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# PERFORMANCE ANALYSIS OF LET-U AND WI-FI CO-EXISTENCE MECHANISMS IN UNLICENSED BANDS

Cui Zhu[1], Li Li[2] and Hongjiu Yang[2]

[1]School of Information and Communication Engineering
Beijing Information Science and Technology University
No. 35, Beisihuan Middle Road, Chaoyang District, Beijing 100101, P. R. China
cuizhu_lzy@bistu.edu.cn

[2]School of Electrical Engineering
Yanshan University
No. 438, West Hebei Ave., Qinhuangdao 066004, P. R. China
{ lili; yanghongjiu }@ysu.edu.cn

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Abstract. *Several categories of LBT methods are investigated. The detailed channel access procedure for LTE-U transmission is discussed and the key parameters related with it are analyzed. Based on that, an enhanced LBT method is proposed by sending a reservation signal to increase the sensitivity of Wi-Fi to detect LTE-U signal. Simulation results show that the collision probability has been affected by the size of contention window and the switching time and the proposed LBT method can obtain obvious benefits for both LTE-U and Wi-Fi performance in dense co-existence scenario.*

**Keywords:** Unlicensed band, Co-existence, Listen-before-talk

1. **Introduction.** Nowadays, a growing number of mobile devices and diverse mobile applications lead to an explosively increased mobile broadband (MBB) traffic data; therefore, a large amount of Wi-Fi access points have been deployed to offload traffic. More and more operators focus on the licensed-assisted access (LAA) technology which extends the long term evolution (LTE) to the unlicensed band, and a working group studying the LAA using listen-before-talk (LBT) has been approved by the 3rd generation partnership project (3GPP) [1]. In January 2016, a feature called supplemental downlink (SDL) has been specified in Release 13 in 3GPP LAA work item. For unlicensed cell, only downlink is supported in Release 13, while the uplink data transmission is supported in Release 14. In 2017, a new work item has been agreed by 3GPP which aims at designing an unlicensed standalone system based on the new radio technology in 5G [2]. At present, radio regulation has been mandated by local governments for the unlicensed band to provide friendly co-existence between different radio technologies, in which the maximum transmission power and the antenna gain are restricted. Technologies such as LAA, LTE Wi-Fi aggregation (LWA), not only enhance mobile broadband, but also expand LTE to new frontiers such as Internet of Things, and vehicle-to-vehicle. However, the unlicensed spectrum is quite different from the licensed spectrum, since it can be shared by different kinds of radio access technologies such as Wi-Fi, Bluetooth, ZigBee and unlicensed LTE (LTE-U). Nowadays, Wi-Fi devices are already widespread in the unlicensed band; therefore, how to coexist with incumbent Wi-Fi system is a critical issue for LTE-U [3-5]. The LBT is one of the most effective methods to resolve the co-existence problem between Wi-Fi and LTE-U, which has been adopted by LAA in 3GPP. In Europe, spectrum sharing technologies based on LBT are considered to be necessary for the co-existence between the heterogeneous devices [6,7]. Frame-based equipment LBT (LBT-FBE) and

load-based equipment LBT (LBT-LBE) procedures have been proposed by ETSI for LTE operation in the unlicensed spectrum [8,9].

In this paper, the performance of co-existence mechanisms using LBT has been analyzed. Simulation results show that the size of contention window and the switching time have great effects on the collision probability. Meanwhile, due to the low sensitivity of Wi-Fi of LTE-U signal, collision probability is extremely high in the dense LTE-U and Wi-Fi co-existence scenario even using the LBT methods. An enhanced LBT method by sending a reservation signal to increase the sensitivity of Wi-Fi of LTE-U burst detection has been proposed and the simulation results show that the proposed method can significantly reduce the LTE-U and Wi-Fi collision probability in the dense scenario.

The rest of this paper is organized as follows. Several co-existence methods in the unlicensed band are analyzed in Section 2. Collision probability analyses for LBT in different scenarios are presented in Section 3. In Section 4, an enhanced LBT method for LTE-U and Wi-Fi co-existence in dense scenario is proposed. Finally, the conclusions are given in Section 5.

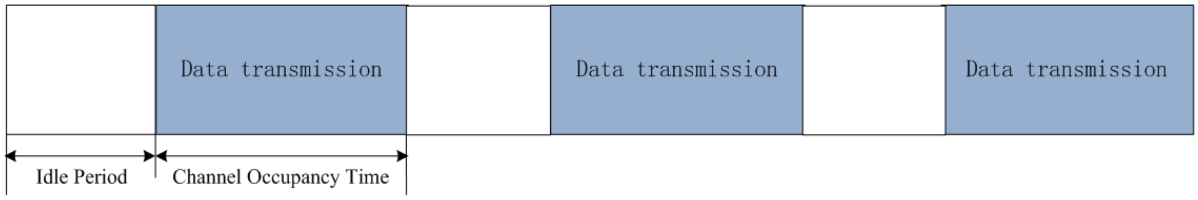
2. **Analysis of Different Co-Existence Methods in the Unlicensed Band.** There are 4 candidate co-existence mechanisms as depicted in Figure 1. Data is transmitted on the channel without LBT in Category 1, while with LBT in Categories 2-4. For LBT in Category 2, the transmitter shall perform a clear channel assessment (CCA) check towards the end of the idle period before transmissions on the medium. If the medium is considered as busy during the CCA slot, the transmitter shall not transmit on that channel during the next fixed frame period; otherwise the transmitter can continuously occupy the medium during the next channel occupancy time. LBT in Category 3 is with random back-off with fixed contention window size (CWS). LBT-LBE with fixed size of contention window as defined in Europe regulation is an example [9]. LBT in Category 4 is with random back-off with variable CWS. Compared with LBT in Categories 2 and 3, it can get more opportunities and more fairness for channel access due to variable CWS, and the method of CWS adjustment can balance channel access opportunity and collision probability [10,11]. Therefore, LBT in Category 4 is adopted by 3GPP as the LAA channel access mechanism due to its benefits on fair channel contention and regulation compliance.

3. **Collision Probability Analyses for LBT in Different Scenarios.** In this part, the collision probabilities for LBT in different scenarios have been discussed.

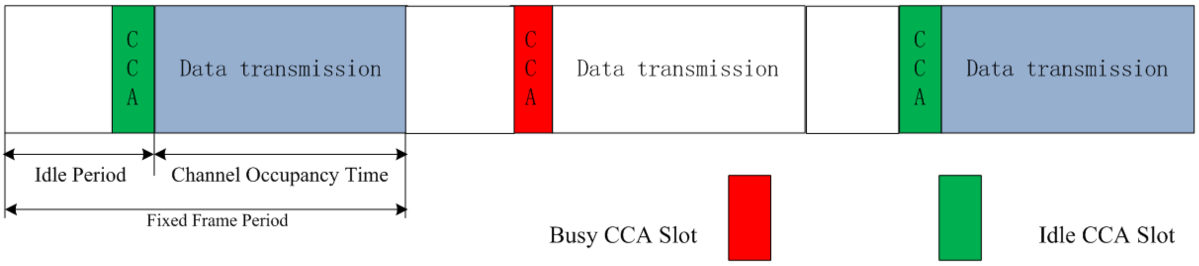
A. Scenario description

In the specifications of IEEE802.11 [12], before a burst of transmission on an operating channel, a CCA check using energy detection (CCA-ED) or CCA based on carrier sense (CCA-SC) shall be performed by the equipment. For CCA-ED, the channel is considered to be busy if the total sensed power during the CCA slot time exceeds the CCA-ED threshold. The value of Wi-Fi CCA-ED threshold for intra-RAT is $-82$dBm (20MHz); however, for inter-RAT this value changes to $-62$dBm (20MHz). That is to say, for LET-U signal, Wi-Fi will transmit data when the detected energy of LTE-U is less than $-62$dBm (20MHz). Therefore, we divide the co-existence of LTE-U and Wi-Fi into three scenarios, which are ultra-dense scenario, dense scenario and sparse scenario. The ultra-dense scenario is defined by the detected energy between the LTE-U evolved NodeB (eNB) and Wi-Fi access point (AP) can reach above $-62$dBm (20MHz). In the dense scenario, the energy is between $-82$dBm (20MHz) and $-62$dBm (20MHz). In the sparse scenario, neither the LTE-U eNB nor the Wi-Fi AP can listen to each other and the interference is weak. In fact, the LBT scheme cannot work in the sparse scenario; thus in this paper we only consider the design of LBT mechanism in the ultra-dense and dense scenarios.

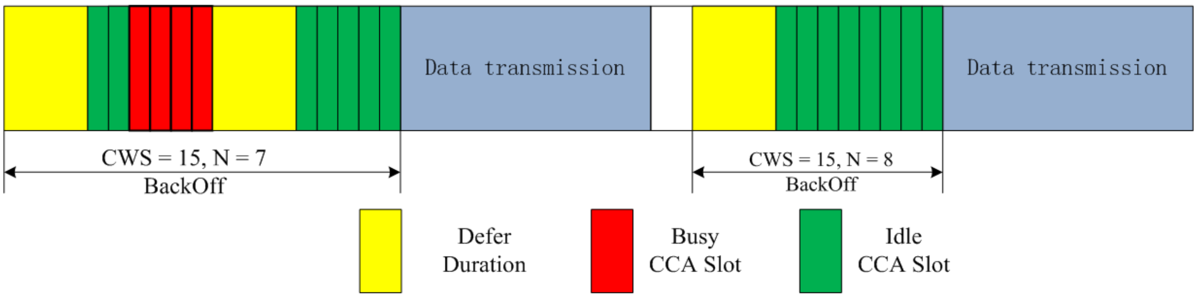
B. Channel access procedure for LTE-U transmission



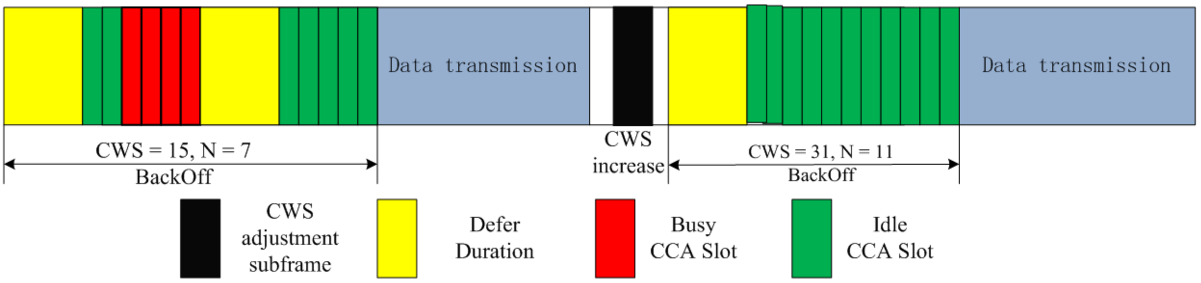
(a) Category 1 without LBT



(b) Category 2 with LBT



(c) Category 3 with LBT



(d) Category 4 with LBT

FIGURE 1. Different categories of LBT mechanisms

The transmitter shall perform a CCA check before a transmission burst on the medium. The value of back-off counter $N$ is randomly generated for each CCA check, and it is decremented by one every time when the medium is considered to be idle during a CCA slot. The transmitter can occupy the channel and send data when $N$ reaches to zero.

The counter $N$ is adjusted by sensing the channel for additional slot duration(s) according to the steps below [13]:

*Step 1: set* $N = N\_init$*, where* $N\_init$ *is a random number uniformly distributed between 0 and CWp;*

*Step 2: if* $N > 0$ *and the eNB chooses to decrease the counter, set* $N = N - 1$*;*

*Step 3: sense the channel for an additional slot duration, and if it is idle, go to Step 4; else, go to Step 5;*

*Step 4: if* $N = 0$*, stop; else, go to Step 2;*

*Step 5: sense the channel during the slot duration and an additional defer duration, and if it is idle, go to Step 2; else, go to Step 5.*

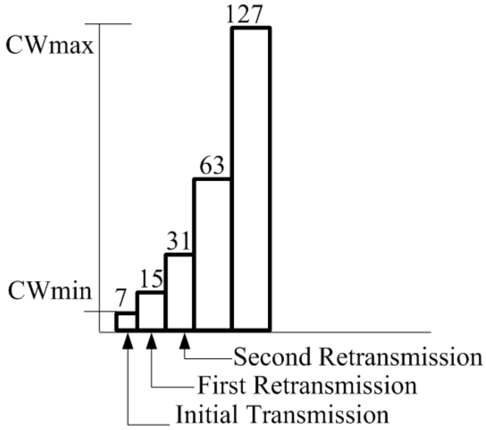


Figure 2. CWp adjustment scheme

Table 1. Channel access priority class

| **Channel Access Priority Class** | **CWmin** | **CWmax** | **Allowed CWp sizes** |
|---|---|---|---|
| 1 | 3 | 7 | $\{3, 7\}$ |
| 2 | 7 | 15 | $\{7, 15\}$ |
| 3 | 15 | 63 | $\{15, 31, 63\}$ |
| 4 | 15 | 1023 | $\{15, 31, 63, 127, 255, 511, 1023\}$ |

Table 2. Wi-Fi and LTE-U parameters

| **Parameters** | **Wi-Fi** | **LTE-U** |
|---|---|---|
| CCA time slot | $9\mu$s | $9\mu$s |
| Channel Occupancy time | Min.1ms<br>Max.10ms | Min.1ms<br>Max.10ms |
| CCA-ED threshold | $-62$dBm | $-62$dBm |
| DIFS | $43\mu$s | $43\mu$s |
| Bandwidth | 20MHz | 20MHz |
| Traffic type | Full buffer | Full buffer |

The CWp adjustment is described in Figure 2. Set CWmin = 7, CWmax = 127, as an example, during the initial data transmission CWp is equal to CWmin, and then it exponentially increases when negative acknowledgment (NACK) has been received.

Generally, the values of CWmin and CWmax are decided by the channel access priority, as shown in Table 1 [13].

C. Simulation results

In the dense scenario, the collision probability is high due to the fact that the transmission of LTE-U cannot be detected by Wi-Fi; thus the ultra-dense scenario is considered in this part. The traffic type is assumed to be a full buffer traffic and the CSMA/CA method is applied for Wi-Fi to preventing collisions with heterogeneous devices. The parameters of Wi-Fi and LTE-U are listed in Table 2, which are the same with the specifications of IEEE802.11n.

From Figure 3, we can see that if only data transmissions of channel access priority class 4 (CWmin = 15, CWmax = 1023) exist, collision probability is 12.3%, while only data transmissions of class 3 (CWmin = 15, CWmax = 63) exist, collision probability is 11.8%. If the transmission fails, the nodes will double the contention window size and try

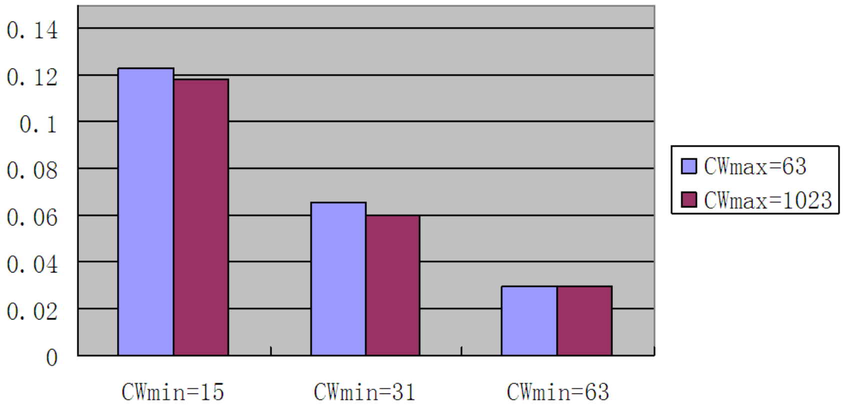


Figure 3. Collision probabilities with different value of CWmin and CWmax

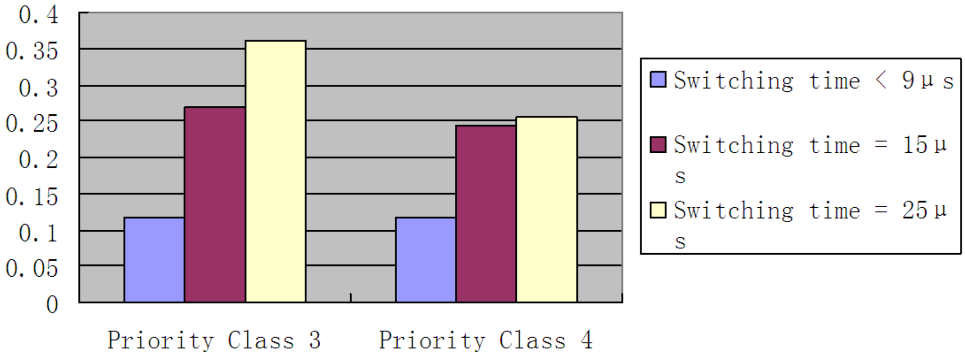


Figure 4. Collision probabilities with different switch time

again. The collision probability decreases when the value of CWmin increases; however, large value of CWmin may get larger latency for data transmission.

Theoretically, both the LTE-U and Wi-Fi devices need to transmit data as soon as the CCA check finished when the counter $N$ reaches to zero. However, in practice there is a delay for the radio unit changing its state from receiving to transmitting. During the switching time, the node cannot detect the channel, and the transmitted signal from it is not strong enough to be detected by the other nodes, and then they will begin to transmit when the back-off counter reaches to zero. Figure 4 shows the collision probability is sensitive to the switching time. When the switching time is 15$\mu$s, the cumulated collision probability is 26.9% for channel access priority class 3 and 24.3% for class 4. Compared to class 4, class 3 is more seriously affected by the switching time. The collision probability increases to 36% when the switching time reaches to 25$\mu$s for class 3.

In fact, there are different traffic types for transmission on the same channel using different access priority. The channel occupation fairness for different access priority classes is shown in Figure 5. It can be seen that the access priority class 3 can get more chance to occupy the channel and the difference becomes larger with the increase of the switching time.

4. **An Enhanced LBT Method for LTE-U and Wi-Fi Co-Existence in Dense Scenario.** In this section, we propose an enhanced LBT method for LTE-U and Wi-Fi co-existence in dense scenario.

A. An enhanced LBT method for LTE-U and Wi-Fi co-existence

In the dense scenario, the detected energy is between −82dBm (20MHz) and −62dBm (20MHz). Wi-Fi nodes cannot hear the LTE-U transmission because of the high CCA-ED threshold (−62dBm) in this scenario; therefore, they will keep on transmitting whether

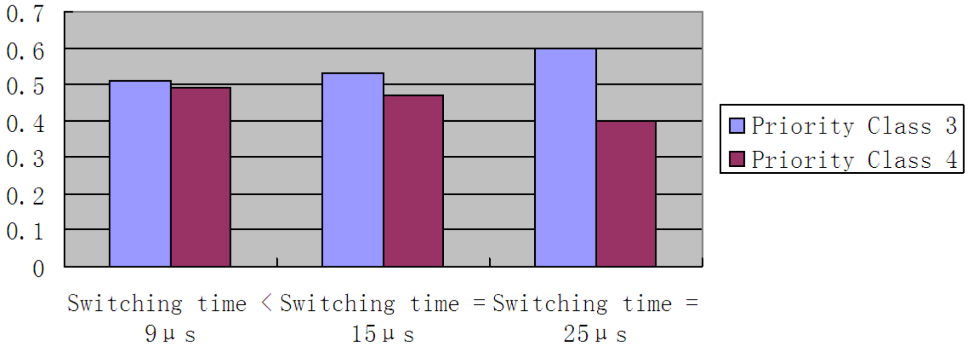


FIGURE 5. Channel occupation fairness for different access priority classes

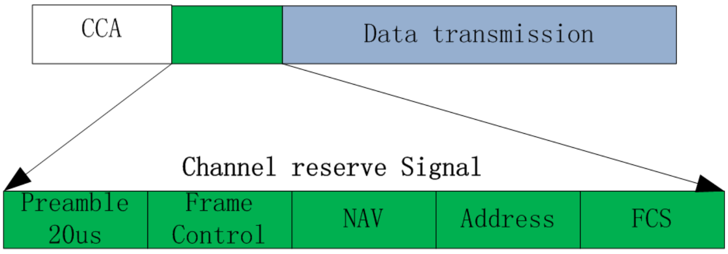


FIGURE 6. Channel reserve signal frame structure for LTE-U

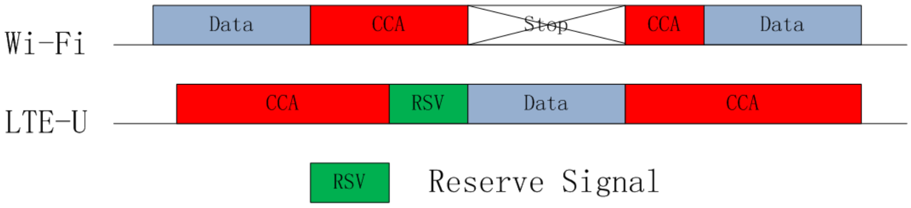


FIGURE 7. Enhanced LBT method for LTE-U and Wi-Fi co-existence

LTE-U is transmitting or not, which inevitably causes interference. To solve this problem, an enhanced LBT method is proposed by sending a channel reservation signal from LTE-U nodes. Figure 6 shows the frame structure for the channel reservation signal, in which the network allocation vector (NAV) field indicates the time of the channel occupied by this transmission. The reserve signal is the same with the CTS-to-self signal in Wi-Fi which can be recognized by Wi-Fi nodes; thus they can detect the signal from LTE-U nodes, and know whether the channel is occupied or not which is indicated by the NAV field. The enhanced LBT method for LTE-U can increase the sensitivity of Wi-Fi of LTE-U burst detection at least 20dB and change CCA check of Wi-Fi from CCA-ED to CCA-CS.

The channel access procedure for a Wi-Fi AP and LTE-U eNB based on the enhanced method is depicted in Figure 7. The CCA threshold for the LTE-U eNB to detect the Wi-Fi signal can be configured, which provides flexibility for eNB to control both the aggressiveness and the friendliness of LTE-U system to Wi-Fi. The LTE-U eNB will stop the transmission when the detected energy is above its CCA threshold. After the CCA procedure, the LTE-U eNB starts to transmit a channel reserve signal which includes the NAV. The Wi-Fi AP can detect the reserve signal, read the NAV part, and then stop transmission for a short time based on the NAV indication.

B. Simulation results

Four cases have been simulated in the dense scenario. In case 1, Wi-Fi coexists with Wi-Fi using CSMA-CA method. In case 2, LTE-U with LBT method coexists with Wi-Fi and the CCA-ED threshold of LTE-U is $-82$dBm. In case 3, LTE-U with LBT method

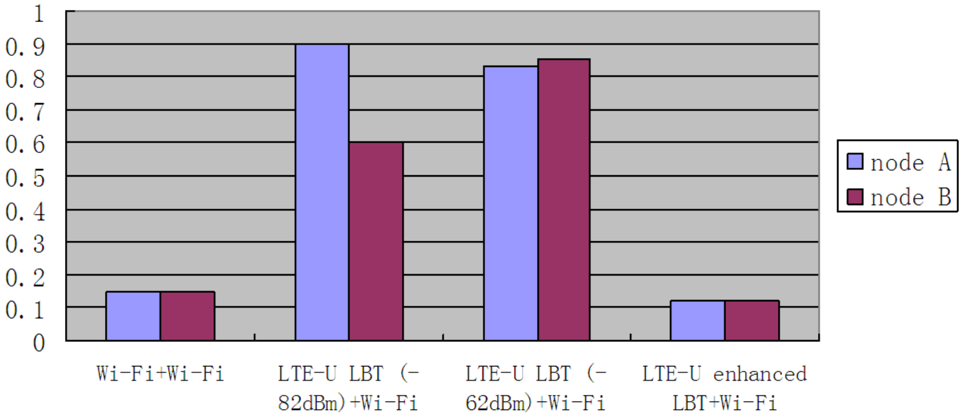


Figure 8. Collision probabilities with enhanced LBT method

coexists with Wi-Fi, while the CCA-ED threshold of LTE-U is −62dBm. In case 4, LTE-U with enhanced LBT method coexists with Wi-Fi and the CCA-ED threshold of LTE-U is −82dBm. As is shown in Figure 8, with the enhanced LBT method, the collision probability for LTE-U and Wi-Fi co-existence is almost the same with that for Wi-Fi and Wi-Fi co-existence and is largely reduced compared with conventional LBT method for LTE-U, since the enhanced LBT method can prevent co-channel Wi-Fi nodes to false-detect low power LTE-U transmission as idle. Additionally, this is also beneficial to the power consumption of Wi-Fi nodes as they can avoid unnecessary channel sensing while the eNB is transmitting. In a word, the enhanced LBT method of LTE-U can provide win-win benefits to the co-existence of LTE-U and Wi-Fi systems.

5. **Conclusions.** In this paper, we have investigated several LTE-U and Wi-Fi co-existence mechanisms including carrier-sensing adaptive transmission and four categories of LBT method. The detailed channel access procedure for LTE-U transmission has been discussed. Furthermore, the key parameters related with the channel access procedure have been analyzed. Simulation results have shown that the collision probability has been impacted by the size of contention window. In particular, the switching time from CCA check to data transmission has great effects on the collision probability. The performance of Wi-Fi and LTE-U system can be degraded by a conventional LBT scheme in the dense scenario; thus an enhanced LBT method has been proposed to solve this problem. Simulation results have shown that the proposed LBT method can obtain obvious benefits for both LTE-U and Wi-Fi performance when they coexist in dense scenario. In the future, the power control and CCA-ED adapting methods will be further studied.

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