off procedure will implicitly countdown only while the medium is free and allowed to transmit reaching zero. In LBT, its CW values range between 4 and 32 [4, 10] which is much lesser compare to Wi-Fi whose range is between 3 and 1023 [5]. The difference in range of LBT back off counter offers LBT to choose lesser N values every time regardless of any Wi-Fi data priority level. Hence, this helps in giving higher priority transmission to LBT LAA contributing unfairness for Wi-Fi. Moreover, in case of dense deployment, this small range of CW values in LBT contributes for collision because many LBT clients will be forced to choose the same CW values for back off process.
- Based on the successful & unsuccessful transmission of frames, LBT LAA and 802.11 adjusts CW values independently. Initially, CW is reset to CW_{min}, and CW_{max}. CW is doubled each time after a collision is detected. And, it resets to CW_{min} after a successful transmission assuming the network is experiencing a low load and node can wait shorter.

Table 1. Used CW parameter for priority Class

Level	Priority	n	CW_{min}	CW_{max}	$TxOP_{max}$
Highest	Voice	2	3	7	1.5ms
Next Highest	Video	2	7	15	3.0ms
Typical	Best effort	3	15	1023	4.0ms
Lowest	Background	7	15	1023	4.0ms

Table 2. Simulation Parameters

Parameters	LAA Value	Wi-Fi value
Technology	LTE-A	802.11n
Frequency	5GHz	5GHz
Bandwidth	20MHz	20MHz
TX power	23dBm	23dBm
Traffic model	UDP 12 mbps	UDP 12 mbps
Access mechanism	LBE	DCF
Traffic	Full buffer	Full buffer
CCA-ED	-62dBm	-62dBm
CCA-slot length	9 µs	9 µs
Frame duration	10ms	10ms
Back off window	4 - 32	15 - 1023
Simulation time	10 sec	10sec

time in order to send a packet. However, in real environments, these assumptions are not always true. The successful transmission of a packet does not necessarily mean the network is not congested. Therefore, resetting CW to CW_{min} may cause more collisions leading a delay, higher jitter and waste of bandwidth. And, in heavy load networks, this continuous transmission opportunity of LTE can lead Wi-Fi towards bandwidth starvation.

4. Simulation Setups and Results

The performance of LTE in unlicensed band and its impact on Wi-Fi has been evaluated in Ns3 system simulator. We assumed a single cell scenario for both the LAA evolved node B (eNB) and the Wi-Fi Access Point (AP), which are collocated within 5 meters for separation with same coverage. Both LTE and WLAN systems share 20 MHz frequency band at 5.8 GHz. According to the 3GPP standard for LAA, we use Supplement Download Link (SDL) transmission for our experiment. The licensed band of the LTE system is not simulated and, thus, all the offered traffic goes through unlicensed band. In simulation, we deploy equal number of UEs for both LAA and Wi-Fi operators. We used the parameters defined in Table 2 for LAA and Wi-Fi in our simulation. The simulation was run for least 10 seconds with 12 Mbps of UDP data of data transfer for each UEs in both the networks. For analysis purpose, we assume full buffer mode for both LAA and Wi-Fi networks (contributing for larger latency time). The average User Perceived Throughput (UPT), Transmission Latency and Jitter are consider as performance metrics for analysis. We perform three types of simulation analysis which are discussed below.

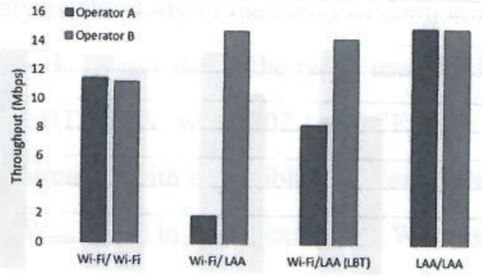


Fig. 3. Throughput per user

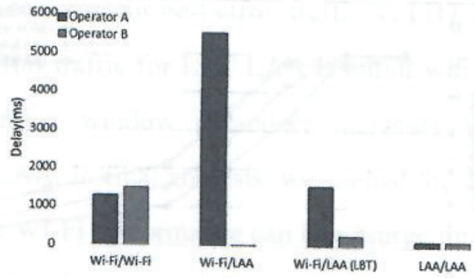


Fig. 4. Delay per user

Our first analysis presented in Figure 3 and 4 shows that LAA performance is about 100% better compared to Wi-Fi performance due to its better spectral efficiency, multi-user scheduling diversity, and spatial diversity gains. We have compared the throughput and delay per user between two operators' viz. operator A and operator B with different settings. As we can see by using LBT LAA, we can improve the Wi-Fi performance by 50% of increased throughput and 83% of reduced latency with very negligible performance degradation for LAA network. Hence, LBT LAA is viable technology in unlicensed band. Additionally, the analysis of both operator in a network using same technology (LBT LAA only or Wi-Fi only) shows overlapping LBT LAA achieves best utilization of channel than Wi-Fi since it achieve highest throughput(93%) performance with less delay than existing other network configuration.

In second analysis, we compare the effect of contention window size for best effort traffic on LBT LAA network as shown in Figure 5(a), 5(b) and 5(c). In simulation, scheme A uses default parameters of contention window for LBT LAA and Wi-Fi networks whereas in scheme B uses 802.11 like contention window parameter 15 to 1023 was used for both operators. The results show that in coexistence LBT LAA is unfair with Wi-Fi as we can see scheme A Wi-Fi experiences least throughput with larger delay and jitter. This is because as explain in Section 3 the difference in range of LBT back off counter offers LBT to choose lesser N values every time giving higher priority to access the channel to LBT LAA. Hence, we modify LBT LAA with 802.11 like contention window parameter in scheme B. Results show that the performance of Wi-Fi is better with increased in throughput by 24% and with reduction in delay by 14% .The jitter was also decrease by 14.5%. And, this was obtain with degradation in throughput in LAA scheme B by only 9% with negligible delay and jitter.

Finally, the effect of reduction of resetting value of CW_{min} after a successful transmission in fair coexistence is studied as discussed in Section 3. We choose different values for CW size reduction after the successful transmission of packets. For this experiment, we increase the CW_{min} by quarterly until CW_{max} i.e. scheme 1 is (default) resetting CW to its minimum size.

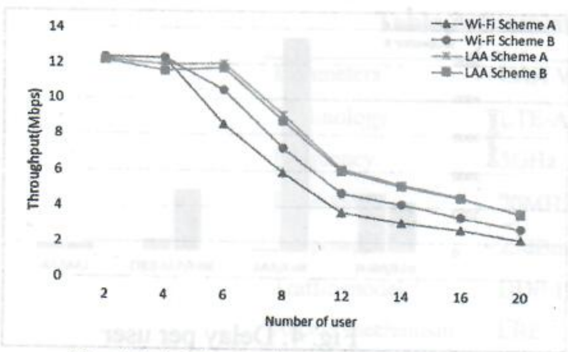


Fig. 5(a). Throughput per user

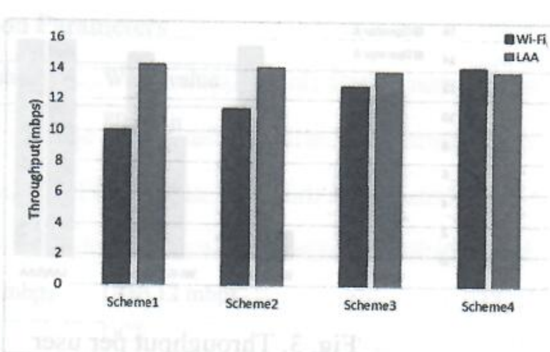


Fig. 6(a). Throughput per user

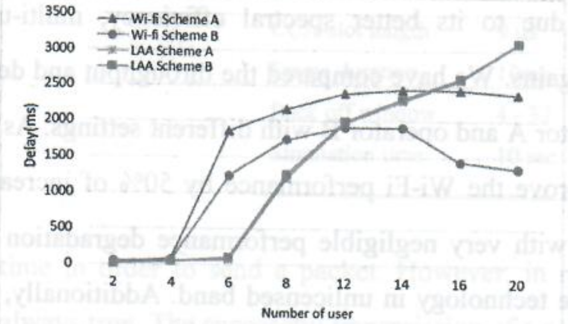


Fig. 5(b). Delay per user

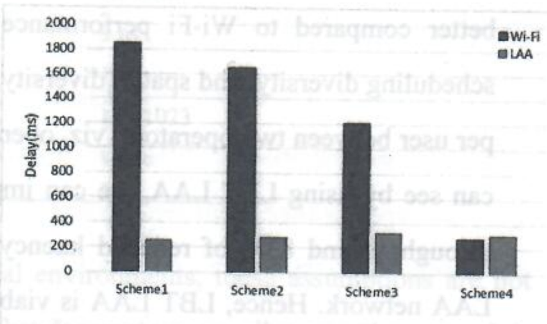


Fig. 6(b). Delay per user

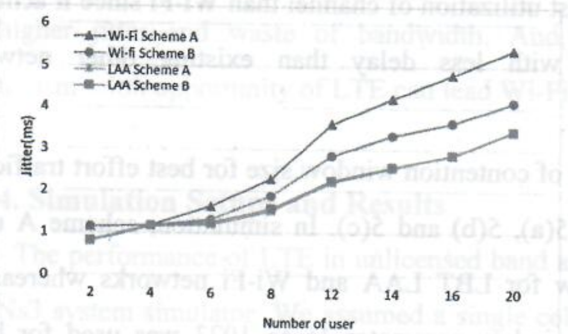


Fig. 5(c). Jitter per user

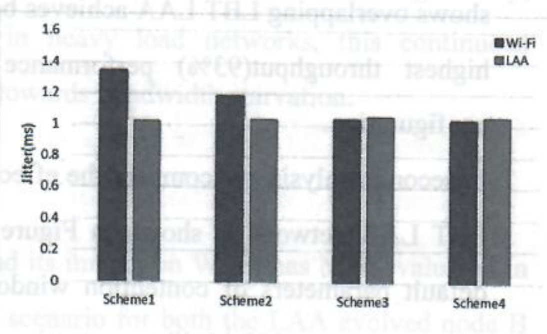


Fig. 6(c). Jitter per user

In scheme 2, CW is set to $CW_{min} + 0.25(CW_{max})$. Scheme 3 sets CW to $CW_{min} + 0.5\ CW_{max}$ and scheme 4 sets CW to $CW_{min} + 0.75CW_{max}$. Hence, from analysis Figure 6(a), 6(b) and 6(c), we found that Wi-Fi performance can be increase as resetting value of LAA upsurge. This is because the high priority LTE operator will not be able to continuously capture the channel hence it leaves enough space for Wi-Fi for carrier sensing. Additionally, reduce jitter benefits multimedia data transmission as resetting value moves towards higher values.

5. Conclusion

In this paper, we have studied the effect of CW size on the performance and fairness of LBT LAA network. Our first analysis shows that LBT LAA is viable technology in unlicensed band with much higher throughput performance than existing Wi-Fi solutions. In second analysis, the study of the effect of contention window size for best effort traffic on LBT LAA network. Result shows the range used for best effort traffic for LBT LAA is unfair with Wi-Fi. LBT LAA with 802.11 DCF like contention window parameter increases Wi-Fi performance with negligible delay and jitter for LAA. In final analysis, we studied the effect of CW_{min} value in fair coexistence. We found that Wi-Fi performance can be upsurge through higher resetting value of LAA and also reduce jitter benefits multimedia data transmission. From this study, we have concluded that the rules and parameter of CW of LBT LAA has trivial effect on performance and fairness of the coexisting network thus it should be chosen carefully.

6. Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2015R1D1A1A01058751).

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