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비면허대역 LTE-면허지원접속에서 멀티캐리어 Listen Before Talk 기법들의 공존성 연구

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Coexistence of Multi-Carrier Listen Before Talk (LBT) Mechanisms for LTE-Licensed Assisted Access (LAA) in Unlicensed Spectrums

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요 약

Licensed-Assisted Access (LAA)는 비면허대역을 이용하기 위한 3GPP LTE 시스템의 새로운 기능이다. LTE 시스템이 비면허대역을 이용하기 위해 고려되어야 하는 중요한 요소는 Wi-Fi 등의 기존 기술과 공평하게 공존하는 것이다. 이를 위해, LAA는 Listen-before-Talk (LBT) 기반의 Clear Channel Assessment (CCA)를 도입하였고, 많은 시뮬레이션 스터디를 통해 Wi-Fi와의 공존성이 확인되었다. 하지만, 다중 캐리어 전송 시 사용 가능한 LBT 옵션들 사이의 공존성은 아직 연구되지 않았다. 서로 다른 LAA 사업자는 개별적인 LBT 옵션을 사용할 수 있으므로, 이들 사이의 공존성 역시 중요한 문제이다. 본 논문에서는 비면허대역에서 다중 캐리어 전송 시 사용 가능한 서로 다른 LBT 방식의 LAA 기지국들이 공존할 때, 이들 사이의 공존성을 시스템 수율과 채널 점유율, 그리고 딜레이 관점에서 시뮬레이션을 통해 분석한다.

Key Words : Coexistence, LTE-LAA, Listen-before-talk, LBT, multi-carrier, unlicensed spectrum

ABSTRACT

Licensed-Assisted Access (LAA) is the new feature of 3GPP Long-Term Evolution (LTE) that utilizes unlicensed bands as a means of providing additional bandwidth to aggregate. An important consideration for LTE's operation in unlicensed spectrum is to guarantee fair coexistence with other incumbent systems such as Wi-Fi and other LAA cells/users. For this purpose, LAA's Clear Channel Assessment (CCA) has been designed based on Listen-before-Talk (LBT) and verified to support fair access with Wi-Fi through extensive simulation studies. However, coexistence between different LBT options for multi-carrier operation has not been studied yet. Since different LAA operators may use individual LBT options, their coexistence could also be a serious issue. In this paper, we study the coexistence problem of different LBT options available for multi-carrier operation in unlicensed bands through extensive simulation in terms of system throughput, channel occupancy rate and delay.

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Ⅰ. Introduction

The recent study of the 3rd Generation Partnership Project (3GPP) has started to enable the operation of a LTE system in unlicensed spectrum, both 2.4GHz and 5GHz with a multi-carrier support. To address the coexistence of LTE and other wireless technologies such as IEEE 802.11 WLANs which has been the prominent technology in these unlicensed bands, a new feature named Licensed-Assisted Access (LAA) is supplemented in the LTE system from 3GPP Release 13[1]. An important consideration for LTE's operation in unlicensed spectrum is the guarantee of fair coexistence with other incumbent systems such as Wi-Fi and other LAA cells/users. For this purpose, LAA's Clear Channel Assessment (CCA) has been designed based on Listen-before-Talk (LBT) concept and verified to support fair channel access with Wi-Fi through extensive simulation studies[2-4].

LAA supports several options of LBT operation for multi-carrier operation. The options are classified into Types A and B according to how to run and coordinate LBT processes among different carriers of aggregation. In Type A, the LBT procedure is performed independently on each carrier. There exist additional variants of Type A based on the usage of self-deferral which is an additional defer duration at the end of backoff to align the beginning of transmission in multiple carriers for avoidance of the RF leakage problem[5,6]. In Type B, the LBT procedure is performed similar with Wi-Fi's known as channel bonding; full LBT (backoff) is performed on a primary carrier only while a single-slot CCA (also known as initial CCA or iCCA) is performed on other carriers of aggregation.

Unlicensed spectrum is shared by not only heterogeneous wireless technologies, but also multiple operators of the same technology. Thus there may be different LAA operators sharing the same bands. Since they are free to choose LBT options for multi-carrier operation, investigating their coexistence is also needed, which has not been attempted yet in the literature.

In this paper, we study the coexistence problem of different LBT options available for multi-carrier operation in unlicensed bands through extensive simulation in terms of system throughput and channel occupancy rate. The results show that fair medium sharing is achieved when operators use the same LBT option. When different LBT options coexist, however, we see that different combinations of coexisting LBT options lead to different coexistence trends. In particular, Type A - noSD shows the best performance among all while Type A - fixedSD is the worst due to missing channel access opportunities during self-deferral.

The rest of the paper is organized as follows. In Section II, we review related works on LTE-LAA and LBT mechanisms. The details of multi-carrier LBT options of LTE-LAA are described in Section III. Section IV shows performance results and discussion. We make a conclusion in Section V.

Ⅱ. Related Works

There have been numerous evaluation studies in 3GPP on LBT mechanisms of LTE-LAA for coexistence with Wi-Fi systems[2,3]. However, studies on the coexistence performance of multi-carrier LBT operation are very limited. In [4], a brief introduction and a performance evaluation of multi-carrier LBT operation with FTP traffic using up to 80MHz bandwidth. By that, LBT Type B has shown better coexistence performance due to the more flexible mechanism to select a primary channel (the carrier which finishes its backoff firstly among all is determined as the primary channel) and better alignment with the Wi-Fi procedure. In [5], the authors evaluated the coexistence of LTE-LAA and Wi-Fi under LBT Type B with and without channel bonding for LAA. The simulation results indicated that channel bonding for LAA has no impact to Wi-Fi while it significantly reduces LAA's performance. A hybrid of LBT Type A and B is proposed in [8] to obtain the advantages of both when the problem of RF power leakage between carriers exists.

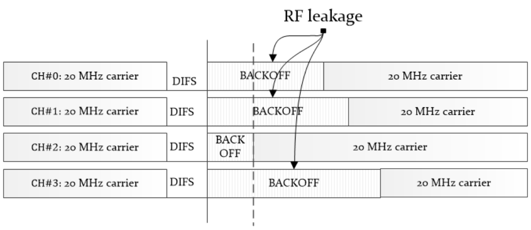
While some studies on the coexistence of each LBT type with Wi-Fi system have been made, there has been no work that considers the fairness between LTE-LAA devices using different LBT types in coexistence scenarios.

Ⅲ. LAA for Multi-Carrier Operation

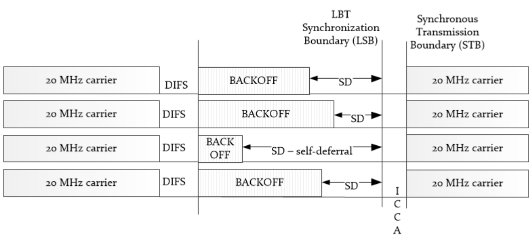
The LBT mechanism of LTE-LAA was designed for fair coexistence with Wi-Fi's distributed coordination function (DCF)[6], by which an LAA eNB performs backoff, decreases a backoff count if the channel is sensed idle for a slot time and begins transmission when the backoff count becomes zero. In LTE-LAA, an energy detection (ED) threshold is used for CCA to determine the presence of any other signal in the channel. In what follows, we describe two LBT options of LTE-LAA for multi-carrier transmission in downlink[7].

3.1 LBT Type A

The illustrative behavior of Type A is shown in Fig. 1. In Type A, eNB performs an independent backoff procedure for each carrier. When a backoff count becomes zero for a carrier, an additional deferral during a specified time can be performed optionally, which is called self-deferral (SD). The purpose of self-deferral is to align the transmissions of all carriers which have finished backoff. This is beneficial when RF leakage from adjacent carriers is present, which causes eNB to always sense a carrier busy when any transmission is being performed on its adjacent carrier(s). If self-deferral is used, eNB defines an LBT synchronization boundary (LSB) and does not allow transmission on any carrier before LSB so that a carrier with a zero backoff count does not disturb ongoing backoff processes of others. At LSB, CCA for a single slot time, called initial CCA (ICCA), is performed to ensure no signal or transmission on the set of carriers for which ICCA was successful.



(a) LBT Type A with no self-deferral



(b) LBT Type A with self-deferral to combat RF leakage

그림 1. 멀티캐리어 LBT 타입 A
Fig. 1. Multi-carrier LBT Type A

3.2 LBT Type B

The operation of Type B is similar with the wide channel access mechanism of Wi-Fi in that backoff is performed in a single channel only, called a primary channel in Wi-Fi. On the other carriers, a CCA check for a single slot time is performed when eNB has just finished backoff on the primary carrier. Transmission starts only on the carriers with a successful CCA check (sensed idle). The operation of Type B is illustrated in Fig. 2.

While a channel bonding rule is applied to Wi-Fi, which restricts channel sets to be aggregated, LAA does not adopt it and support any set of carriers for aggregation. The authors of [5] studied the impact of channel bonding to the system performance of LAA in Wi-Fi coexistence scenarios and showed that the channel boding rule of LAA has no impact on Wi-Fi performance while deteriorating LAA performance.

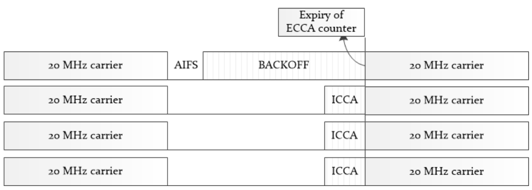


그림 2. 멀티캐리어 LBT 타입 B
Fig. 2. Multi-carrier LBT Type B

Ⅳ. Evaluation Results

4.1 Settings

In simulation, we evaluate three cases of LBT options: Type A without self-deferral (noSD), with it (fixedSD) and Type B. In Type A – fixedSD, the LSB of self-deferral is determined as the time apart by a predefined self-deferral period fixed as 10 slots from the time when an LAA eNB triggers self-deferral. The coexistence scenarios under consideration are (1) identical LBT options among two operators, (2) different LBT options among two, and (3) all different LBT options among three operators. For each operator, a single LAA eNB is deployed and a User Equipment (UE) is connected to each. Since we focus on the channel access behavior of different LBT options when they coexist, we deploy all eNBs and UEs in the same location, thus letting each sense the others. RF leakage between carriers is not considered in the simulation. Therefore, the difference between Type A-fixedSD and –noSD is the transmission timing after backoff only. We use an in-house simulator written in C++. More simulation parameters are listed in the Table. 1.

The performance metrics for evaluation are eNB throughput, channel occupancy rate (channel occupancy time of successful transmissions over total simulation time) and access delay (time interval from the beginning of a packet transmission attempt to the successful transmission of the packet).

표 1. 시뮬레이션 설정 파라미터
Table 1. Simulation configuration parameters

Parameter	Value	Parameter	Value
Carrier frequency	5GHz	Carrier bandwidth	20MHz
Number of carriers	2	Transmission direction	DL and UL
Data traffic Model	Full-buffer	MAC payload size	1500 bytes
Slot time	9us	SIFS	16us
DIFS	34us	CWmin	16
CWmax	63	Max. Tx duration	1ms
MCS	LTE Rel. 9		

4.2 Simulation Results

Figs. 3 and 4 show the throughput performance and access delay of each eNB, respectively, in the identical LBT option scenario. As we expect, eNBs achieve similar performance between them for each LBT option case since they behave same. The results also show that different LBT options achieve similar throughput performance. However, with respect to access delay, there is a significant difference between Type A and Type B; Type B has almost doubled delay compared with Type A. This is because Type A starts transmission when any carrier finishes its backoff while Type B does when the primary carrier finishes backoff. If the primary carrier has heavy background traffic, eNB will experience long access delay. In the meantime, Type A with a fixed SD period has slightly longer access delay than Type A with no SD since an additional waiting period for self-deferral is added at the end of backoff for each round of LBT.

The coexistence of different LBT options is explored and the results are shown in Figs. 5 and 6 in terms of throughput and delay, respectively. In the figures, the first three groups are the coexistence cases of two different LBT options (with two eNBs) while the last one is the coexistence case of all three

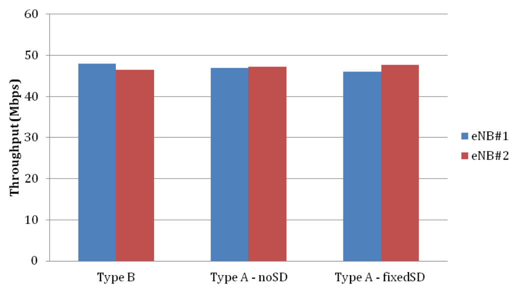


그림 3. 동종 LBT 상황에서 하향링크 수율
Fig. 3. Downlink eNB throughput in the identical LBT scenario

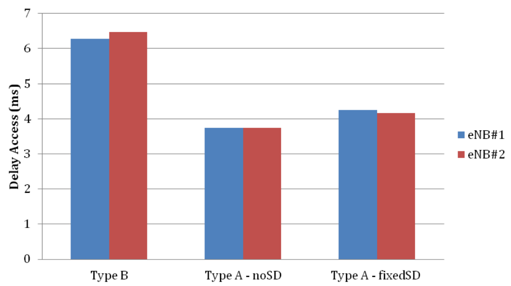


그림 4. 동종 LBT 상황에서 액세스 딜레이
Fig. 4. Access delay in the identical LBT scenario

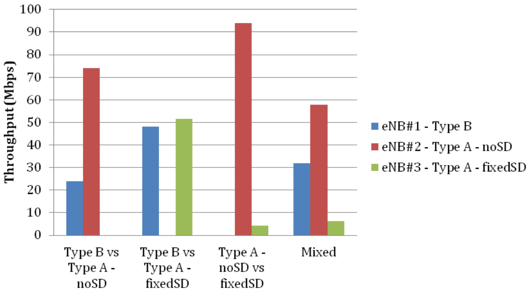


그림 5. 이종 LBT 공존 상황에서 하향링크 수율
Fig. 5. Downlink throughput in the coexistence scenarios of different LBT options

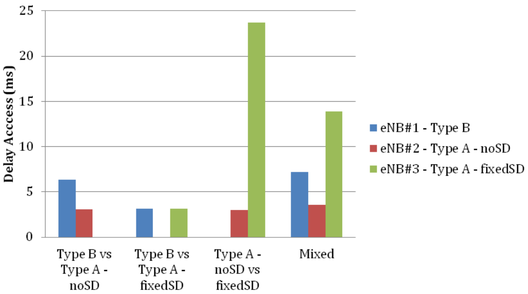


그림 6. 이종 LBT 공존 상황에서 액세스 딜레이
Fig. 6. Access delay in the coexistence scenarios of different LBT options

options (with three eNBs). Therefore, for the first three cases, there exist only two bars of performance. In Fig. 5, we observe a significant gap between different LBT options except the coexistence case of Type A – fixedSD and Type B. When Type A - noSD coexists with Type B, the throughput of Type B is only one third of that of Type A – noSD; the throughput of Type B is almost halved from the case of Type B only in Fig. 3 (from 47 to 23.5Mbps). To investigate the cause of such gaps, Table 2 shows the channel occupancy rate of each carrier for different coexistence scenarios. Type A – noSD and Type B achieve almost the same channel occupancy rate for CH#0 which is the primary carrier of Type B since they behave almost same on CH#0. However, they have different behaviors for CH#1; Type B checks the availability of CH#1 only at the highly limited set of time points when backoff finishes for CH#0 while Type A – noSD runs individual backoff for CH#1, thus checking its availability continuously. Such a difference results in the unfair channel occupancy that Type A – noSD uses CH#1 almost exclusively. The sensing duration on the secondary carrier of LBT Type B (ICCA) is as short as 25μs. If the carrier is sensed busy in this one-shot CCA, eNB loses the opportunity to use this carrier until the backoff process of the primary carrier finishes next time. Therefore, the channel occupancy rate of Type B on the secondary carrier (CH#1) is low.

In Fig. 5, it looks like Type B and Type A – fixedSD coexist well since they show similar throughput performance. However, as given in the Table 2, there is a huge gap of the channel occupancy rates between them. The one that uses CH#0 is mostly the eNB with Type B (54.4 vs. 1.6%) while the eNB with Type A - fixedSD mostly uses CH#1 (0.2 vs. 53.8%). The small rate of channel usage on CH#0 of Type A - fixedSD is due to the additional deferring while Type B transmits immediately at the end of backoff, which significantly reduces the channel access rate of Type A - fixedSD on CH#0. Similarly in Type B vs. Type A – noSD, Type A – fixedSD has the dominant channel occupancy rate on CH#1. The additional self-deferral duration of Type A - fixedSD also

표 2. 이종 LBT 공존 상황에서 CH#0와 CH#1의 점유율
Table 2. Channel occupancy rate of CH#0 and CH#1 - different LBT options scenarios

Scenario	LBT option	Channel occupancy rate	
		CH#0	CH#1
Type B vs. Type A – noSD	Type B	27.3%	0%
	Type A - noSD	27.4%	56.9%
Type B vs. Type A - fixedSD	Type B	54.4%	0.2%
	Type A - fixedSD	1.6%	53.8%
Type A - noSD vs. Type A - fixedSD	Type A - noSD	53.1%	53.7%
	Type A - fixedSD	2.5%	2.2%
All three LBT options	Type B	24.1%	12.5%
	Type A - noSD	27.1%	39.2%
	Type A - fixedSD	3.7%	3.1%

causes a huge impact reducing the throughput and channel occupancy rate in the coexistence scenario of Type A - noSD vs. type A – fixedSD. In the last case of all LBT options case, the performance of Type B is improved while that of Type A - noSD is reduced since more eNBs are contending for channel access, especially on CH#1 as shown in Table 2.

We also evaluate the access delay for all scenarios and the results are shown in Fig. 6. First, Type A - noSD achieves the smallest delay. The worst performance is in Type A - fixedSD under the coexistence with Type A - noSD due to its small channel access probability. In the scenario of Type B vs. Type A - fixedSD, both eNBs have almost similar delay performance as small as 3ms. This is because, although they show pretty different trends of channel occupancy between carriers, they happen to have similar channel occupancy rates in total.

Ⅴ. Conclusion

In this paper, the coexistence of different LBT options for multi-carrier operation of LTE-LAA was investigated in terms of system throughput, channel occupancy rate and access delay obtained through extensive simulation work. As expected, fair medium sharing is achieved when operators use the same LBT option. When different LBT options coexist, however, we showed that different combinations of coexisting LBT options lead to different coexistence trends. Type A - noSD showed the best performance among all while Type A - fixedSD was the worst due to missing channel access opportunities during self-deferral. Type B showed low usage on the secondary carrier when coexisting with Type A. We plan more comprehensive simulation work with the consideration of coexisting Wi-Fi systems for future work.

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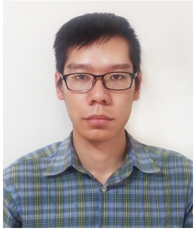

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