An Enhanced Listen Before Talk (e-LBT) Mechanism for Avoiding Hidden Nodes in an LTE-U and WiFi Coexistence System

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Abstract. This paper considers the hidden node avoidance problem in an LTE-U and WiFi coexistence system operating in unlicensed bands. An enhanced Listen Before Talk (e-LBT) mechanism is proposed for coordinating the LTE-U and WiFi systems. To support the e-LBT mechanism, we first enhance an LTE-U node by introducing a WiFi module in the LTE-U eNB and redefining the RRC and MAC functional blocks in both LTE-U eNB and LTE-U UE in order to enable information exchange between an LTE-U node and a WiFi node. Moreover, the e-LBT mechanism incorporates an RTS/CTS handshaking mechanism in the basic LBT mechanism to resolve the hidden node problem. Simulation results show that the proposed e-LBT mechanism can significantly improve the performance of the coexistence system in terms of LTE-U system throughput as compared with the basic LBT mechanism.

Keywords: Coexistence · Hidden node · LBT · LTE-U · WiFi

1 Introduction

Unlicensed spectrum bands are being considered as the supplement of licensed spectrum for cellular networks [1]. The third Generation Partnership Project (3GPP) is currently studying Licensed-Assisted Access (LAA) using LTE in the unlicensed spectrum (LTE-U), and the LTE-U and WiFi coexistence in the unlicensed bands [2]. A critical issue that arises with the use of unlicensed spectrum for cellular users is the coexistence of an LTE-U system and a WiFi system in the same unlicensed band. Due to the different channel access mechanisms employed by the two systems, how to coordinate the channel access of users from the different systems becomes a challenging issue for the coexistence of LTE-U and WiFi. According to the study results in [3], if there is no additional mechanism to coordinate LTE and WiFi coexistence, an LTE system will occupy the majority of channel access opportunities and thus significantly affect the performance of a WiFi system. To address this issue, several MAC mechanisms have been proposed to improve the performance of LTE-U and WiFi coexistence, such as Almost Blank Subframe (ABS), Carrier Sense Adaptive Transmission (CSAT), and Listen Before Talk (LBT) [4–6].

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LBT was originally proposed in 3GPP LAA specifications [2]. In some regions, like Europe and Japan, LBT is one of mandatory regulations in LTE-U implementation. The main idea of LBT is to allow an LTE-U node to sense a channel for a while before starting transmission. If the channel is idle, the node will transmit after a predefined time interval. Otherwise, the node needs to keep quiet and periodically sense the channel in the subsequent subframes until the channel becomes idle. However, as the range that the node can sense is limited, the classical *hidden node* problem is unavoidable with LBT. In the IEEE 802.11 (WLAN) standard [6], a node is referred to be hidden from other node(s) when it is out of the sensing or detection range of other node(s). When more than two hidden nodes transmit data simultaneously, often referred to as *collision*, the transmitted packets cannot be successfully decoded at the receivers with a high probability. To address this problem, request to send/clear to send (RTS/CTS) was introduced in the IEEE 802.11 standard. Two communicating nodes need to *handshake* by exchanging RTS and CTS messages before transmission to avoid collision. For an LTE-U and WiFi coexistence system, however, different channel access mechanisms are employed in LTE-U and WiFi, which makes an LTE-U node unable to exchange RTS/CTS messages with a WiFi node, and cannot resolve the hidden node problem to an extent as expected.

In this paper, we consider the hidden node avoidance problem in an LTE-U and WiFi coexistence system operating in an unlicensed spectrum band. We first enhance LTE-U nodes by introducing a WiFi module in the LTE-U eNB and redefine the RRC and MAC functional blocks in both LTE-U eNB and LTE-U UE in order to enable information exchange between an LTE-U node and a WiFi node. Based on the enhanced LTE-U nodes, we further propose an enhanced listen-before-talk (e-LBT) mechanism, which incorporates an RTS/CTS handshaking mechanism in the basic LBT mechanism to resolve the hidden node problem. Simulation results are shown to evaluate the performance of the proposed e-LBT mechanism in terms of LTE-U system throughput.

The rest of this paper is organized as follows. Section 2 reviews recent related work. Section 3 presents the proposed e-LBT mechanism. Section 4 shows simulation results to evaluate the performance of the e-LBT mechanism. Section 5 concludes this paper.

2 Related Work

LTE in Unlicensed bands (LTE-U) has become a hot research area in recent years and considerable work has been conducted in this area. In [2], 3GPP recommends LTE-U deployment scenarios, introduces unlicensed spectrum band ranges in different countries, and defines indoor and outdoor channel models. For LTE-U, a main concern is how to coordinate LTE and WiFi systems coexisting in the same unlicensed band. To address this concern, a variety of coexistence mechanisms have been proposed in the literature [4–6]. In [4], Almeida et al. introduced Almost Blank Subframes (ABS) in LTE-U to coordinate the LTE-U and WiFi coexistence. In [5], Qualcomm proposed a carrier sense adaptive transmission (CSAT) mechanism, in which an LTE-U eNB dynamically activates and deactivates its transmission in a time cycle based on the sensed channel status. In [6], 3GPP proposed a listen before talk (LBT) mechanism, in which an LTE-U node senses an unlicensed channel before data transmission.

As mentioned in Sect. 1, a MAC mechanism based on channel sensing, such as LBT and CSMA/CA, will inevitably cause the hidden node problem due to the limited sensing coverage of a node. In [7, 8], Panasonic and Samsung evaluated the influence caused by hidden nodes when LBT is employed. Moreover, they used UE reporting and RTS/CTS signaling to detect hidden nodes. However, no specific MAC mechanism is presented in [7, 8]. In [9], however, Lien et al. pointed out that RTS/CTS cannot be used in an LAA-WiFi coexistence scenario due to the lack of a unified information exchange interface between an LTE-U system and a WiFi system. Regardless of the above work, the hidden node problem in an LTE-U and WiFi coexistence system has not been well studied and resolved, which motivated us to conduct this work.

3 Enhanced Listen Before Talk (e-LBT) Mechanism

In this section, we present the proposed e-LBT mechanism for an LTE-U and WiFi coexistence system.

3.1 System Model

We consider a basic LTE-U and WiFi coexistence system consisting of multiple LTE-U networks and multiple WiFi networks, as shown in Fig. 1. Both the LTE-U networks and WiFi networks operate in the same unlicensed band. The LTE-U network uses the LBT mechanism to access the channel, while the WiFi network uses the CSMA/CA access mechanism.

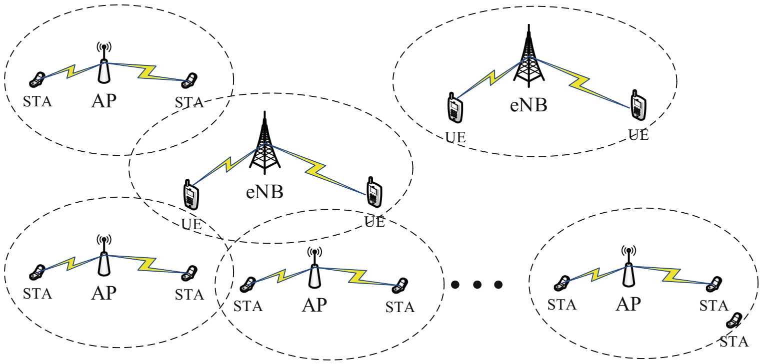

Fig. 1. System model

In Fig. 1, the dotted lines stand for the transmission ranges of different networks. The LTE-U eNB senses the channel before transmission. However, the access points (APs) of the WiFi networks are out of the sensing range of the LTE-U eNB. Thus the LTE-U eNB cannot sense the existence of the APs. When the APs and eNB transmit simultaneously, the hidden node problem will occur. Similarly, the hidden node problem will also occur when a WiFi node has data to transmit and an LTE-U node is out of the sensing range of the WiFi node.

3.2 Enhanced LTE-U Nodes

In the system model described in Fig. 1, the LTE-U networks and WiFi networks employ different channel access mechanisms. Typically, an LTE-U node and a WiFi node cannot implement information exchange between each other. As indicated in [9], without a universal air interface for information exchange between a Wi-Fi network and an LTE-U network, RTS/CTS cannot be used to resolve the hidden-node problem. To enable the information exchange between the two different networks, we introduce a WiFi module in the LTE-U eNB to enhance the functionality of the eNB, and redefine the RCC functional block in the LTE module of the eNB, renamed e-RRC, as shown in Fig. 2. For an LTE-U UE, we redefine the RCC functional block in its LTE module and the MAC functional block in its WiFi module [10], which are renamed e-RRC and e-MAC, respectively.

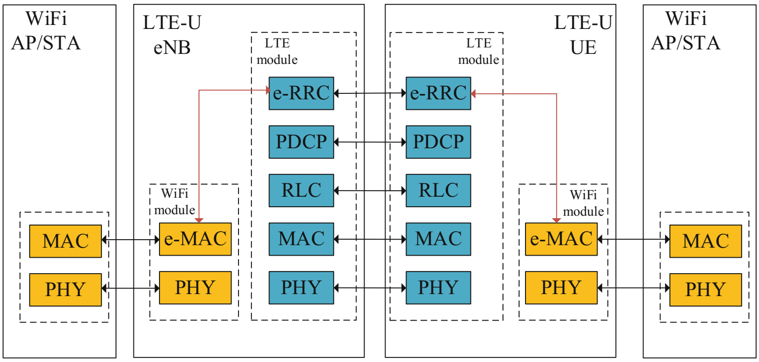

Fig. 2. Functional blocks of enhanced LTE-U nodes

The enhanced eNB is composed of two components, LTE module and WiFi module. The LTE module is used to transmit data, and determine whether the LTE node needs to transmit and whether it can transmit. The WiFi module is used to sense a channel, receive/send WiFi signaling messages, reserve a channel, and exchange relevant information with the LTE module. In the LTE module, a new function is added in e-RRC to implement the information exchange with e-MAC in the WiFi module. Similarly, in the WiFi module, a counterpart function is added in e-MAC to implement the information exchange with e-RRC.

3.3 Enhanced Listen Before Talk (e-LBT) Mechanism

The e-LBT mechanism is a channel access mechanism for resolving the hidden node problem in the LTE-U and WiFi coexistence system. It is based on the enhanced LTE eNB and UE nodes described in Sect. 3.2. Meanwhile, it introduces RTS/CTS in the basic LBT mechanism.

In the e-LBT mechanism, each LTE-U node will sense the channel through the WiFi module before data transmission. If the channel is idle, the e-MAC of the WiFi module will report the channel status to the e-RRC of the LTE module. Once the LTE module receives the channel status, it will send the destination address, source address, and transmission length information to the WiFi module. Once the WiFi module receives the information, it will send an RTS message to all neighbor nodes within its transmission range, and includes all the information in the RTS message. After the destination node receives the RTS message, it will reply with a CTS message after a short interframe space (SIFS) duration. Once the LTE-U node receives the CTS message, the e-MAC of the WiFi module will report the information contained in the received CTS message to the LTE module. After the LTE module receives the reported information, it will start to transmit data after another SIFS duration. If the RTS/CTS exchange is unsuccessful or the ACK message is absent, the node will wait a backoff time and then start the RTS/CTS exchange again. The RTS and CTS messages include a time field to inform other nodes of the length of the current transmission. All neighbor nodes that receive the RTS or CTS messages will update their Network Allocation Vector (NAV) fields with the value of the time field in the RTS and CTS messages. A neighbor node will not access the channel until the value of its NAV field reaches 0 [6]. Figure 3 illustrates the signaling procedure of the e-LBT mechanism when an LTE-U eNB has data to transmit to an LTE-U UE.

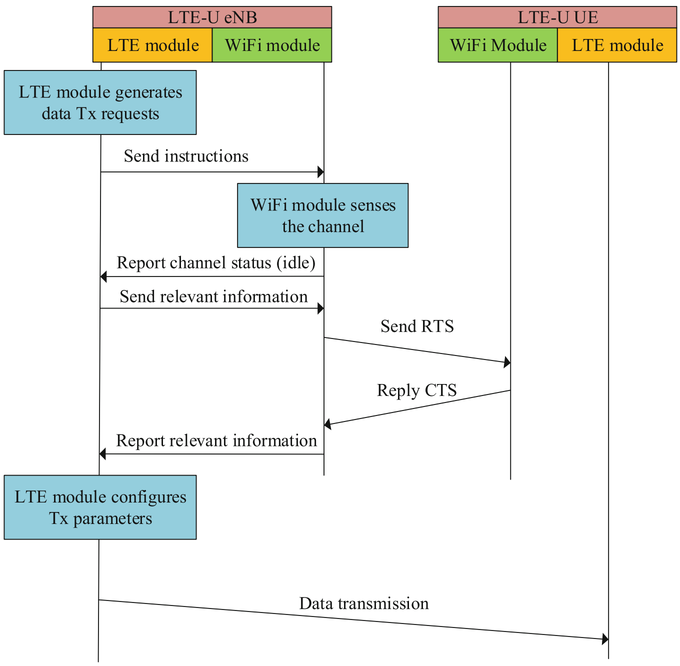

Fig. 3. Signaling procedure of LTE-U transmission

4 Simulation Results

In this section, we evaluate the performance of the proposed e-LBT mechanism through simulation results. The simulation experiments were conducted on a simulator developed using NS3 [11]. We use the LTE-U system throughput and WiFi system throughput as the performance metrics, which are defined as the average number of bits that LTE-U users transmit and the number of bits that WiFi users transmit in a second, respectively. The parameters used in the simulation experiments are given in Table 1.

Table 1. Simulation parameters

Parameter	Value
Network layout	Indoor
eNB/AP transmission power	18 dBm
Unlicensed channel bandwidth	20 MHz
Unlicensed spectrum frequency	5.18 GHz
Antenna type	2D omnidirectional
eNB antenna height	6 m
UE antenna height	1.5 m
Number of UEs	20
Traffic model	FTP model-1

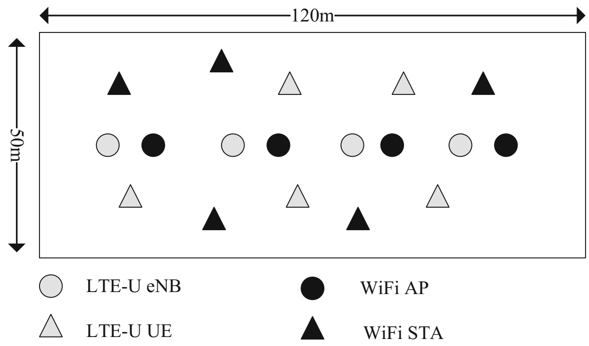

Fig. 4. Center placement

We consider two simulation scenarios, “center placement” and “corner placement”, to evaluate the influence of hidden nodes. In both scenarios, four eNBs and four APs are placed in a 120 m*50 m room, and 20 UEs are randomly distributed in the rectangular region, without redropping [2]. In the center placement, the eNBs and APs are evenly spaced and centered in the shorter dimension of the room, as shown in Fig. 4. The distances between two neighbor eNBs or APs are equal. If we set the bottom-left corner as the origin of the coordinate system, the eNBs (LTE-U) are placed in (15,25), (40,25), (75,25) and (100,25), and the APs (WiFi) are placed in (20,25), (45,25), (80,25) and (105,25), respectively. In the corner placement, the eNBs and the APs are placed at the corners of the room, as shown in Fig. 5. In the same coordinate system, the eNBs are placed at (0,0), (0,50), (120,0) and (120,50), and the APs are placed at (1,1), (1,49), (119,1) and (119,49) [11], respectively.

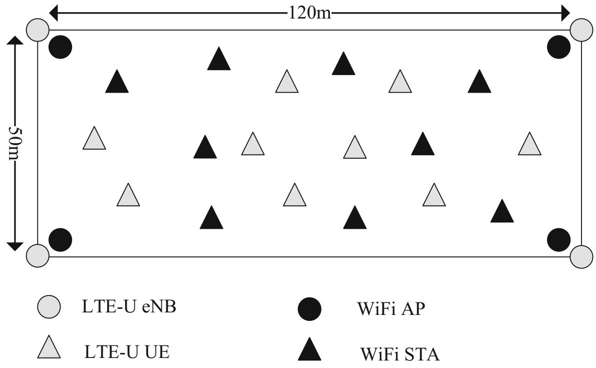

Fig. 5. Corner placement

The simulation results are shown in Figs. 6 and 7, where we use “center” and “corner” to represent the center placement and corner placement, respectively, and use “LBT” and “e-LBT” to represent the basic LBT mechanism and the e-LBT mechanism, respectively.

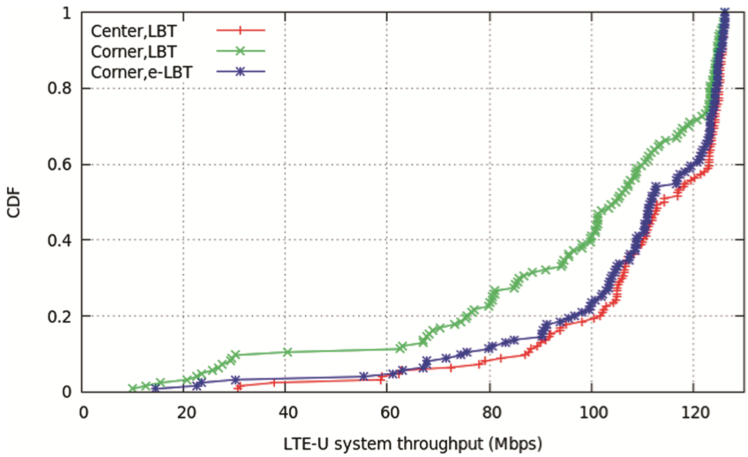

Fig. 6. LTE-U system throughput

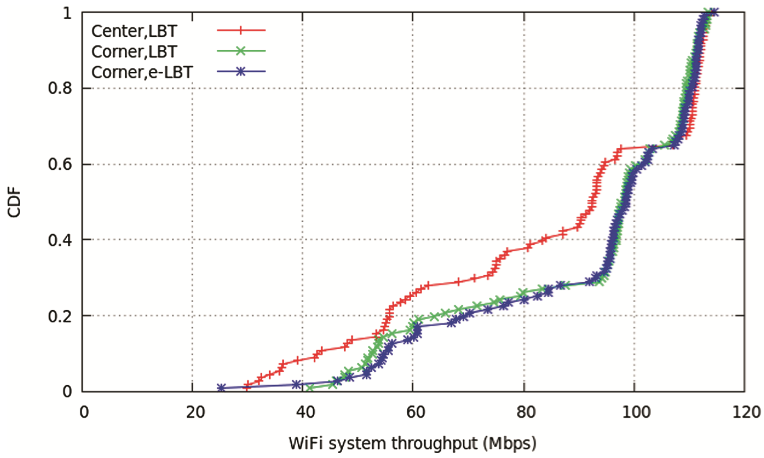

Fig. 7. WiFi system throughput

Figure 6 shows the LTE-U system throughput with the basic LBT mechanism and the e-LBT mechanism in the two scenarios, respectively. It is seen that with LBT the LTE-U system throughput is larger in the center placement than that in the corner placement. This is because that the distance between eNBs and UEs in the corner placement are much larger than that in the center placement, which results in more hidden nodes in the corner placement and thus causes more serious interference. On the other hand, in the corner placement, the LTE-U system throughput with e-LBT is larger than that with LBT. This is because that with e-LBT an LTE-U node is enhanced with an additional WiFi module which can exchange signaling information with the WiFi nodes. Meanwhile, the RTS/CTS mechanism is introduced to avoid the collisions caused by the hidden node problem.

Figure 7 shows the WiFi system throughput with the basic LBT mechanism and the e-LBT mechanism in the two scenarios, respectively. It is seen that with LBT the WiFi system throughput in the corner placement is larger than that in the center placement. This is because the distances between WiFi nodes are smaller than those in LTE-U nodes in the corner placement. As a result, there are less hidden nodes with the WiFi systems in the corner placement. According to Fig. 6, there are more hidden nodes with the LTE-U systems in the corner placement, which would degrade the throughput of the LTE-U system and thus improve the WiFi system throughput. On the other hand, it is seen that the WiFi system throughput with e-LBT in the corner placement is larger than that with LBT in the center placement, but does not have much difference as compared with that with LBT in the corner placement.

5 Conclusions

In this paper, we considered the hidden node avoidance problem in an LTE-U and WiFi coexistence system operating in unlicensed bands. An e-LBT mechanism was proposed for coordinating the LTE-U and WiFi systems. To support the e-LBT mechanism, an LET-U node was first enhanced by introducing a WiFi module in the LTE-U eNB and redefining the RRC and MAC functional blocks in both LTE-U eNB and LTE-U UE to enable information exchange between an LTE-U node and a WiFi node. To resolve the hidden node problem, the e-LBT mechanism incorporates a RTS/CTS handshaking mechanism in the basic LBT mechanism. Simulation results show that the proposed e-LBT mechanism can significantly improve the performance of the coexistence system in terms of the LTE-U system throughput as compared with the basic LBT mechanism.

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