Cell Cooperation Based Channel Access Mechanism for LAA and WiFi Coexistence

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Abstract. In 2014, the 3rd Generation Partnership Project (3GPP) proposed the "Licensed-Assisted Access using LTE" (LAA) research project, with the intention to further improve LTE network capacity by deploying LTE system in 5GHz unlicensed frequency band. But deploying LAA in unlicensed band will inevitably affect other existing wireless systems such as WiFi and increase the risk of data collision. Therefore, the research of coexistence between LAA and WiFi is of great significance to facilitate the fair sharing and efficient utilization of unlicensed spectrum sources. However, the existing studies consider the relationship between LAA and WiFi in the coexistence scenario from the perspective of contention. In this paper, we proposed a cell cooperation based channel access mechanism. The basic idea of the proposed scheme is let an LAA cell and a WiFi cell establish a pair of cooperative relationship. Once LAA node accesses the channel, it will notify its cooperated pair WiFi node to share the transmission opportunity, and vice versa. After the transmission of the LAA node, the WiFi node can access the channel without performing backoff again. Simulation results manifest that the proposed cell cooperation based channel access mechanism improves the communication performances of both LAA and WiFi as well as the spectrum efficiency in the coexistence scenarios with high channel resources demand.

Keywords: LBT-Cat4 · CSMA/CA · Cell cooperation

1 Introduction

In the era of mobile Internet advancement, the number of mobile devices is increasing rapidly, together with mobile applications showing a trend of diversification. Mobile devices transmit a large amount of data through interconnection, and the traffic carried by cellular network systems is greatly increased, which makes wireless operators experience explosive data traffic growth. This brings a great challenge for operators on how can further enhance the capacity of mobile communication systems, satisfy the increasing demands of users, especially the reliability of mobile communication and business continuity. However, the licensed frequency spectrum resources are insufficient, and the research on the utilization of the licensed frequency resources is deep enough to make

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further breakthrough, which makes the service pressure of the licensed frequency band raised sharply, difficult to guarantee higher service quality.

In response to the above phenomenon, the research of LTE network system deployed in unlicensed frequency bands has become an important part to improve the performance of communication network [1]. In 2014, 3GPP (3rd Generation Partnership Project) launched the research project “Licensed-Assisted Access using LTE (LAA)”. LAA provides a feasible way for major operators to make reasonable use of unlicensed frequency band resources and helps to improve the overall performance of mobile communication networks. LAA extends the spectrum of LTE to unlicensed frequency bands to enhance the network performance of LTE and LTE-A (LTE-Advance), as well as effectively alleviate the shortage of spectrum resources in the licensed frequency band of LTE systems. Especially in areas with heavy service demands, various data services in LTE can be effectively offloaded to unlicensed spectrum resources, thereby improving the service capacity of LTE operators. LAA is mainly deployed in 5 GHz unlicensed band [2], affecting WiFi systems’ operating, and will increase the risk of data collision. Therefore, how to establish a suitable coexistence access mechanism is a significant research direction to help LAA system and WiFi system coexist fairly in the unlicensed frequency band.

In order to minimize the interference, 3GPP introduced LBT mechanism into the standard, hoping to realize the protection of WiFi system under the influence of LAA as well as guarantee the performance of LAA system [3]. Literature [1] shows that simply introduce LTE system to the LTE-WiFi coexistence scenario will affect the performances of both WiFi and LTE; the performance of LTE system is slightly influenced by the coexistence while WiFi is greatly impacted by LTE. LTE-U (LTE-Unlicensed) takes a duty cycle based channel access mechanism and literature [4] suggests that LTE-U performance is closely related to duty cycle parameters and it may lead to more flexible resource sharing between systems with adaptive solutions like CSAT (carrier sensing adaptive transmission) added. Literature [5] tests two proposed channel sensing schemes for LTE-U, simulation shows that both of them can provide a promising tradeoff between WiFi and LTE-U in the coexistence scenario. Literature [4] also states that LAA can be a kind resource sharer for WiFi because the LBT mechanism of LAA is a reasonable solution for coexistence scenarios. In [6], it is concluded that LBT is essential for fair coexistence between WiFi and LAA, but the LBT scheme and scheme settings also matter. However, the studies all consider the relationship between WiFi and LAA in the coexistence scenario from the contention aspect. The performance improvement of one system and the whole scenario are achieved by sacrificing the performance of the other system.

To improve the efficiency of the coexistence scenarios, make the two systems as fair as possible in channel access and data communication, an LAA-WiFi cell cooperation based channel access mechanism is proposed in this paper. Under the condition that LAA devices and WiFi devices are aware of each other, once LAA node access the channel, it will inform its cooperated pair AP (Access Point) to share the transmission opportunity, and vice versa. The shared transmission opportunity allows the AP or the eNB (eNodeB) to access the channel after the former transmission is complete. Simulation results reveal that the cell cooperation scheme improves the performance of WiFi system as well as the efficiency of the coexistence especially in the scenarios with high traffic density and heavy channel access demands.

The following chapters are organized as follows. Section 2 elaborates the channel access mechanisms of LAA and WiFi in unlicensed frequency bands. And the research literature on LAA and WiFi coexistence is investigated. Section 3 introduces the idea of proposed cell cooperation based access method, with the protocol described in detail. Section 4 evaluates the proposed cell cooperation scheme by simulation. The LAA-WiFi coexistence simulation platform is firstly introduced and the results analysis of adopting and not adopting cell cooperation mechanism is carried out in two coexistence scenarios. Section 5 summarizes the content of this paper and puts forward the prospect of future work.

2 Related Work

2.1 LAA-LBT Access Mechanism

When deploying LTE systems to 5 GHz unlicensed frequency band, a problem that cannot be overlooked is how to make it coexist with WiFi system without affecting its performances. As a result, LAA system implements the LBT mechanism which requires clear channel assessment (CCA) before LAA transmit data, it needs to determine whether the channel can be accessed according to the channel state before data transmission.

According to whether backoff is required and how to adjust the contention window, the downlink LBE-LBT can be divided into four types:

No LBT (Cat-1): No channel monitoring before data transmission.

LBT without random backoff (Cat-2): The time at which the channel is monitored as idle before transmission is fixed.

Static backoff LBT (Cat-3): Before transmitting, the node randomly selects an integer N in a fixed contention window, and uses the random number N to determine the backoff time before the is channel is available for transmission.

Exponential backoff LBT (Cat-4): Before transmitting, the node randomly selects an integer N in the contention window, and use the random number N to determine the backoff time before the channel is available for transmission. The contention window size adjustment follows the exponential law during the LBT process.

The downlink Cat-4 LBT access mechanism and its contention window adjustment procedure are described in details [7].

Cat-4 LBT Procedure for Downlink Transmission. For downlink data transmission, if the eNB detects the channel is idle within the defer duration of Initial Clear Channel Assessment (ICCA) state, it can directly transmit data. otherwise the eNB enters the Extended Clear Channel Assessment (ECCA) backoff state, which means it defers its access, and the channel needs to be monitored within a delay time T_d. In this state, CW is used to indicate the size of contention window. the backoff counter N is the number of idle CCA slots monitored by the eNB before transmission, and the value is a randomly chosen integer between 0 and CW (Fig. 1).

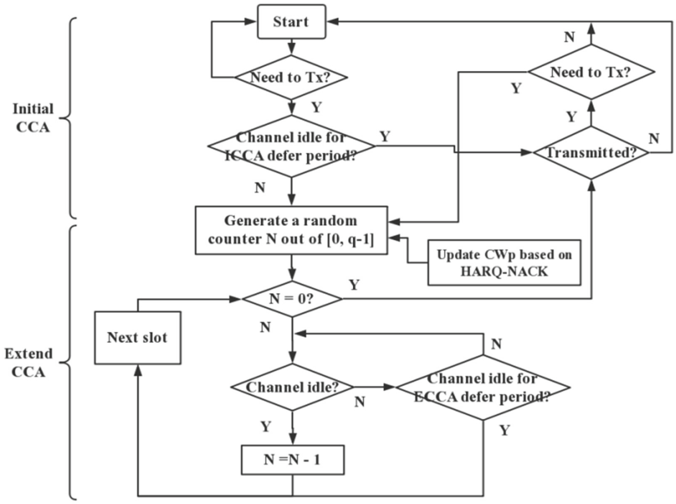


Fig. 1. LBT access procedure.

The adjustment steps of the backoff counter N in ECCA stage are as follows:

Step1: let $N = N_{init}$, with N_{init} the initial random counter selected in the domain from 0 to CW_p;
Step2: if $N > 0$, decrease the backoff counter by 1, that is, $N = N - 1$;
Step3: monitor another slot, if the slot is idle, go to Step4; otherwise go to Step5;
Step4: if $N = 0$, eNB can transmit data; otherwise go to Step5;
Step5: detect another delay time T_d;
Step6: if the delay time is idle, go to Step2; otherwise go to Step 5.

If eNB does not transmit immediately after completing Step4, eNB continues to detect at least one additional delay time T_d. If the channel is idle, eNB can transmit data.

For each priority, there are defined values for m_p, $CW_{\min,p}$, $CW_{\max,p}$, maximum channel occupation time $T_{m\cot,p}$, and delay duration T_d. Delay time T_d includes $T_f = 16\,\mu s$ and m_p successive time slots, and the length for each time slot is $T_{slot} = 9\,\mu s$, thus

$$T_d = T_f + m_p * T_{slot} = 16\mu s + \mathrm{m_p} * 9\mathrm{ms} \tag{1}$$

CW_p is the size of the contention window, with the relation $CW_{\min,p} < CW_p < CW_{\max,p}$. The value of m_p, $CW_{\max,p}$ and $CW_{\min,p}$ is determined by eNB according to the transmitting access priority. The eNB shall not continuously transmit on a carrier, where the LAA transmission is conducted, for a time period exceeding the maximum channel occupation time $T_{m\cot,p}$. Under certain conditions, $T_{m\cot,p}$ can reach 10 ms for $p = 3$ and $p = 4$.

The lower the value of p, the higher the priority, and the shorter the waiting time when data needs to be sent (Table 1).

Table 1. Downlink LBT access priority.

p	m_p	$CW_{\min,p}$	$CW_{\max,p}$	$T_{m\cot,p}$	Allowed CW_p sizes
1	1	3	7	2 ms	{3,7}
2	1	7	15	3 ms	{7,15}
3	3	15	63	8 or 10 ms	{15,31,63}
4	7	15	1023	8 or 10 ms	{15,31,63,127,255,511,1023}

Contention Window Adjustment Procedure. For every priority class p, Let $CW_p = CW_{\min,p}$. If 80% or more received HARQ-ACK values in reference subframe are HARQ-NACK, the data transmission is considered as failed and CW_p is increased to the next higher value specified in every p.

2.2 WiFi CSMA/CA Access Mechanism

CSMA/CA Access Procedure. WiFi device gets the opportunity to transmit data through competing the channel according to DCF mechanism based on CSMA/CA.

When WiFi device has data to transmit, it firstly monitors the channel. If the channel is idle for DIFS (Distributed InterFrame Space) duration, it can perform backoff and send data frame. If the destination device correctly receives the data, it sends an ACK frame to the source device after SIFS (Short InterFrame Space) duration. Then if the source device does not receive the ACK frame, it will re-transmit the data frame after waiting for a period of time. DIFS is expressed as

$$DIFS = 2 * SlotTime + SIFS \tag{2}$$

where *SlotTime* is time length of a slot.

When the channel is busy, the device delays the sending of data. After the channel becomes idle, device delays DIFS time and waits for a random backoff time before sends the data. The expression of backoff duration is

$$BackoffTime = N * SlotTime \tag{3}$$

where N is the generated backoff counter, which is a random integer uniformly distributed in the domain of [0, CW]. Contention window size CW is in an integer between $CW_{\min}$ and $CW_{\max}$.

The binary exponential backoff (BEB) algorithm is used in DCF to lower the collision probability between stations transmitting at the same time. The backoff counter randomly selects a positive integer value as the initial value in the interval. The backoff process and contention window size adjustment of BEB are as following steps:

Step1: randomly select an integer N in the contention window [0, CW_1], where CW_1 is the contention window size of the first try, and the integer N is backoff counter.

Setp2: keep monitoring the channel. If the channel is idle during DIFS duration, the backoff counter then begins to decrease according to the number of idle slots.
Step3: transmit frames when backoff counter reaches 0.
Setp4: if the transmission fails, double the contention window size.
Step5: when contention window size CW_i in the i th try reaches $CW_{\max}$, maintains the value of $CW_{\max}$.
Step6: the data is discarded after twice unsuccessful transmission with the competition window size of $CW_{\max}$, then the contention window is reset to $CW_{\min}$ to compete the channel for other data frames.

Enhanced Distributed Channel Access (EDCA). DCF mechanism treats all data equally, and all types of data will be put into the same queue. Therefore, some services with higher real-time requirements cannot be immediately served. EDCA is an optimized version of DCF Access mechanism, which is also based on competition but provides differentiated services to guarantee QoS (Quality of Service).

Table 2. Parameters of different ACs.

Priority	AC	$CW_{\min}$	$CW_{\max}$	AIFSN
Lowest	Background	$CW_{\min}$	$CW_{\max}$	7
	Best effort	$CW_{\min}$	$CW_{\max}$	3
	Video	$(CW_{\min}+2)/2-1$	$CW_{\min}$	2
Highest	Voice	$(CW_{\min}+1)/4-1$	$(CW_{\min}+1)/2-1$	2

Four access categories (AC) are specified in IEEE 802.11e protocol, and the transmission priority of each AC is different. Data of different types enter the corresponding queue respectively. The priority of the four access categories is Voice (AC_VO) > Video (AC_VI) > Best Effort (AC_BE) > Background (AC_BK).

Different ACs use different AIFS (Arbitration InterFrame Space) to replace the single DIFS in DCF. The expression of AIFS is

$$AIFS[i] = SIFS + AIFSN[i] * SlotTime \tag{4}$$

where $AIFSN[i]$ is the number of idle time slots for a certain AC that have to defer after SIFS when the channel is idle.$AIFS[i]$ times of different ACs can be obtained from Eq. 4. Different ACs also have different contention windows size CW. The expression of backoff time in EDCA is the same as in DCF, while the value of CW changes. It can be seen from Table 2 that the queue with high priority has a smaller contention window size, so the randomly generated backoff counter and the calculated backoff time are smaller. Figure 3 shows the transmission schematic of the EDCA mechanism (Fig. 2).

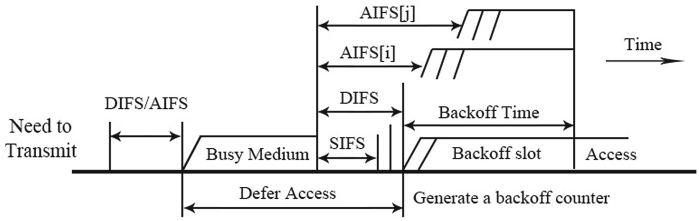


Fig. 2. Access schematic of EDCA mechanism.

2.3 Literature Research

A large number of literature studied the access method of LAA under the scenario of LAA and WiFi coexistence, hoping to get better coexistence performance.

To provide foundations for LAA standardization, literature [8] analytically derives a dynamic switch based optimum access method for LAA between random access and scheduling. However, it overlooks the impact of the proposed LAA scheme on the WiFi performance. In [9], the linear backoff LBT is used to modify the channel usage and the communication performance of the overall scenario with the validation provided by simulations. But the evaluation of WiFi performance is not taken into its consideration. In [6], LAA with and without LBT and LBT are analyzed and simulated. It is concluded that LAA without LBT may have a significant performance impact to WiFi, which is much greater to that of introducing another WiFi system. It also demonstrates that including LBT in LAA is the necessary condition but not the sufficient condition for fair coexistence between LAA and WiFi, the LBT scheme and parameter settings of LBT must be carefully selected to be more WiFi like to ensure fairness. Aiming to analyze and compare the effect of different LBT schemes, literature [10] studies the fixe, linear and the 3GPP specified exponential LAA coexistence schemes. Both theoretical expects and simulation results reveal that the 3GPP specified LAA scheme is the fairest one among the three LAA schemes when coexist with WiFi system, while the fixed LAA scheme is more beneficial to LAA but more unfriendly to WiFi.

And there also literature to modify the LBT channel access mechanism. Literature [11] and [12] studies the performance of adaptive contention window size based on the Cat-4 LBT mechanism. [11] focuses on enhancing the access scheme with the contention window size adjusted to a reasonable value by collecting the QoS information from neighbor nodes so as to achieve the access fairness as well as QoS fairness. [12] calculates the slot utilization rate in a short time duration and adjust the contention window size accordingly to achieve fairness and higher throughput gain. Literature [13] finds out that the fairness largely depends on the energy detection threshold used by LAA. The higher the sensing threshold of LAA, the better the overall system throughput at the cost of WiFi performance; whereas lower threshold results in better WiFi performance but degrades the overall network performance. Thus, there is a tradeoff in the selection of LAA energy sensing threshold. In [14], the relationship of fairness and TXOP (transmission opportunity) of LAA is studied. It summarizes that if the TXOP exceeds a certain threshold, an LAA-WiFi coexistence scenario can realize a higher maximum sum rate of the coexistence network than the single WiFi network. [15] quantifies the

WiFi throughput as the function of LAA transmission time, from which the constrains of LAA transmission time can be determined in order to achieve different protective targets of WiFi system. Under the constrains, the maximum overall channel rate can be optimized by properly setting LAA transmission time.

Above researches all consider the LAA-WiFi coexistence scenarios from the contention aspect. The performance improvement of one system and the whole scenario is achieved by sacrificing the performance of the other system.

3 Cell Cooperation Based Channel Access Mechanism

3.1 Basic Idea of Proposed Scheme

Considering that the performance of the WiFi system is always inferior to that of LAA in the scenario where the mutual influence of LAA and WiFi is serious, the scheme of cell cooperation is proposed to help improve the performance of WiFi system, so as to improve the data transmission capacity and spectrum efficiency of coexistence scenario by treating the two systems from the collaborative perspective.

The basic idea of cell cooperation is to establish cooperative cells with LAA and WiFi on the premise that the LAA and the WiFi device can understand the signal from each other. An LAA-eNB and a WiFi AP form a pair of cooperative relationship. During the channel access and transmission of the LAA-eNB, the LAA-eNB notifies the paired WiFi AP to share the transmission opportunity with the information piggybacked in the header of the transmitted frame. Then, the WiFi AP as well as the STAs who are associated with this AP and successfully received the information need to update its NAV with time duration equal to the transmission time of the ongoing LAA frame. Later, after the LAA-eNB completes the transmission, the WiFi AP can directly access the channel for data transmission, no longer need to perform backoff. Similarly, when WiFi transmits frames, the cooperating LAA-eNB gets the shared transmission opportunity information from the WiFi frames and updates its NAV with the time duration equal to the information exchange time of WiFi system. Then, when WiFi finishes the transmission, the LAA-eNB accesses the channel and transmits data frames.

It has to be noted that this cooperative relationship should be finished after the cooperation completes, and then the two cells need to compete for the channel resources if they have data to send. After competing for the channel and one of them successfully access the channel, they can cooperate again by informing the other one the shared transmission opportunity. The above cooperative access process is cyclical. In short, after a cooperative transmission, the two cells cannot cooperate again immediately and need to compete for the channel. When one of the cells gets the channel resources, they can cooperate again. This suspension is necessary, otherwise if the paired cells always have data to send, these two cells will always occupy the spectrum resources, affecting the communication of other cells.

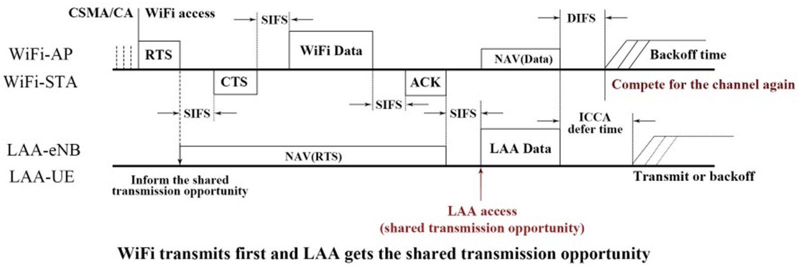


Fig. 3. Cooperation diagram for LAA.

3.2 Protocol Description

For LAA-ENB. For cooperating LAA cell, the backoff access process of LAA-ENB is basically the same as that of LAA-ENB not involved in cooperation, that is, ICCA and ECCA monitoring and LBT process are also required. The protocol is described as follows.

Every time the eNB notices that the channel enters a busy state, it needs to figure out which station is sending data. If it is the paired WiFi AP that is transmitting, the eNB gets the shared transmission opportunity and the WiFi data exchange time duration from the frame header, and updates its NAV with the time duration informed.

After the transmission of AP, the NAV time expires. The eNB uses its shared transmission opportunity and accesses the channel directly after the channel is idle for SIFS time.

For WiFi AP. For cooperative WiFi cell, the backoff process of AP is basically the same as that of WiFi AP not involved in cooperation, that is, channel monitoring and CSMA/CA process are also required. The protocol is described as follows.

When the cooperating LAA-eNB is transmitting, it notifies the AP and the relevant STAs with the shared transmission opportunity and time duration needed for LAA data transmission. Then the WiFi devices update their NAV with the informed time duration.

After the paired LAA-eNB finished transmission, and the channel is idle during the SIFS time, the cooperating AP can access the channel directly due to the shared transmission opportunity from the LAA-eNB.

Considering that there are four queues with different priorities in the EDCA mechanism, before transmitting, AP needs to determine which of the four queues has the shortest waiting time duration (the sum of the AIFS duration and the remaining backoff time), and let the chosen queue to access the channel and transmit data right after the channel is idle for SIFS time. Other queues remain the default backoff procedure (Fig. 4).

Cooperation Procedure. If eNB completes the transmission and AP follows eNB to transmit directly using the shared transmission opportunity, the AP finishes the cooperation, which means the eNB cannot follow the AP that to send data again. If they still have

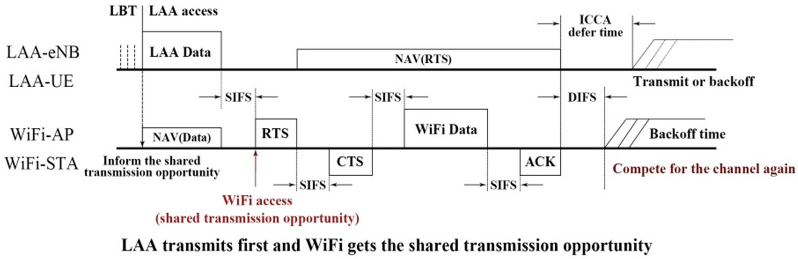


Fig. 4. Cooperation diagram for WiFi.

data frames in the buffer, they need to compete the channel resources After the cooperation is finished to guarantee transmission opportunities for other cells in the whole coexistence scenario. And it is also the case when AP transmits first in a cooperative pair.

If the cooperation is not finished after the use of the shared transmission opportunity, the two cells in cooperation will continuously occupying the spectrum resources when they always have data to transmit, which will affect the communication of other cells. So the interaction between the two cells in a pair of cooperative relationship is described as following steps.

Step1: LAA-eNB and WiFi AP do the contention to access the channel;
Step2: LAA-eNB/WiFi AP access the channel and transmit;
Step3: WiFi AP/LAA-eNB gets the shared transmission opportunity;
Step4: WiFi AP/LAA-eNB access the channel and transmit follows the Step2′s transmission after the channel is idle for SIFS duration, then go to Step1.

4 Performance Evaluation

4.1 Simulation Platform

All the simulations in this paper is implemented on the NS-3 network simulation platform.

The LAA and WiFi coexistence module [16] provides support to simulate the WiFi and variant LTE systems coexistence scenarios in the 5 GHz frequency band. This module develops LAA models for LBT defined in LTE Release-13 by 3GPP, and will not affect the function of original LTE module and WiFi module.

In order to modify an LTE network device into an LAA network device, the link between the MAC layer and the physical layer of LTE device is disconnected and an intermediate object, ChannelAccessManager, is added between to realize information synchronization and control between LAA and WiFi devices. ChannelAccessManager monitors the channel state by registering a listener of WiFi physical layer, and it could also be extended for receiving the Network Allocation Vector (NAV) from the lower MAC layer. The default ChannelAccessManager allows the LTE device to transmit at all times. The LbtAccessManager class, which is specialized from ChannelAccessManager, implements the function of sensing the channel as well as providing the necessary exponential backoff procedure specified in Release-13. To configure the type of channelaccessmanager, a new global value called channelaccessmanager need to be selected form three possible values: default, dutycycle, and LBT. When configuring the LAA network device, WiFi physical layer is attached to the LAA-eNB device with reception of WiFi frames disabled to ensure the information synchronization between the LAA and WiFi. The LAA network device and WiFi network device are connected to the same SpectrumChannel.

4.2 Scenario Design

Scenario Settings. Deploy two kinds of LAA-WiFi scenarios to run the downlink transmission simulation. All the parameters, except the standard and testing variables, are set to be as similar as possible to evaluate the performances of two operators and the proposed accessing mechanism. The detailed scenario design is as follows (Fig. 5 and Tables 3 and 4).

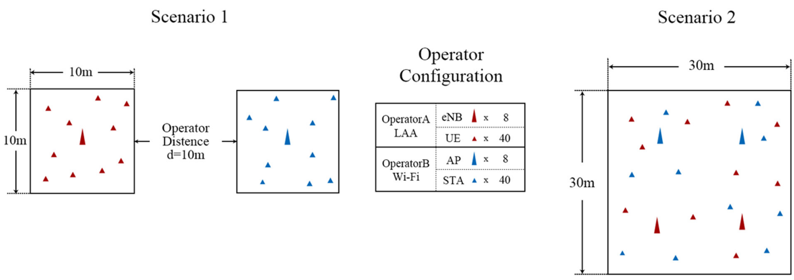


Fig. 5. Coexistence scenarios.

Table 3. Scenario configurations.

Two scenarios	2 * 8 * 5 LAA-WiFi downlink transmission
Operator number	2
Cell number each operator	8
UE/STA number each cell	5
Cooperative pair number	8
Number of nodes need to transmit	16

Varying Parameters. Compare the network performance with different WiFi carrier sensing threshold between −82 dBm and −62 dBm. Since the proposed cell cooperation scheme may shows its advantages in scenarios with higher channel access demands, let

Table 4. Parameter settings.

Parameters	LAA	WiFi
Access standard	Cat-4 LBT (Release 13)	CSMA/CA (802.11n)
Access priority	3	AC_BE
Carrier sensing threshold	−72 dBm	variable
Scheduling	proportional Fairness	/
Radio bearer	UM	/
RTS/CTS	/	Yes
A-MPDU	/	65535 Bytes
Working frequency	5 GHz	
Bandwidth	20 MHz	
Physical layer data rate	9.9 Mbps	
Rate control algorithm	constant rate	
Packet size	1000 bytes	
Buffer size	always full buffer	
Service type	constant bit flow with UDP protocol	
Propagation loss model	log distance propagation loss model	
Tx power	18 dBm	
Tx gain	5 dB	
Antenna mode	SISO	

the required UDP rate of a UE or STA varying from 0.05 Mbps to 0.4 Mbps, and observe the communication performances of the two systems.

Performance Metrics. Calculate the throughput and average time delay per packet of the two operators respectively in the scenarios. If necessary, calculate and compare the total throughput of the scenario, that is, the sum throughput of the two systems. All the simulation figures use the UDP rate (unit: Mbps) as horizontal axis.

4.3 Results Analysis

Results of Scenario 1. The operator throughput and average time delay per packet of scenario 1 are shown in the following Fig. 6 and Fig. 7.

After the implementation of cell cooperation based channel success mechanism, performance of WiFi in the coexistence scenario is greatly improved especially when WiFi is in a more conservative state. In Fig. 6, when the carrier sensing threshold of WiFi is −82 dBm, the throughput is increased about 1 Mbps in average before the channel is saturated (namely the UDP rate is less than 0.1 Mbps) and about 1.5 Mbps in average

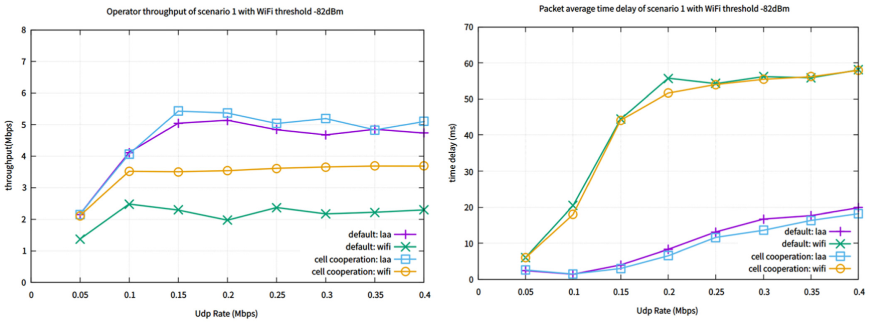


Fig. 6. Performance of scenario 1 with WiFi threshold −82 dBm.

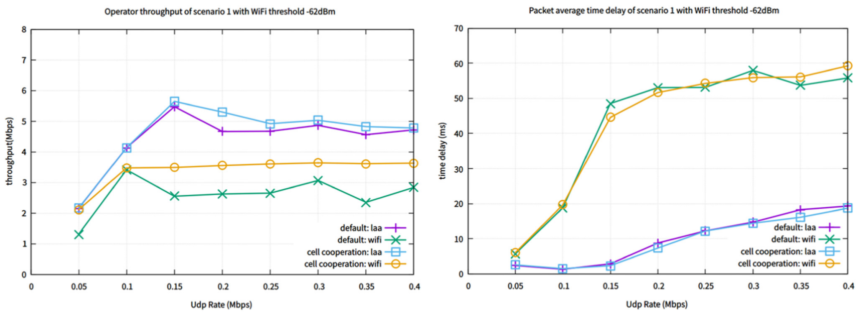


Fig. 7. Performance of scenario 1 with WiFi threshold −62 dBm.

after the saturation of channel with the average time delay per packet gets shortened. In Fig. 7, even when WiFi is radical with a carrier sensing threshold of −62 dBm, WiFi can get a throughput increment by about 1Mbps in average. Meanwhile, the performance of LAA also benefits from the proposed cell cooperation scheme. The throughput of LAA slightly increases and average time delay slightly decreases.

Results of Scenario 2. The operator throughput and average time delay per packet of scenario 2 are shown in the following figures. The simulation results of scenario 2 (Fig. 8 and Fig. 9) are similar to that of scenario 1, with throughput of WiFi and LAA both increased and average Time delay per packet slightly decreased. And the performance improvement of LAA in scenario 2 is more obvious than that in scenario 1.

Total Throughput Comparison. The total throughput comparison of scenarios with/without cell cooperation scheme are shown in Fig. 10 and Fig. 11.

According to above results analysis of the two scenarios, since both LAA operator and WiFi operator get better communication performance in throughput and average time delay per packet, the total throughput of the coexistence scenario is raised about 2 Mbps in average and almost reaches the maximum allowed data rate in the parameter settings due to the proposed cell cooperation based channel access mechanism, which also means the spectrum resources are utilized in a more efficient way.

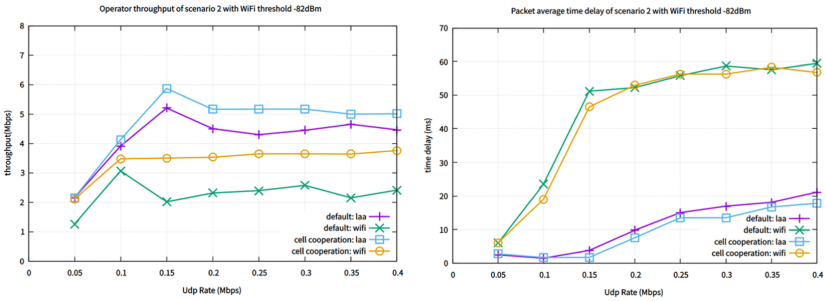


Fig. 8. Performance of scenario 2 with WiFi threshold −82 dBm.

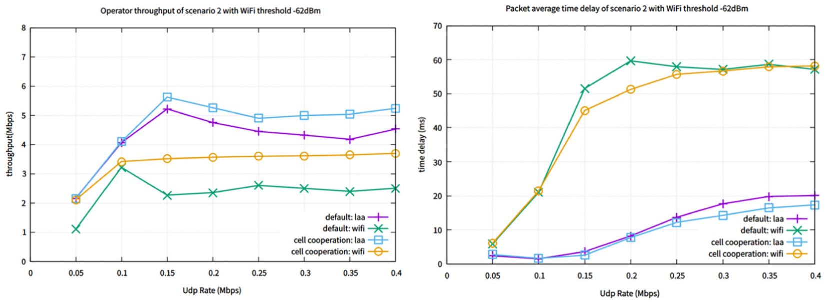
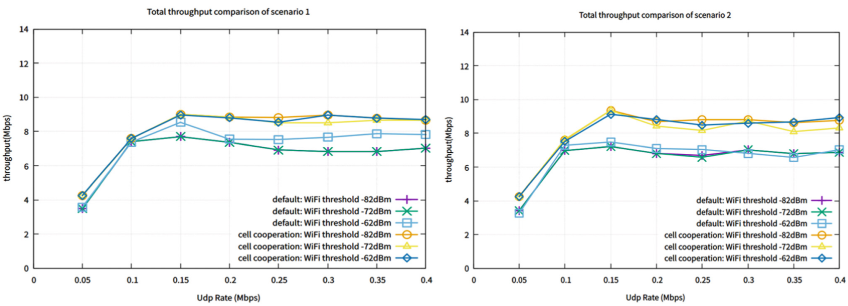


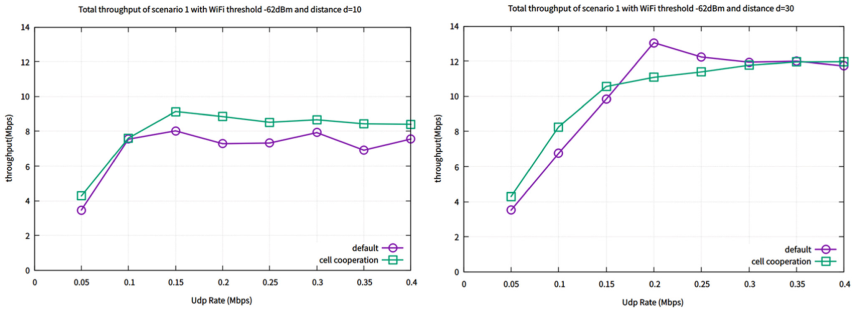
Fig. 9. Performance of scenario 2 with WiFi threshold −62 dBm.



(a) Scenario 1. (b) Scenario 2.

Fig. 10. Total throughput comparison of scenarios with/without cell cooperation scheme.

The simulation is also conducted in scenario 1 with a larger operator distance under the condition of a −62 dBm WiFi carrier sensing threshold to evaluate the effectiveness of the proposed cell cooperation scheme when the mutual influence between the two operators is not severe. However, simulation results in Fig. 11 show that the throughput improvement effect of the proposed scheme reduces when the distance between two operators increases, which means the proposed scheme can better reveal its advantages in the coexistence scenarios with higher traffic density and more channel access demands.



(a) d=10m. (b) d=30m.

Fig. 11. Total throughput comparison of scenario1 with different distance d.

And it is not necessary to be implemented to promote the spectrum efficiency in "non-hotspot" areas.

5 Conclusions and Future Works

This paper proposed a cell cooperation based channel access mechanism, making an LAA cell and a WiFi cell in the coexistence scenario form a pair of cooperative relationship. If one in the cooperative relationship accesses the channel, it will notify the other cell the shared transmission opportunity. Then the latter cell can access the channel directly without performing backoff again when the former transmission is finished and channel is detected to be idle for SIFS duration. Simulation and analysis of cell cooperation mechanism is performed in two kinds of LAA-WiFi coexistence scenarios. The simulation results show that the cell cooperation based channel access mechanism can improve the throughput and time delay performances of the WiFi system as well as the entire system of the coexistence scenario with a high channel resources demand. The cell cooperation scheme will be more complex in the uplink transmission coexistence scenarios which will be included in our future work.

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