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Performance Evaluation of Changing Energy Detection Threshold on Wi-Fi and LTE-LAA Coexistence Networks

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ABSTRACT

The demand on cellular and Wi-Fi infrastructure has increased exponentially along with the number of mobile devices in use today, thus requiring that both licensed (cellular) and unlicensed (Wi-Fi) spectrum be utilized as efficiently as possible. Licensed-Assisted Access (LAA) based unlicensed spectrum LTE service is seen as an alternative to improve the capability of 4G/5G wireless networks. This approach helps eNodeB to compete with other nodes by using the shared medium and using both licensed and unlicensed bands via carrier aggregation to provide best-effort services. Nevertheless, in order to minimise or prevent performance degradation issues, the hidden node issue over shared medium access networks is a challenge that must be tackled. The performance evaluation of an energy detector is described in this study, which takes into account the energy detection technique for spectrum sensing. The main objective of this research is to develop an energy detection sensing for LTE-LAA and Wi-Fi coexistence networks. The study will proceed with identifying the parameters used such as signal to noise ratio (SNR), energy detection threshold and energy detection probability for energy detection threshold following by derivation of mathematical equation for energy detection threshold. Next, the development of analytical framework for threshold of energy detection in Wi-Fi and LTE-LAA coexistence networks will be developed using MATLAB software. According to our findings, the detection probability will be higher if the detection threshold is dynamically adjusted based on the noise level present during the detection process than it would be if a fixed threshold value were taken into account. The results that obtained from energy detection threshold can achieve fair coexistence between LTE-LAA users and Wi-Fi users and thus, successfully reduces the interference in both coexistence networks.

1. Introduction

Presently, to coexist LTE with Wi-Fi, Licensed Assisted Access (LAA) and LTE Unlicensed (LTE-U) are two conditions to allow it in the 5 GHz unlicensed band. It establishes LTE-LAA as a structured solution within the 3rd Generation Partnership Project (3GPP) and specifies a Listen-Before-Talk (LBT) system, like Wi-Fi [1]. Besides, Qualcomm was proposed the LTE-U and it does not implement LBT, but instead uses a duty-cycling technique along with the Carrier Sense Adaptive Transmission (CSAT)

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sharing channel mechanism that adapts the LTE-U duty cycle according to the Wi-Fi load on the channel [2]. As presently specified, for enhanced data, both LTE-LAA and LTE-U use carrier aggregation between a licensed and an unlicensed carrier for all uplink traffic and downlink throughput and is transmitted to the licensed carrier [3]. Finalization of 3GPP Release 13 have enhanced an interest in the co-existence of LTE-LAA and Wi-Fi that prompted significant industry-driven research. One of the previous works shows that transmission-implying LTE can be severely affected the Wi-Fi thus, archiving fair coexistence for some measure of LTE-LAA and Wi-Fi [4].

Licensed-Assisted Access (LAA) based unlicensed spectrum LTE service is seen as an alternative to improve the capability of 4G/5G wireless networks. This approach helps eNodeB to compete with other nodes by using the shared medium and using both licensed and unlicensed bands via carrier aggregation (CA) to provide best-effort services. Nevertheless, in order to minimize or prevent performance degradation issues, the hidden node issue over shared medium access networks is a challenge that must be tackled.

To minimize interference and ensure coexistence, LTE-LAA eNB attempt to choosing a channel not used by nearby Wi-Fi nodes or using a channel selection mechanism. In heavy traffic situations, the presence of high numbers of sensors in 5G networks would require the use of unlicensed bands when the restricted licensed band is unable to satisfy the demand for the service. The huge use of the free band for various operators would lead to an increase amount of interference from hidden nodes that LBT mechanisms cannot prevent. Hidden node occurs when node is visible to LTE-LAA evolved NodeB (eNB) or a Wi-Fi Access Point (AP) and it cannot hear transmission by other neighbouring nodes to eNB or AP, which resulting in a degraded network performance. Due to various thresholds of sensitivity, the hidden node issue is more serious in LTE-LAA and Wi-Fi coexistence, used to defend against various systems. As the distance between LTE-LAA BS and the Wi-Fi AP increases, both LTE-LAA and Wi-Fi will lead to hidden node problems when using a same energy detection threshold (-62 dBm) [2].

Within the context of LAA, few researchers consider hidden node problems [5]. Some of them proposed user offloading and channel selection mechanisms based on average values of CQI (CQIav) recorded by UEs. One of the researchers discussed the use of full-duplex radio (FDR) for channel reservation while the other proposed the used of an RTS/CTS approach that RTS/CTS signal last a short period. Furthermore, some researchers proposed power-based approach to raise the transmission power to UEs affected by hidden nodes based on Channel State Information (CSI). However, the proposed researches have their limitations such as for each unlicensed channel, the user needs to perform a CQIav measurement, radio resources waste due to neighbouring eNB is not permitted to transmit all the time during server eNB transmits, decreased the efficiency of communication and considerable overhead, and the channel might not be able to reach the other nearby nodes due to sense the exceeding power. Therefore, there is a need to have an optimum energy detection threshold for interference reduction by highlighting characteristic function of the energy detection decision variable in LTE-LAA and Wi-Fi coexistence networks. In this research, the main objective is to evaluate LTE-LAA and Wi-Fi energy detection threshold to obtain fair coexistence between the two networks. Calculation for energy detection threshold is used in this research. Simulations for probability of detection in energy detector performance are performed using MATLAB. The rest of the paper is organized into three different sections. Section 1.1 will further explain the related works on the coexistence performance between LTE-LAA and Wi-Fi. The research methodology will be presented in Section 2. Simulation results and discussion are explained in Section 3 and finally, a conclusion is drawn in Section 4.

1.1 Related Works

In the recent exponential growth of modern wireless communication, wireless technology advances are expected to satisfy the growing number of users that demands which need wireless communication access at high data rates. As a result, several researchers have been investigated around the world in order to address the needs of the users. This research approaches to investigate energy detection threshold in LTE-LAA and Wi-Fi coexistence networks. Wi-Fi and LTE-LAA in channel access mechanisms, challenges, privileges, coexistence problems, and, LTE and Wi-Fi coexistence features have studies in [6] and provided the LBT mechanism-based simulation for LTE-LAA and Wi-Fi to demonstrate that when the same unlicensed 5GHz channel was used, the LBT mechanism and LTE-LAA was friendly to the Wi-Fi networks. These two technologies, LBT channel access mechanism; a fair coexistence cannot be made by the LTE-LAA alone as obtained in the simulation results, and therefore, it needs further improvement. At first, the concept of fair coexistence of 3GPP was investigated using new analytical models thus, demonstrated situations when the fairness principle of 3GPP is achieved and, conversely, when not achieved, by tuning the LTE-LAA parameters. In order to contrast and compare these situations with the 3GPP description, the proportional fairness and formal concepts of access are then taken into consideration [7].

The effect of asymmetry energy detection threshold between the Wi-Fi (-62 dBm) and LTE-LAA (-72 dBm) coexistence are evaluated and developed a coexistence simulator in ns-3 and energy detection thresholds were varied for both Wi-Fi and LTE-LAA networks [2]. The results demonstrated that performance of Wi-Fi and LTE-LAA were improved by lowering the Wi-Fi energy detection threshold from -62 dBm. It can be concluded that an overlapping Wi-Fi with LTE-LAA would improve coexistence performance compared to LTE-LAA are assumed by Wi-Fi as noise. For LTE-LAA, in [1] focused on different architecture aspects of LBT systems that seek to equate the Wi-Fi contention-based scheme and provide fair channel access opportunities for both technologies while considered and analysed the different design factors affecting fairness across several main performance metrics. The simulation results illustrated that the proposed schemes can maintain good coexistence with Wi-Fi-LAA when LBT applied to LTE. To estimate the Wi-Fi and LTE-LAA throughput in coexistence scenarios, previous work [3] have developed a new framework and it is called as Bianchi model via suitable modifications. The various network impacts of parameters was examined as a by-product such as the energy detection threshold for the coexistence of Wi-Fi and LTE-LAA through the experimental testbed of the National Instrument and validating the results of LTE-LAA for priority level access 1 and 3. Next, the different LBT procedures for performance of unlicensed spectrum coexistence between Wi-Fi and cellular networks are analysed and Markov chain was modelled for a cellular base station behaviour and combined with Bianchi's Markov model that illustrated the Wi-Fi access point behaviour [4]. The proposed mathematical framework spotted the optimal cellular base station contention window size maximises the overall throughput for both networks and satisfies the necessary throughput for each network.

The focus in studies [8] is the LTE-LAA and Wi-Fi networks coexistence in 5GHz using traffic optimization and analysis of interference which are used selection channel schemes. By implement Monte Carlo method analysis tool, named "3DMCAT", the LBT protocol was implemented as a simulation domain in both the frequency domains and time on frame-based spatial, time, spectrum domain equipment. From the result, it can be concluded that the performance information that facilitated the analysis and reconfiguration of a high frequency bandwidth wireless system; in addition, 3DMCAT can also be used with any wireless system with a pre-defined configuration. The design factors of LBT schemes for LTE-LAA as a means of providing equal opportunity channel access in the presence of Wi-Fi were explore in previous work [9]. Thus, researchers [10] designed the MAC protocol for LTE-LAA for fair coexistence by optimized the transmission time for maximized the overall normalized channel rate contributed by both networks while protecting Wi-Fi. Wi-Fi energy tracking algorithm to identify the duration a dynamic ED threshold and Wi-Fi frame are proposed in previous work [11] while researchers [12] created a new analytical model for performance analysis of unlicensed LTE by fixed duty cycling of LTE in coexistence with Wi-Fi. The focus of paper [13] are maximum backoff stages, initial backoff window sizes, retry limits, transmission opportunities and sensing durations to obtain coexistence between both networks.

Therefore, a residential heterogeneous scenario and simulated 802.11n Wi-Fi traffic at various load (low, medium and high) and concurrent LAA and analyse the performance of MAC for LTE and comparative study to Wi-Fi thus, better efficiency of Wi-Fi channel access under high competition was obtain [14,15]. In addition to the various standard solutions that allow UE to discover neighbouring networks effectively, such as those proposed in [16,17] several researchers have put in significant effort to develop different approaches that enhance the network discovery process energy and time efficiency for the UE. These approaches are aimed at reducing the amount of energy and time the UE spends during the network discovery phase and have been proposed in studies such as in [18-20]. As a conclusion from all the mentioned papers, it shows that what have the previous researcher done, what have been achieved and what have not been done yet. Thus, a model that considers energy detection for handover process is mandatory for LTE-LAA and Wi-Fi networks keeping in mind the coexistence effect of each network performance and perceived quality of service.

2. Methodology

Hidden nodes happen in a CSMA-based Wi-Fi network when a node is visible to an AP but its transmissions to the AP cannot be heard by other nearby nodes. The hidden node problem is particularly severe in LTE-/Wi-Fi coexistence because multiple sensitivity levels (-62 dBm, -72 dBm) are employed to guard against various systems. Wi-Fi employs -82 dBm to safeguard other Wi-Fi users and -62 dBm to safeguard all other spectrum users (including LTE-LAA and LTEU). While the most recent LTE-U specification employs -62 dBm as the protection level against Wi-Fi, LTE-LAA has specified -72 dBm as the energy detection threshold to be utilized to safeguard Wi-Fi. An analytical framework for Wi-Fi and LTE-LAA coexistence is shown in Figure 1. Consider a deployment where an IEEE 802.11 Wi-Fi network and an LTE-LAA network that supports LBT coexist in part and share a 20 MHz channel. When a node is visible to an LTE-LAA evolved NodeB (eNB) or Wi-Fi Access Point (AP) but unable to hear transmission from nearby nodes to the eNB or AP, it is said to be in the "hidden node area," which lowers network performance.

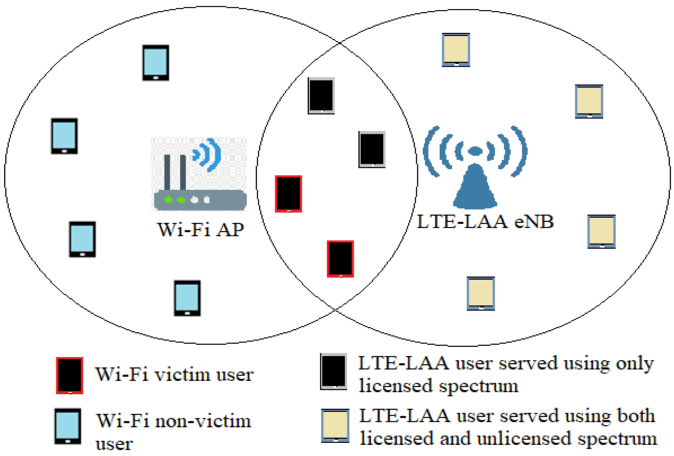

Fig. 1. Wi-Fi and LTE-LAA coexistence framework

2.1 Probability of Energy Detection Threshold

In a 20 MHz Wi-Fi channel with a sampling rate of 50 ns, the received signal with interference (H1) and without interference (H 0) is given by Ref. [5] as shown in Eq. (1).

$$H_0: \text{(without interference) } r(n) = \omega(n)$$
$$H_1: \text{(with interference) } r(n) = x_s(n) * h(n) + \omega(n) \quad (1)$$

where $r(n)$ is the received signal, $\omega(n)$ is the AWGN noise, $x_s(n)$ is the modulated interference signal, and $h(n)$ is the channel impulse response (assume normalized channel, i. e $\sum_n |h(n)|^2 = 1$). The test statistic for the energy detector (ED) is given by [5] as written as Eq. (2).

$$\epsilon = \frac{1}{M}\sum_{i=1}^{M}|r(i)|^2 \quad (2)$$

where M is the length of received sample sequence for test statistics. For Wi-Fi DIFS duration of 34 µs, $M = 680$, σ_n^2 is the noise power, σ_x^2 is the signal power and η represent the energy detection threshold thus the probability of detection is calculated as in [5] as shown in Eq. (3).

$$P_d = P(\epsilon > \eta) = Q\left(\frac{\eta-(\sigma_n^2+\sigma_x^2)}{\frac{2}{M}(\sigma_x^2+\sigma_n^2)^2}\right) \quad (3)$$

where Q represent the Gaussian Q-function and can be expressed in terms of the error function, or the complementary error function, as in Eq. (4).

$$Q(x) = \frac{1}{2}\operatorname{erfc}\left(\frac{x}{\sqrt{2}}\right) \quad (4)$$

2.2 Modifying Probability of Energy Detection Threshold

The power control scheme compensates the path loss between UE and eNB/AP as the open loop approach of the power control is the intended for different received SINR for UE of different locations. In other words, this is to allow users near to the eNB/AP to have a better receive SINR compare to users far from eNB/AP. The SINR is strongly correlated to connectivity (in term of spectral efficiency) of a communication link and can be calculated based on the RSRP. In this project, Pdw is modified by changing the signal power with RSRP as the cross-network energy detection probability of the Wi-Fi AP and Pdl as the cross-network energy detection threshold probability of the LTE-LAA eNB in order to take the effect of the energy detection threshold probability on cross network detection into account. The energy detection threshold probability of Wi-Fi and LTE-LAA is rewriting as Eq. (5) and (6).

$$P_{dw} = Q\left(\frac{\eta-(\sigma_n^2+RSRPw)}{\frac{2}{M}(RSRPw+\sigma_n^2)^2}\right) \tag{5}$$

$$P_{dl} = Q\left(\frac{\eta-(\sigma_n^2+RSRPl)}{\frac{2}{M}(RSRPl+\sigma_n^2)^2}\right) \tag{6}$$

In Table 1 shows parameter settings for LTE-LAA and Wi-Fi systems used in the MATLAB simulation.

Table 1
LTE-LAA and Wi-Fi parameters [5]

System parameter	Value
PhyH	20 µs
ACK	112 bits+PHYH
DIFS	34 µs
SIFS	16 µs
Slot Time σ	9 µs
Wifi rate r_w	9 Mbps
LTE-LAA rate r_l	9 Mbps
Samples, M	68-0

3. Results and Discussion

To achieve the goals of this research, data from the simulation will be analysed and discussed in this part.

3.1 Simulation Result for Gaussian Q-Function

Figure 2 illustrates a simulation result for Gaussian Q-function. It shows that when value of x increase, the Q value will be decrease due to bell-shaped curve symmetrical about its mean.

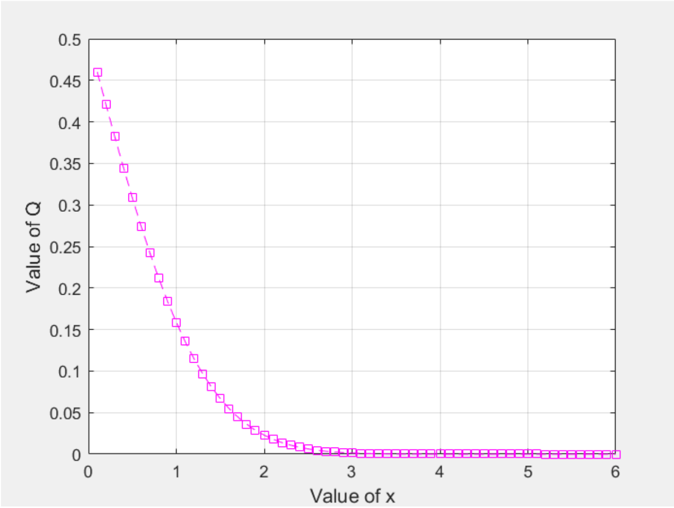

Fig. 2. Gaussian Q-function simulation result

Figure 3 shows the simulation result for detection probability. The figure illustrates the probability of detection increases when an energy detection threshold increases and influenced by Q value where high value of Q contribute high value of detection probability.

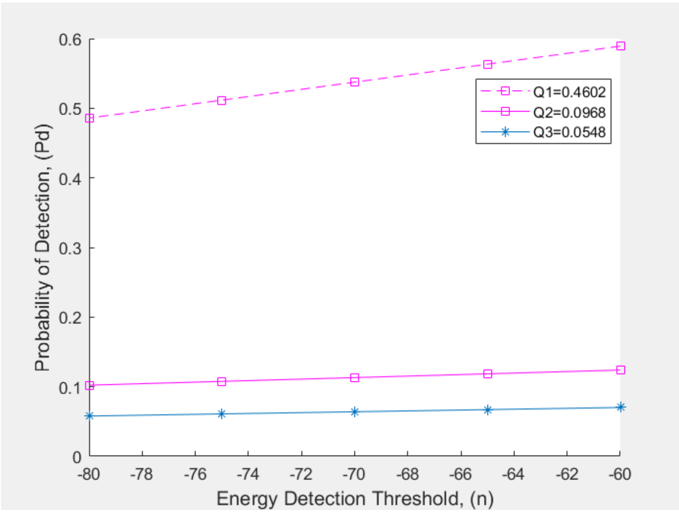

Fig. 3. Probability of detection versus energy detection threshold for 3 different values of Q

Figure 4 shows the simulation result for probability of detection after applied power control. The power control scheme is important for minimizing interference between neighbouring cells. This is to ensure the UE to receive appropriate values of SINR even though the UE located near to each other in a small area or network. It is to avoid the potentially of high transmit power of the UE will interfere with the signal from neighbouring BS rather the nearest BS. By changing the LTE-LAA threshold improves performance for both systems.

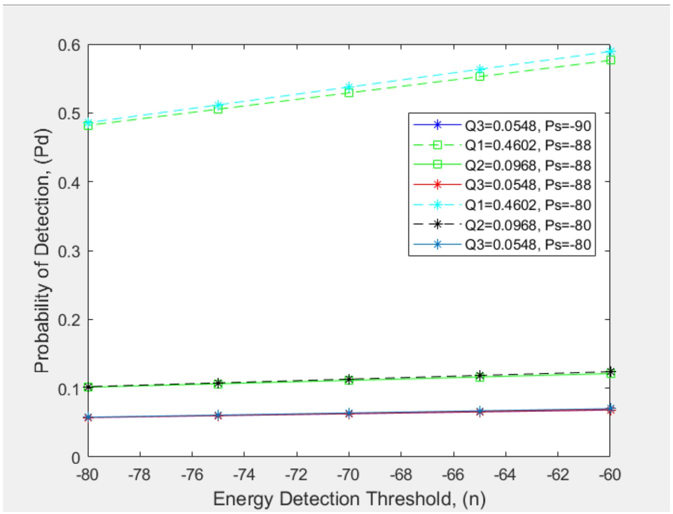

Fig. 4. Probability of detection versus energy detection threshold after applied power control

Next, we look into how changing the energy detection threshold affects how quickly Wi-Fi and LTE-LAA can transmit data in a coexistence network. The energy detection threshold in a standard Wi-Fi system is -62 dBm, but in LTE-LAA, it is -72 dBm. Figure 5 shows the graph of the detection probability for Wi-Fi using 3 different RSRP values of -40 dBm, -50 dBm and -60 dBm.

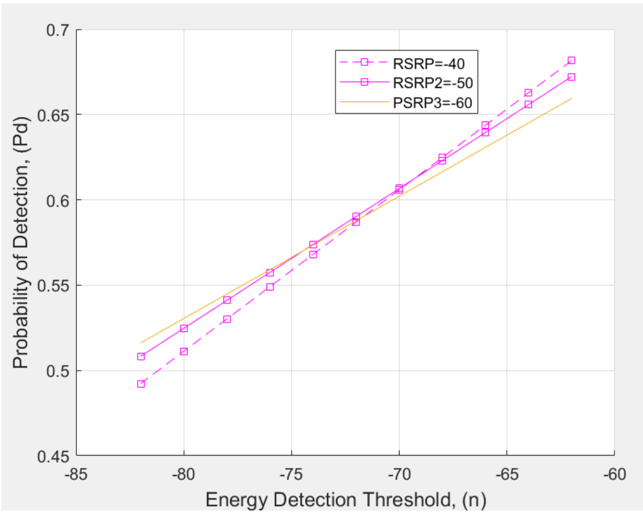

Fig. 5. Probability of detection Wi-Fi versus energy detection threshold for 3 different values of RSRP

Figure 6 shows the detection probability for LTE-LAA using RSRP value of -80 dBm, -90 dBm and -100 dBm. From the graphs, it can be seen that lowering the energy detection threshold affect the respective Wi-Fi and LTE-LAA networks performance.

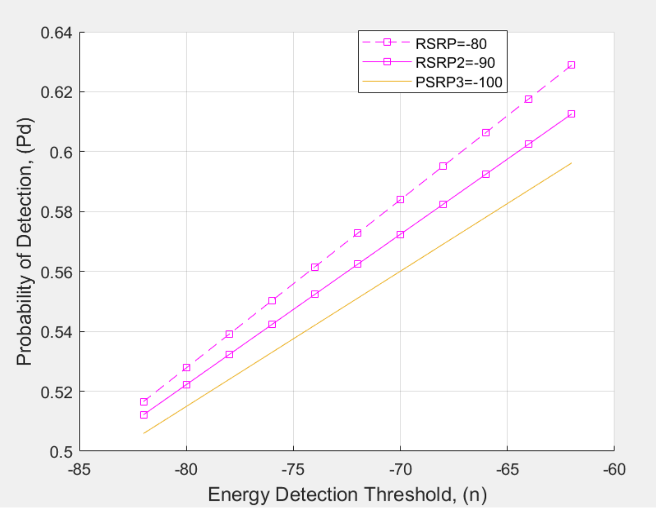

Fig. 6. Probability of detection LTE-LAA versus energy detection threshold for 3 different values of RSRP

4. Conclusions

Our thorough simulation study's key finding is that Wi-Fi and LTE-LAA performance can be enhanced when the energy detection threshold employed by Wi-Fi in the presence of LTE is adaptive. Thus, this finding suggests a coexistence scenario in which Wi-Fi employs the same energy detection threshold to defend against both Wi-Fi and LTE-LAA. Wi-Fi would need to integrate LTE detection, which can be done quickly by detecting the LTE synchronisation signals, in order to discriminate between LTE-LAA and other signals. Future work will extend to throughput performance, using combinations of Wi-Fi and LTE-LAA in realistic deployment scenarios.

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