Cross-Retransmission Techniques in Licensed and Unlicensed Spectrum Bands over Wireless Access Networks

Eunkyung Kim(✉)

Department of Artificial Intelligence Software, Hanbat National University, 125, Dongseo-daero, Yuseong-gu, Daejeon 34158, Korea
ekim@hanbat.ac.kr

Abstract. In this paper, we propose HARQ retransmission algorithms in the wireless access networks exploiting not only licensed spectrum band but also unlicensed spectrum band with meeting the regulatory requirements such as Listen-Before-Talk. In particular, the proposed HARQ retransmission via one available component carrier regardless of the spectrum is licensed or unlicensed is beneficial in a sense that it doesn't increase the transmission latency with potential retransmissions. We also show that the proposed algorithm achieves lower transmission latency without increasing HARQ RTT through the simulation.

Keywords: Wireless networks · Latency reduction · HARQ retransmission · Unlicensed spectrum channel access

1 Introduction

Recently, wireless access networks are deploying to support drastically increasing network traffic. It is mainly due to the large demand on the mobile-related services including Internet of Things (IoT) service, Machine-to-Machine (M2M) service, etc. [8]. It is also shifting toward a new paradigm that enhances user's high quality of experience to provide continuous services with a large amount of data packets as well as low latency with high reliable data transmission between the application server and end-user in wireless access networks [9].

In order to provide the extremely large amount of network traffic in cellular system by improving spectral efficiency and data rates for broadband data services, 3GPP LTE [1] and NR [5] employ various enhanced techniques such as multiple antenna transmissions, carrier aggregation, interference management [11]. However, it is still difficult to catch up with the network explosion with the network capacity achieved by those techniques. In other words, the explosive increase in demand for mobile services is surpassing the improvement of spectral efficiency. Thus, more frequency bands and the wireless access techniques operated in those new frequency bands such as 5 GHz unlicensed band and mmWave band became a promising solution [10,11]. In particular, extending

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LTE to 5 GHz unlicensed spectrum, which is called Licensed-Assisted Access (LAA), has attracted great attention as a means to accommodate the rapid mobile data growth. In contrast to wireless access operated typically in licensed band, LAA can be operated with a shared spectrum band, i.e., 5 GHz unlicensed band [6,10]. However, it is very complicated to operate cellular systems in unlicensed spectrum. It is due to the fact that in the wireless access network such as LTE and NR, a base station (BS), e.g., eNB, and gNB, and a mobile station (MS), e.g., UE. can enjoy the spectrum band, particularly in licensed band, without any accessing the channel for the data transmission, but those transmitters shall access the channel for the data transmission with meeting the regulatory requirements for shared spectrum band. In particular, a transmitter, e.g., eNB, gNB, and UE, shall access the channel prior to the data transmission for shared spectrum band according to either the dynamic channel access mode on the top of Load Based Equipment (LBE) or the semi-static channel access mode on the top of Frame Based Equipment (FBE) [3,7]. In both channel access modes for the shared spectrum, the transmitter may apply Listen-Before-Talk (LBT) prior to performing a transmission on a cell configured with the shared spectrum channel access. In addition, it is considered that access to the shared spectrum shall be in compliance with regulatory requirements, including: (i) Clear Channel Assessment (CCA) as part of LBT operation shall be performed to ensure that the channel is not in use by any other device including initial data transmission as well as HARQ retransmissions. If the channel is considered as available, the transmitter can transmit data on the unlicensed band and (ii) Channel Occupancy Time (COT) is limited. For instance, maximum COT is 4 ms for Japan and 10 ms for Europe. Here, the COT is the total time for which a transmitter and its corresponding receiver(s) sharing the channel occupancy perform transmission(s) on the unlicensed channel after performing a CCA.

Meanwhile, low-latency with high reliability is one of the requirements to support emerging new use cases in wireless access networks such as factory automation, intelligent transport systems, and remote medical surgery [12]. In contrast to the wireless access in the licensed spectrum where a base station and a mobile station can enjoy the spectrum band without any accessing the channel for the data transmission, LAA leads to the overhead due to the CCA for the initial transmission as an additional CCA for the contiguous transmissions when the COT expires.

Figure 1 shows an example of transmission and retransmission in an unlicensed component carrier (UCC), where maximum COT and feedbacks corresponding to the downlink transmissions are assumed to be no more than 10 subframe lengths and to be transmitted via licensed component carrier (LCC), respectively. As shown in the example, HARQ retransmission for the last part of the COT may not be performed within the COT, which means additional CCA needs to occupy the channel for the HARQ retransmission. It is due to the fact that data transmission (possibly including HARQ retransmission) in unlicensed bands shall be performed with meeting the regulatory requirement, which is the CCA shall be performed whenever the occupied channel access time exceeds

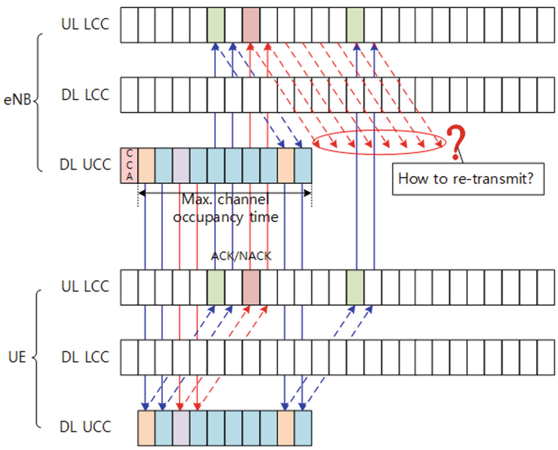

Fig. 1. An example of HARQ retransmission in shared spectrum, where LCC and UCC denote licensed component carrier and unlicensed component carrier, respectively. Maximum COT is assumed to be no more than 10 subframe lengths (i.e., 10 ms) and response for the downlink data transmission is assumed to be fed back via LCC.

the maximum allowed COT. Hence, inspired by the question *how to offer HARQ retransmission service in unlicensed spectrum*, we propose HARQ retransmission process in unlicensed spectrum as follows: (i) retransmission is only performed via UCC, (ii) retransmission is only performed via LCC, and (iii) retransmission is performed via one of any available CC (including LCC and UCC). In particular, the proposed cross-carrier retransmissions allowing the transmitter to perform retransmissions via either LCC or one of any available component carriers (CCs) including LCC and UCC can provide low-latency retransmission.

The rest of this paper is organised as follows: In the following section, we describe the channel access mechanism in unlicensed spectrum. In Sect. 3, we propose HARQ retransmission algorithms in unlicensed spectrum. Next, we compare the performance of the proposed algorithms via simulation in Sect. 4. Finally, we conclude this paper in Sect. 5.

2 Channel Access Mechanism in Unlicensed Spectrum

In this section, we summarise the channel access mechanism, adaptivity described in [3]. Here, adaptivity means that an automatic channel access mechanism by which a device avoids transmissions in a channel in the presence of transmissions from other devices in that channel. In other words, adaptivity is intended to be used to detect transmissions from other devices operating in the unlicensed bands.

In unlicensed spectrum bands according to the regulatory requirements, a device shall access the channel prior to the data transmission for shared spectrum band according to one of the channel access modes. Figure 2 shows the channel

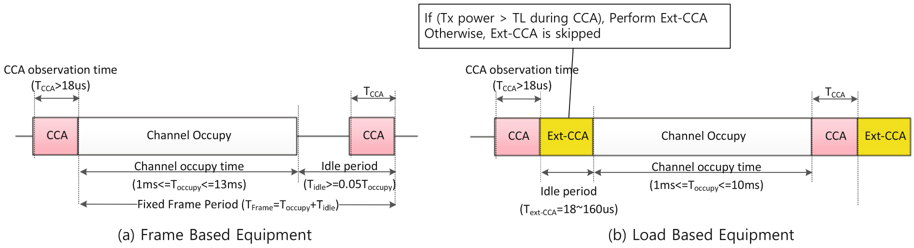

Fig. 2. Channel access modes in unlicensed spectrum band. (a) Frame Based Equipment (FBE). (b) Load Based Equipment (LBE).

access mode, which is performed semi-statically on the top of Frame Based Equipment (FBE) or dynamically on the top of Load Based Equipment (LBE).

For the semi-statical channel access mode based on FBE (see Fig. 2(a)), a device, which is intending to start transmissions on an operating channel in an unlicensed spectrum band, shall perform a clear channel assessment (CCA) check using energy detection for a duration of the time, i.e., CCA observation time (e.g., 18 μs). During the given time, if the energy level in the channel exceeds the threshold corresponding to the power level given as a CCA threshold level, the operating channel is considered occupied by another device. In this case, the device considers the channel is occupied and shall not transmit on that channel during the next Fixed Frame Period. Otherwise (i.e., if the device finds the operating channel to be clear), it is allowed to transmit data immediately. In addition, for a device having simultaneous transmissions on that channel, the device is allowed to continue transmissions on the given the channel without re-evaluating the availability of that channel. Here, the total allowed time is defined as Channel Occupancy Time (COT), which is given in range 1 ms to 10 ms, e.g., 4 ms for Japan and 10 ms for Europe. Towards the end of the Idle Period, the device shall perform a new CCA as described above, where the minimum Idle Period shall be at least 5% of the Channel Occupancy Time used by the device for the current Fixed Frame Period.

In contrast to FBE which is based on the semi-statical channel access, LBE (see Fig. 2(b)) is a dynamic Listen-Before-Talk (LBT) based spectrum sharing mechanism based on the CCA mode using energy detect, as described in IEEE 802.11 [4]. Similar to the channel mode based on FBE, a device performs a CCA check using energy detection whether to decided the channel is occupied or clear. Instead of trying CCA to transmit on that channel during the next Fixed Frame Period in FBE, the device performs an Extended CCA (Ext-CCA) check in which the operating channel is observed for a random duration in the range between 18 μs and at least 160 μs. During the Ext-CCA check, if there are no transmissions, the period is considered as the Idle Period in between transmissions. If the Ext-CCA check has determined the channel to be no longer occupied, the device may resume transmissions on this channel. The device is

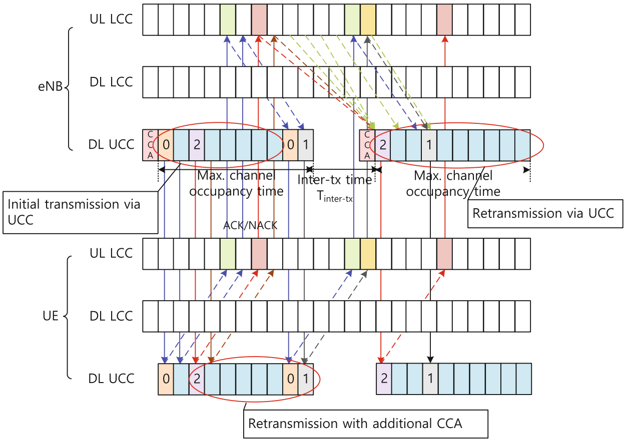

Fig. 3. An example of HARQ retransmission in shared spectrum, where retransmission is performed via UCC. Maximum COT is assumed to be no more than 10 subframe lengths (i.e., 10 ms) and response for the downlink data transmission is assumed to be fed back via LCC. Also, inter-tx time is assumed to be 4 ms due to additional CCA.

also allowed to continue transmission on the channel within the providing the COT, which is the same as that in FBE.

3 HARQ Retransmissions in Licensed and Unlicensed Spectrum

In this section, we propose HARQ retransmission process in licensed component carrier (LCC) and unlicensed component carrier (UCC) over wireless access networks where the LCC is the licensed frequency band operated as a primary component carrier and UCC is the unlicensed frequency carrier operated as a secondary component carrier. For simplicity, we assume that initial transmission is performed at the beginning of the COT after the channel is occupied after CCA. Also, the CCA is assumed to be terminated right before the subframe for the data transmission starts.

3.1 HARQ Retransmission via UCC

Figure 3 shows an example of the HARQ retransmissions via UCC, where the UCC is the same as the component carrier (CC) of initial transmission. We also assume that the maximum COT is to be 10 ms. As shown in the example, HARQ retransmission of the beginning parts of COT (e.g., HARQ Process ID #0) can be performed without additional CCA to re-occupy the same UCC. In other words, the HARQ retransmission for the HARQ Process ID #0 can be performed prior to the expiry of the COT. For instance, on the other hand, HARQ retransmission for HARQ Process ID #2 may not be performed within

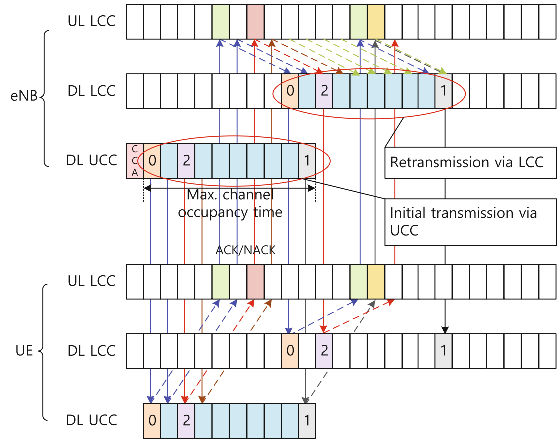

Fig. 4. An example of HARQ retransmission in shared spectrum, where retransmission is performed via LCC. Maximum COT is assumed to be no more than 10 subframe lengths (i.e., 10 ms) and response for the downlink data transmission is assumed to be fed back via LCC.

the COT. Instead, the HARQ retransmission may be delayed due to limited COT as well as additional CCA until the channel is determined as "idle." Thus, we propose the modification of HARQ process such as HARQ RTT timer[1], especially in the case of synchronous HARQ and/or long latency exceeding HARQ RTT timer due to consecutive un-accessible (i.e., busy) channel as the result of CCA. The modified HARQ RTT timer can be expressed by:

$$\min\{\max\{8, (K_i\%8) + T_{inter-tx}\}, max\_RTT\}, \quad (1)$$

where K_i and max_RTT denote the index from the last subframe within maximum channel occupancy time and preconfigured maximum RTT timer, respectively. Note that if the latency due to the CCA is greater than the max_RTT, data transmission is failed and the transmitter may re-initiate new transmission.

The main advantages of this HARQ retransmission via UCC are the same as the legacy method defined in [2]. In particular, those are including: (i) independent MAC scheduler can be exploited on each CC and (ii) buffering the data in any other CC for the UCC is not needed. On the other hand, disadvantages of this approach include (i) it may be hard to perform retransmission in the same UCC due to limited transmission duration, i.e., COT, and (ii) after maximum transmission duration, i.e., expiry of COT, additional CCA is necessary to occupy the same UCC for the retransmission via the occupying UCC.

[1] We assumed HARQ RTT timer is 8 subframe according to LTE [2].

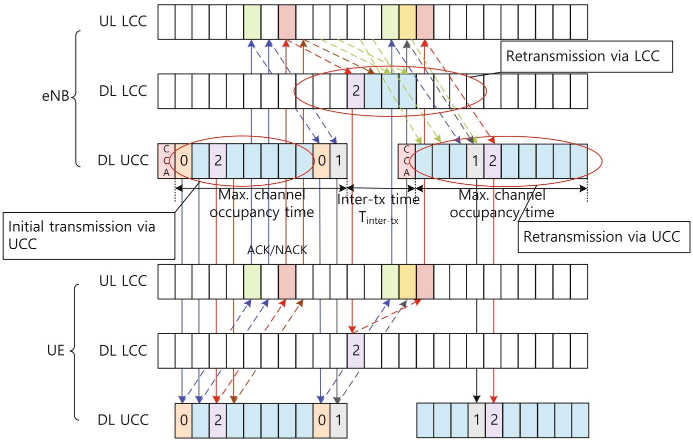

Fig. 5. An example of HARQ retransmission in shared spectrum, where retransmission is performed via any available LCC or UCC. Maximum COT is assumed to be no more than 10 subframe lengths (i.e., 10 ms) and response for the downlink data transmission is assumed to be fed back via LCC. Also, inter-tx time is assumed to be 4 ms due to additional CCA.

3.2 HARQ Retransmission via LCC

Figure 4 an example of the HARQ retransmission via LCC, where COT is assumed to be 10 ms. As shown in the example, any HARQ retransmission (e.g., HARQ Process IDs #0 and #2) is performed via LCC at least $n + 4$ subframe after receiving HARQ ACK/NACK feedback in subframe n. Only CCA on UCC for the initial transmission is necessary but the additional CCAs for the HARQ retransmissions are not necessary. It is due to the fact that regardless of occupying the UCC, the retransmissions are performed via the LCC where the transmitter can transmit data without any accessing the channel for the data transmission. Thus, it is applicable to the synchronous HARQ since we don't have to modify HARQ RTT in contrast to the HARQ retransmission via UCC in Sect. 3.1. In addition, the latency of HARQ retransmission is the same the legacy latency of HARQ retransmission. However, it may be overloaded in the LCC due to the data transmission in LCC and additional HARQ retransmission of UCC. Furthermore, the receiver shall monitor the LCC and UCC at the same.

3.3 HARQ Retransmission via One of Any Available LCC and UCC

Figure 5 shows an example of the HARQ retransmission via any available CC, where COT is assumed to be 10 ms. As shown in the example, HARQ retransmission of HARQ Process ID #2 is performed via LCC, and HARQ retransmission of HARQ process ID #0 is done via UCC. Compared to the HARQ retransmission via UCC in Sect. 3.1, HARQ RTT doesn't have to change and additional CCA may not be necessary for the HARQ retransmission. It is due to the fact

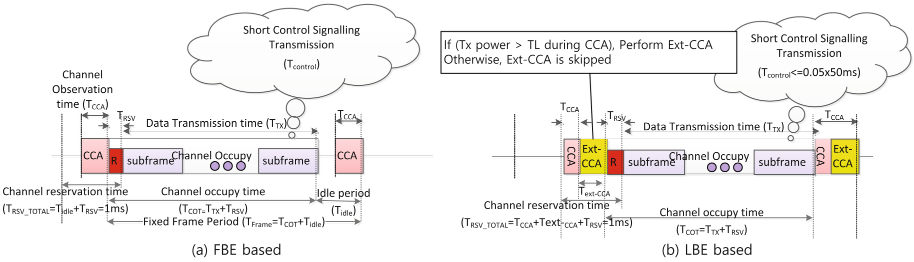

Fig. 6. Frame format for LBT operated in subframe boundary with reservation signal. (a) FBE and (b) LBE.

that whenever the UCC is available as a part of CCA of other data transmission, HARQ retransmission can also be performed in the UCC (e.g., HARQ Process ID #0). In contrast to the HARQ retransmission via LCC in Sect. 3.2, it is flexible since retransmission is up to scheduling policy when more than two CCs, where at least one of CCs is LCC, are available for HARQ retransmissions. It means that at least one CC, i.e., LCC, is available and it doesn't lead to performing CCA to access and occupy the UCC for the retransmission. Meanwhile, in addition, the traffic steering to the UCC can be achieved.

4 Performance Evaluation

4.1 Simulation Results

We compare the performance of proposed HARQ retransmissions in unlicensed spectrum, in terms of average delay and maximum delay. We also compare the proposed HARQ retransmission schemes in the view of what/how impact on the 3GPP LTE system.

For the simulation, we consider the total number of simulations is 10 times and the total number of trials is 100 trials for each simulation. We consider 4 BSs (i.e., eNBs) which perform CCA for data transmission in the same unlicensed carrier. We set the COTs to be 4 and 10 ms. We also set qs to be 12 and 26 for COT = 4 ms and 10 ms, respectively. Thus, when a BS occupies the UCC, the maximum allowed COT can be calculated, i.e., max COT $\leq 13/32 \times q$ for FBE based LBT and LBE based LBT (see Fig. 6 for frame format) [3]. In order to align the frame boundary, we assume that data is transmitted with subframe boundary after CCA and reservation signal, denoted by "R" in Fig. 6, may be included after CCA (including extended CCA for LBE) and before the subframe transmission. Thus, the total channel occupancy time, denonted by T_{COT}, for a BS when it occupies the channel after CCA can be calculated by $T_{\mathrm{COT}} = T_{\mathrm{TX}} + T_{\mathrm{RSV}}$, where T_{TX} and T_{RSV} denote the data transmission time (i.e., the number of subframes) and time to transmit reservation signal, respectively. In addition, the channel reservation time, denoted by $T_{\mathrm{RSV\_TOTAL}}$, is in a unit of subframe, i.e., 1 ms. In particular, the total amount of channel reservation times for FBE

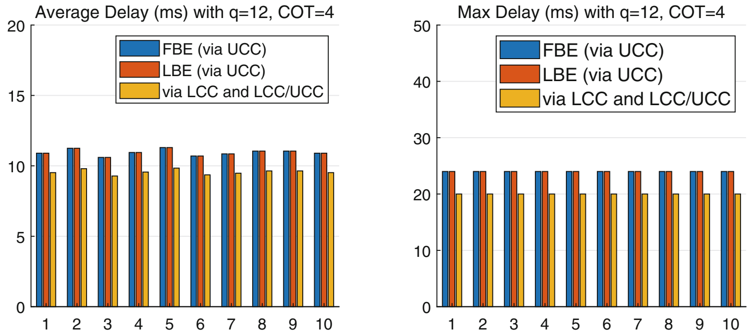

Fig. 7. (a) Average delay and (b) Maximum delay for HARQ retransmission of proposed schemes with $q = 12$ (COT = 4 ms).

and LBE are calculated by $T_{\mathrm{RSV\_TOTAL}} = T_{\mathrm{CCA}} + T_{\mathrm{RSV}}$ and $T_{\mathrm{RSV\_TOTAL}} = T_{\mathrm{CCA}} + T_{\text{ext-CCA}} + T_{\mathrm{RSV}}$, respectively. For the HARQ retransmission, we set the maximum number of retransmission trials to be 4 and frame error rate (FER) to 0.1.

Figures 7 and 8 show the average delay and maximum delay for HARQ retransmission schemes in unlicensed spectrum in Sect. 3, with $q = 12$ (i.e., COT = 4 ms) and $q = 26$ (i.e., COT = 10 ms), respectively. (i) Latency of HARQ retransmission via UCC is longer than that of HARQ retransmission via LCC and LCC/UCC (i.e., any one of available CCs), relatively. It is due to the fact that additional CCA for the HARQ retransmission may be necessary for the HARQ retransmission via UCC. However, those additional CCAs for the HARQ retransmission is not necessary for the HARQ retransmission via LCC and LCC/UCC since the transmitter can access any available CC either LCC or UCC. (ii) Delay in the larger value of q is much longer than that in the small value of q, relatively. It implies that a larger value of COT makes the system worse because if a station occupies the channel, the other (needs to perform HARQ retransmission in the UCC) shall wait till the COT expires or till the channel is available (i.e., idle).

4.2 Comparison of HARQ Retransmission Techniques

Table 1 summaries the comparisons of the proposed HARQ retransmissions via UCC, via LCC, and via any available CC (i.e., either LCC or UCC). As shown in Table 1, HARQ retransmissions via UCC do not impact the current 3GPP LTE [1], but latency due to the retransmission increases when the COT exceeds the HARQ RTT. It is due to the fact that additional CCA is necessary to occupy the UCC, which is the same CC as that for the initial transmission. Otherwise, the transmission is dropped and the transmitter shall re-initialise data transmission. In addition, as shown in Figs. 7 and 8, the average delay and maximum delay for HARQ retransmissions via LCC and via any available CC are shorter than those for HARQ retransmissions via UCC, relatively. It is due to the fact

Table 1. Comparison of HARQ retransmission schemes.

	Via UCC	Via LCC	Via LCC/UCC
What/How	- HARQ Retransmissions via the same carrier (UCC) as the carrier for initial transmission	-HARQ Retransmissions via LCC	-HARQ Retransmissions via one of any available LCC and UCC
Pros	- Same (or similar) legacy approach	- No additional CCA	- No additional CCA
	- Applicable to any scheduling (cross-carrier and self-carrier scheduling)	- Same (or similar) HARQ performance (RTT timer, latency of retransmission)	- Same (or similar) HARQ performance (RTT timer, latency of retransmission)
Cons	- Additional CCA is necessary (due to regulatory requirements)	- Overhead in LCC due to retransmission and initial transmissions	- May be overhead in LCC due to retransmissions and initial transmissions
	- Relatively long latency	- HARQ channel ID mapping and relevant operation is necessary	- HARQ channel ID mapping and relevant operation is necessary for the retransmission via LCC
DL PHY control impact	- No impact	- UE monitors UCC (for initial transmissions) and LCC (for retransmissions)	- UE monitors UCC (for initial transmissions) and LCC/UCC (for retransmissions)
		- DCI needs to be modified for HARQ channel mapping	- DCI needs to be modified for HARQ channel mapping
HARQ impact	- Timing for retransmission may be longer due to CCA and limited COT	- No change on HARQ timing	- No change on HARQ timing
	- No impact on HARQ Processing ID	- HARQ channel ID mapping and relevant operation is necessary	- HARQ channel ID mapping and relevant operation is necessary
Impact on LBT (FBE)	- UCC shall be occupied for retransmissions. Otherwise, latency increases due to Fixed Frame Period	- No impact since CCA is only necessary for the initial transmission	- No impact since CCA is only necessary for the initial transmission, but CCA is only necessary for the retransmission via UCC
Impact on LBT (LBE)	- UCC shall be occupied for retransmissions. Otherwise, latency increases due to additional CCA	- No impact since CCA is only necessary for the initial transmission	- No impact since CCA is only necessary for the initial transmission, but CCA is only necessary for the retransmission via UCC

that the LBT time for the retransmissions is unnecessary since the transmitter can retransmit the data via CC, which is always available without accessing the channel for retransmissions. However, additional modifications related to HARQ processing such as distinguishing method between the retransmission and other transmissions in the occupied CC and indicating the CC which is used for the initial transmission. Nevertheless, it is clear that latency of data transmission due to additional CCA of the system operating in unlicensed spectrum band decreases.

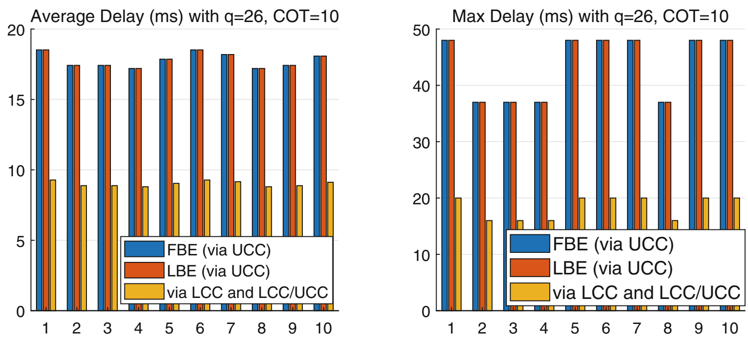

Fig. 8. (a) Average delay and (b) Maximum delay for HARQ retransmission of proposed schemes with $q = 26$ (COT = 10 ms).

5 Conclusion

In this paper, taking into account the regulatory requirements in the unlicensed spectrum such as CCA, we propose new HARQ retransmission techniques in unlicensed spectrum, i.e., HARQ retransmission via UCC, HARQ retransmission via LCC, and HARQ retransmission via any available CC. Although all proposed HARQ retransmission techniques in the unlicensed spectrum need to modify the current system, i.e., LTE, those algorithms are applicable to the retransmission in the unlicensed spectrum. In particular, proposed HARQ retransmission via LCC and via any available CC attain high performance in terms of transmission time. In addition, the proposed algorithms and further extensions taking into account regulatory requirements in the unlicensed spectrum can be used in the uplink service and in the coexistence of downlink and uplink service.

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