Licensed-Assisted Access LTE: Coexistence with IEEE 802.11 and the Evolution toward 5G

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The authors present a detailed overview of the design agreements for LAA, the impact of unlicensed spectrum operation on the LTE physical layer architecture, and the scope of additional enhancements beyond LTE Release 13. A range of simulations for indoor and multicarrier scenarios show that fair coexistence between LAA and WiFi can be achieved, and that deployment of LAA can provide a boost in WiFi performance.

ABSTRACT

LAA is a new operation mode of LTE in the unlicensed spectrum, which will be featured in LTE Release 13. Under LAA, licensed carriers will be aggregated with unlicensed carriers in order to opportunistically enhance downlink user throughput while still offering seamless mobility support. In order to coexist with WiFi, some of the new functionalities required of LAA LTE include a mechanism for channel sensing based on listen-before-talk, discontinuous transmission on a carrier with limited maximum transmission duration, and multicarrier transmission across multiple unlicensed channels. This article presents a detailed overview of the design agreements for LAA, the impact of unlicensed spectrum operation on the LTE physical layer architecture, and the scope of additional enhancements beyond LTE Release 13. A range of simulations for indoor and multicarrier scenarios show that fair coexistence between LAA and WiFi can be achieved, and that deployment of LAA can provide a boost in WiFi performance.

INTRODUCTION

The proliferation of Third-Generation Partnership Project (3GPP) Long-Term Evolution (LTE) in different regions of the world demonstrates that both demand for wireless broadband data is increasing, and that LTE is an extremely successful platform to meet that demand. Existing and new spectrum licensed for use by International Mobile Telecommunications (IMT) technologies will remain fundamental for providing seamless wide-area coverage, achieving the highest spectral efficiency, and ensuring the highest reliability of cellular networks. To meet ever increasing data traffic demand (e.g., video streaming) from users and, in particular, in concentrated high traffic buildings or hotspots, more mobile broadband bandwidth will be needed. Given the large amount of spectrum available in the unlicensed bands around the globe, unlicensed spectrum is being increasingly considered by cellular operators as a complementary tool to augment their service offering. Coordinated transmission across licensed and unlicensed spectrum is also perceived to be a key feature of upcoming fifth generation (5G) radio access networks [1].

As part of this evolution, a new initiative of LTE Release 13 is the specification of licensed-assisted access (LAA) operation in the unlicensed spectrum [2, 3]. Based on the principle of carrier aggregation (CA), LAA secondary cells (SCells) carry data transmissions in the unlicensed spectrum with assistance from a primary cell (PCell) in the licensed spectrum. The PCell retains the exchange of essential control messages and also provides always available robust spectrum for real-time or delay-sensitive traffic. It enables operators to enhance the existing or planned universal seamless coverage in the LTE network with additional bandwidth and capacity. LTE Release 13 includes the specification of DL-only LAA operation as the most relevant initial use case, while uplink (UL) LAA is being incorporated into Release 14.

A key objective of the LAA feature is that the LAA design should target a fair coexistence mechanism with existing WiFi networks so as to not impact WiFi services more than another WiFi network on the same carrier would, with respect to metrics such as throughput and latency. The usage of LTE in unlicensed spectrum is a fundamental paradigm shift, since LTE physical channels have largely been designed on the basis of uninterrupted operation on licensed carriers (although Release 12 LTE added a new ON/OFF operations mode of SCells in the licensed bands).

In addition, different geographical regions have distinct regulatory requirements in terms of power spectral density for transmission in the unlicensed spectrum [2]. Therefore, Release 13 LAA targets a single global framework for LAA, with functionalities that meet regulatory requirements in different regions and bands. Furthermore, LAA design should provide sufficient configurability to enable efficient operation in different geographical regions. The LAA design should also target fair coexistence among LAA networks deployed by different operators so that the LAA networks can achieve comparable performance.

Some of the new functionalities required of LAA from a coexistence perspective include a mechanism for clear channel assessment based

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on listen-before-talk (LBT), discontinuous transmission (DTX) on a carrier with limited maximum transmission duration, and dynamic frequency selection (DFS) for radar avoidance in certain bands. The DTX and LBT functionalities will have a major impact on various aspects of LTE ranging from downlink physical channel design, channel state information (CSI) estimation and reporting, hybrid authomatic repeat request (HARQ) operation, to radio resource management (RRM). Prior to the LAA initiative, the coexistence of LBT-based LTE and WiFi was not evaluated in detail, with most works featuring semi-static coexistence mechanisms such as LTE almost blank subframes or time-division duplexing [4–8]. Preliminary LAA designs and coexistence evaluations corresponding to the 3GPP LAA Study Item phase were presented in [9, 10], while a Markov-chain-based analysis of LTE-WiFi coexistence with simplified LBT and no random backoff was performed in [11].

This article presents an overview of the impact of unlicensed spectrum operation and the introduction of coexistence mechanisms on the LTE physical layer framework. The LAA system architecture for downlink operation is described in detail, covering aspects such as coexistence with WiFi via channel selection and LBT, physical channel design, multicarrier operation, and RRM. Enhanced LBT algorithms are presented that further improve coexistence over the baseline LAA LBT schemes. A range of simulations for indoor and multicarrier scenarios show that fair coexistence between LAA and WiFi can be achieved, and that deployment of LAA can provide a boost in WiFi performance.

LAA Channel Access

Carrier Selection and DFS

Carrier Selection: In Japan, Europe, and the United States, between 455 and 555 MHz of unlicensed spectrum is currently available for use in the 5 GHz band. The unlicensed band can be divided into multiple carriers of 20 MHz bandwidth each. The judicious selection of one or more 20 MHz carriers with low ambient interference for operation is therefore the first step for LAA nodes to achieve good coexistence with other unlicensed spectrum deployments. However, in dense deployments with a large number of nodes, interference avoidance cannot be guaranteed through channel selection, and sharing of unlicensed carriers between different technologies is inevitable.

Carrier selection can be performed periodically in a semi-static manner since average interference levels may change in the long run due to varying numbers of neighboring nodes and traffic loads. These carriers are then configured and activated as SCells for the LAA user equipments (UEs). Carrier selection can be implemented autonomously without any specification impact by an LAA eNB by computing average received interference power estimates on candidate carriers. Additionally, UE received signal strength indicator (RSSI) measurements with configurable measurement granularity and time instances of the reports were introduced in Rel-13 LAA, and they can be a valuable tool for the assessment of hidden nodes by the evolved NodeB (eNB) near specific UEs. For example, UE measurement reports that show a high RSSI when the serving cell is inactive due to LBT can imply the presence of hidden nodes, and can be taken into account for channel (re)selection.

Dynamic Frequency Selection: DFS is a regulatory requirement for certain frequency bands in various regions, for example, to detect interference from radar systems and to avoid co-channel operation with these systems by selecting a different carrier on a relatively slow timescale. The corresponding timescales for DFS are on the order of seconds and can therefore be considered to be on an even slower timescale than carrier selection. It has been agreed in 3GPP that this functionality is an implementation issue and will not have an impact on the LTE specifications [2].

To support coexistence with other technologies in the unlicensed spectrum, LAA adopts dynamic carrier measurement/selection, listen-before-talk protocol, and discontinuous transmission with limited maximum duration.

Baseline LBT Framework for a Single Carrier

The LBT procedure is defined as a mechanism by which a device performs one or more clear channel assessment (CCA) checks prior to transmitting on the channel. It is the LAA counterpart of the distributed coordination function (DCF) and enhanced distributed channel access (EDCA) medium access control (MAC) protocols in WiFi. Japanese and European regulations currently require the usage of LBT in the 5 GHz unlicensed bands, and also limit the maximum channel occupancy time for a particular transmission (e.g., 4 ms channel occupancy limit in Japan). Hence, LBT is considered to be a required functionality for fair and friendly operation in the unlicensed spectrum under a single global framework.

A straightforward approach to fair coexistence would be to make the LAA LBT procedure for both data and discovery reference signals (DRS) as similar as possible to the DCF/EDCA protocols of WiFi. This is the guiding principle behind the LAA LBT mechanism as depicted in Fig. 1, which has the following major features when energy detection (ED) is used to detect the presence of WiFi:

- Before data transmission, an LAA node must sense the medium to be idle for a *random backoff* phase comprising N CCA slots, where each CCA slot is of 9 μs duration. N is a counter drawn randomly within a dynamic contention window (CW), that is, $0 \leq N \leq \text{CW}$. The N idle slots do not need to be contiguous in time, and the backoff counter can be decremented after each idle CCA slot.
- If the energy in a CCA slot is sensed to be above the ED threshold during random backoff, the backoff process is suspended and the counter is frozen. The backoff process is resumed, and the counter can be decremented once the medium has been idle for the duration of a defer period. A *defer period* consists of a 16 μs silent period followed by multiple CCA slots. For example, an LAA defer period of 43 μs (16 + 3 × 9 μs) is well aligned with the arbitration inter-frame space (AIFS) of EDCA best effort traffic. The backoff counter may be decremented by one after deferring is completed.
- If HARQ feedback from UEs indicates that the first subframe of the most recent DL transmission burst had 80 percent or more decoding

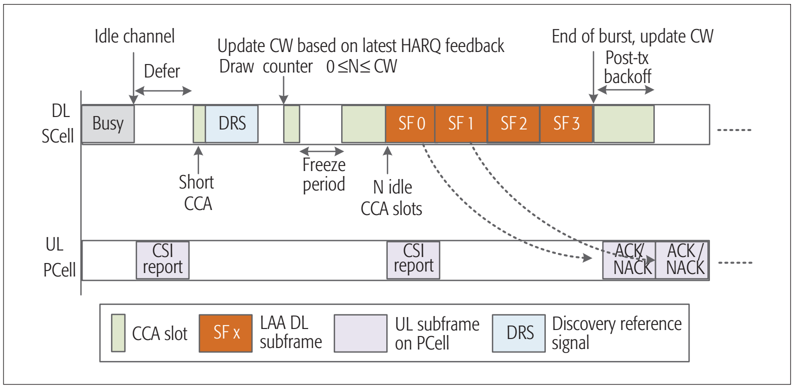

Figure 1. LAA DL transmissions with LBT CW updates based on HARQ ACK/NACK feedback. A post-transmission backoff is applied between DL bursts to prevent monopolizing the unlicensed channel. The UE provides HARQ ACK/NACK feedback and CSI reports on the licensed carrier.

errors (negative acknowledgments, NACKs), then the CW is doubled for the next LBT (up to a pre-defined maximum value such as 63 for eNBs with best-effort traffic). The CW is reset to the minimum value otherwise.

- Once the random backoff and subsequent DL transmission have been completed, a post-transmission random backoff is performed wherein a new random backoff counter is drawn and counted down before trying to transmit another DL burst, as seen in Fig. 1.
- A single short CCA period of 25 μs can be used to transmit control information without accompanying data, such as DRS.
- Four sets of minimum and maximum CW sizes, maximum channel occupancy times (MCOTs), and defer period CCA slots have been defined, corresponding to four LBT priority classes as in EDCA. For LBT class 3, CW ∈ {15, 31, 63}, and MCOT is up to 10 ms [12].

Coexistence Enhancements for LAA LBT

Coexistence with WiFi is greatly enhanced by restricting the LAA CCA starting points to LAA subframe boundaries and enforcing "freeze periods" where the backoff procedure and CCA sensing are completely suspended [13], as shown in Fig. 1. The notion of a freeze period is not a part of the LAA LBT specification, but is an implementation enhancement that can further improve coexistence. Configuring freeze periods during the LBT procedure reduces the overhead due to the possible transmission of any initial signals, since it may not be feasible to immediately start LTE data transmission at an arbitrary time instance due to the alignment of LAA SCell and PCell subframe boundaries.

As an example, the eNB may voluntarily decide to not contend for the channel for up to 11 out of the 14 orthogonal frequency-division multiplexing (OFDM) symbols (OSs) in a 1 ms period if transmission of partial subframes shorter than 11 symbols is eschewed. When coexisting with WiFi nodes that may access the channel and start transmissions at any time, the LAA eNB then essentially forfeits the channel to the WiFi nodes 78.6 percent of the time.

This is verified in Fig. 2, which shows the coexistence performance in terms of average per user throughput and outage probability of WiFi VoIP users when the LAA eNB can adapt the degree of freeze period it uses based on the observed buffer occupancy in the LAA network. The buffer occupancy metric quantifies the fraction of time there is data waiting in the eNB buffer to be served to its UEs [2]. The scenario considered here is an in-building deployment with four co-located WiFi access points (APs) and eNBs per building, along with 20 FTP users and two VoIP users per carrier per building. The performance metrics are obtained using an event-driven system simulator implemented in MATLAB with a total of 45 buildings in the simulation. For each trial (set of user drops), the simulation runtime is set to the average time needed to serve 15 files per user, and 15 such trials are conducted per traffic load point. The FTP traffic generation is based on a Poisson process model for the file arrivals, where each file is 0.5 MB in size. The maximum LAA LBT freeze period implemented here can be as large as 11 out of 14 OFDM symbols.

Figure 2 shows both per-user FTP throughput (user throughput is the average of all of its per-file throughputs) and VoIP outage metrics as a function of the total served traffic, which increases as the file arrival rate per user is increased. Here, VoIP users with 98th percentile latency greater than 50 ms are considered to be in outage (out of a total of 90 VoIP users in the simulation). The figures clearly show that good coexistence with WiFi is possible in the indoor scenario, even when a conservative ED threshold of –62 dBm is used by LAA. For example, the mean per user throughput in the WiFi network of operator A is increased by around 40 percent in both DL and UL when coexisting with LAA for the same served traffic level of 8 Mb/s.

Multicarrier LBT

Simultaneous operation on multiple unlicensed channels or carriers is a key technique for maximizing the data delivered during a transmission opportunity. As an example, IEEE 802.11ac supports transmission bandwidths of up to 160 MHz, which would span eight contiguous 20 MHz unlicensed channels in the 5 GHz band. The design of a multicarrier operation mode for LAA with concurrent transmission on multiple unlicensed SCells should continue to adhere to the principle of fair coexistence with WiFi, while being able to quickly detect transmission opportunities across multiple channels.

With regard to coexistence, a brief overview of the multicarrier LBT procedure in WiFi is provided next. WiFi adopts a hierarchical channel bonding scheme by combining contiguous 20 MHz sub-channels in a non-overlapping manner. One of these contiguous sub-channels is designated as a primary channel on which a complete random backoff cycle is performed, while the others are designated as secondary channels. Counting down of the random backoff counter is based only on the outcome of clear channel assessments on the primary channel. On the secondary channels, only a quick CCA check is performed for point coordination function interframe space (PIFS) duration (generally 25 μs) before the potential start of transmission,

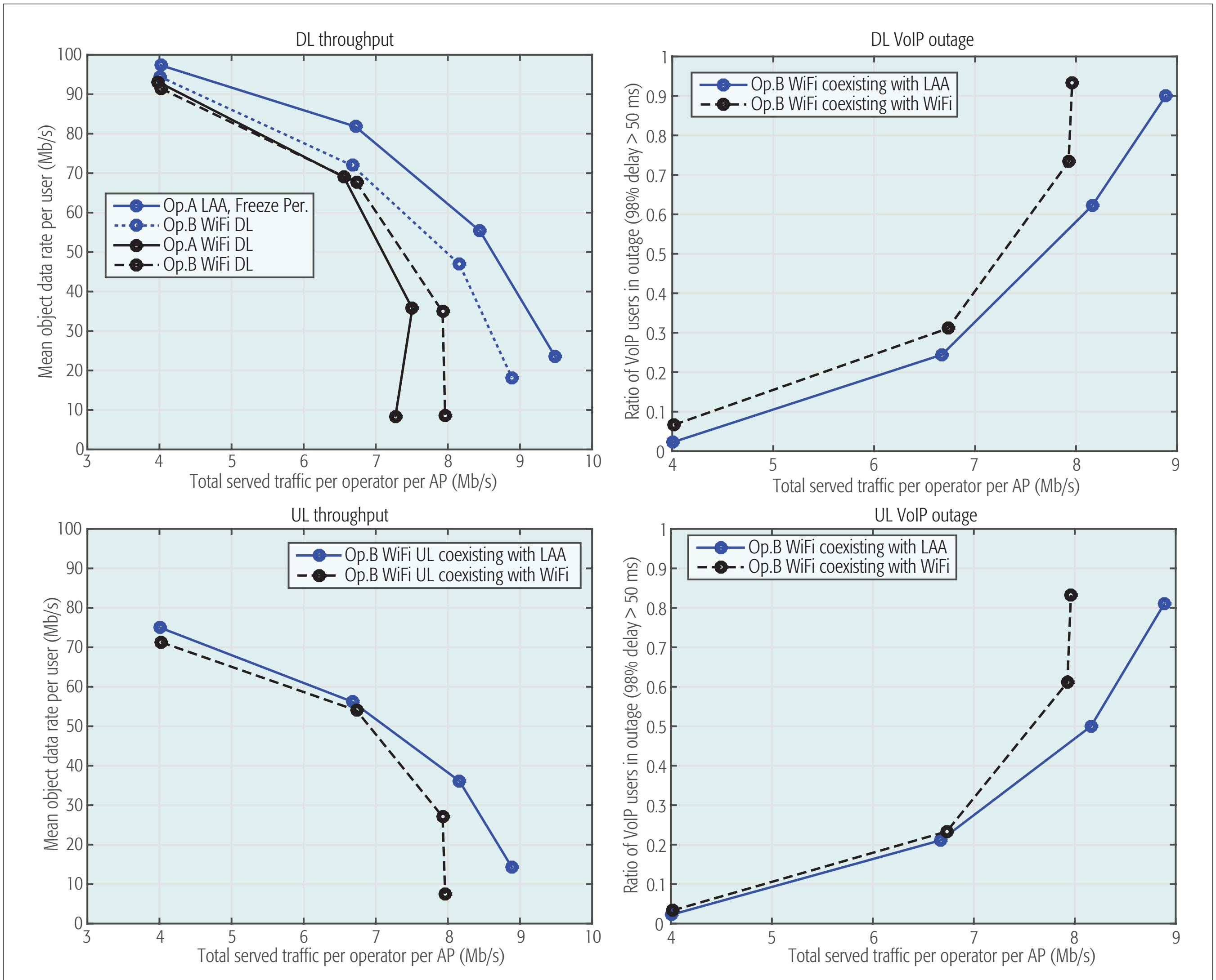

Figure 2. 3GPP indoor single-carrier deployment showing the improvement in Wi-Fi FTP and VoIP performance when LAA LBT employs freeze periods together with an ED threshold of –62 dBm per CCA slot. Blue lines indicate Wi-Fi-LAA coexistence, while black lines indicate WiFi-WiFi coexistence scenarios. LAA does not utilize the licensed carrier for data. Operator A's network has only DL traffic, and operator B network has both DL and UL FTP traffic with 80/20 split, along with 20 FTP users and two VoIP users per carrier per building. For both WiFi and LAA, transmit bursts are of 4 ms duration, 256-quadrature modulation (QAM) is supported, and antenna configuration is 2 Tx–2 Rx [2].

to determine which of the secondary channels are also available in addition to the primary. The final transmission therefore always includes the primary channel. Upon expiration of the backoff counter, the overall transmission bandwidth (20 MHz, 40 MHz, 80 MHz, or 160 MHz) is determined by the results of the secondary CCA checks. The signal and energy detection thresholds for secondary channels are generally higher than those for the primary channel, and scale up with increasing channel bandwidth.

Thus, two main alternatives for LAA multicarrier LBT are apparent.

- **Alt. 1: Single Random Backoff Channel:** Similar to WiFi, only one full-fledged random backoff (as defined above) needs to be completed on any one carrier, along with quick CCA checks on the other channels, before transmission occurs.
- **Alt. 2: Parallel Random Backoff Channels:** Multiple SCells need to each have individually completed full-fledged random backoffs before transmitting simultaneously.

Both alt. 1 and alt. 2 are supported in Release 13 LAA. Representative examples of these multicarrier LBT alternatives are compared in Fig. 3 for a scenario with three LAA SCells that are assigned a common random backoff counter. In the case of alt. 1, SCell 1 finishes counting down first and is designated as the channel with the full-fledged random backoff procedure. To determine whether any other channels are eligible for transmission, the most recent slots of the random backoff procedure corresponding to these channels are examined, and the channels that are found to have been idle for the duration of a PIFS are also used for transmission, which is SCell 3 in Fig. 3. In the case of alt. 2, all SCells that finish their countdown before a predefined wait limit (defined in terms of CCA slots) transmit simultaneously.

A performance evaluation for multi-car-

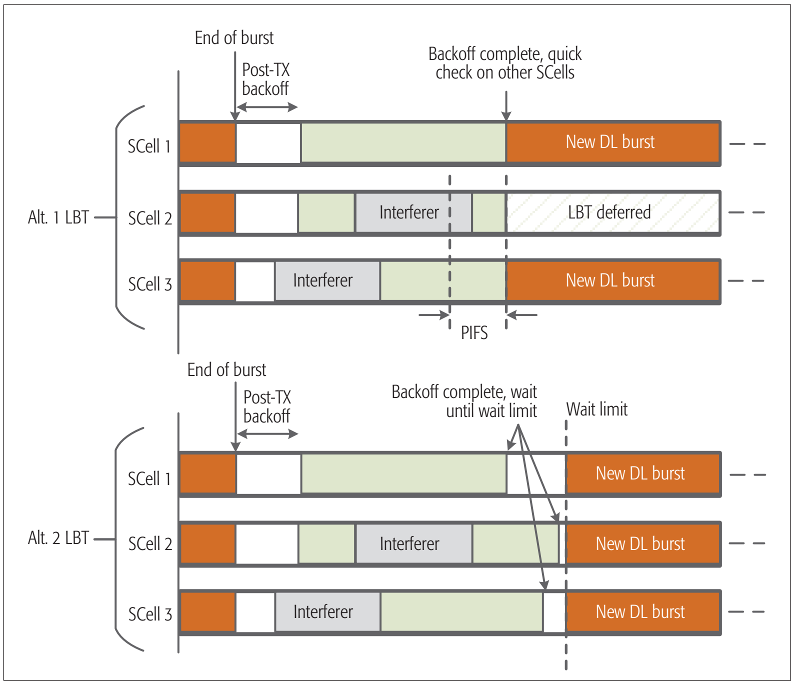

Figure 3. Comparison of LAA multicarrier LBT access schemes: alt. 1, with a single random backoff channel, and alt. 2, with multiple random backoff channels. In the alt. 2 example, a static prespecified wait limit is defined; SCells that have completed backoff before the wait limit defer transmission accordingly.

rier LBT over 80 MHz is shown in Fig. 4. The overall system performance results clearly show that from the coexistence point of view and the impact on the non-replaced WiFi network, both classes of multi-channel LAA LBT schemes are viable and can increase the performance of a multi-carrier WiFi network compared to when it is coexisting with another WiFi network. Also, alt. 1 with a single random backoff channel offers better coexistence due to the more agile random backoff channel selection and better alignment with the WiFi procedure.

Downlink LAA Framework

Physical Channels and Partial Subframes

A summary of the major differences in physical channel and RS design between Release 13 LAA and Release 12 LTE is shown in Table 1. The design of the data-bearing physical downlink shared channel (PDSCH) was one of the major focus areas of Release 13 LAA. One of the main issues regarded the usage of partial subframes that occupy fewer than 14 OFDM symbols (a 1 ms TTI) at the beginning or end of DL bursts. At the start of a burst, a partial subframe can be useful since the starting point for data transmission varies due to the random completion time of LBT. Furthermore, the end of a DL burst may have to be truncated into a partial subframe due to regulatory restrictions on maximum channel occupancy.

In practice, it is difficult to implement a large number of different starting symbol positions at the beginning of a DL burst. This is because of the multiple steps involved in preparation of a data subframe, ranging from scheduling, layer 2 control processing, encoding, scrambling and modulation, and transport of digital samples to remote radio heads. Furthermore, preemptively preparing different subframe versions for different possible starting points raises costs due to increased memory requirements. Ultimately, it was agreed to support up to two starting points (either the first or eighth OFDM symbol) at the start of a DL burst, and multiple partial subframe lengths (from 3 to 12 OFDM symbols) for the last subframe of a burst. The LBT scheme with freeze periods described earlier has a natural synergy with limiting the starting positions at the initiation of a burst: if LBT does not succeed until the first/eighth symbol, the next CCA is deferred until the end of that subframe/slot. If the LAA eNB is unable to start PDSCH transmission immediately after clearing LBT, a short initial signal, for example, comprising primary and secondary synchronization sequences, may optionally be transmitted before PDSCH transmission begins.

The length of a partial subframe at the end of a DL burst will be indicated both in the partial and previous subframes using cell-specific physical downlink control channel (PDCCH) signaling. PDSCH in LAA will support most of the single-codeword and dual-codeword transmission schemes in LTE Release 12, with the exception of multi-user multiple-input multiple-output (MIMO), closed-loop unit-rank spatial multiplexing, and single antenna port beamforming (transmission modes 5, 6, and 7). Since the motivation is to use LAA as a throughput booster, it is reasonable to focus on the MIMO transmission modes with the highest spectral efficiency, such as modes 9 and 10. To facilitate detection of bursts and fine synchronization, every DL subframe will carry at least one symbol of cell-specific reference signals (CRSs).

With a single starting position at subframe boundaries together with LBT with freeze periods described above, there is no impact on UE-specific demodulation reference signals (DMRSs) and channel state information reference signals (CSI-RSs) in the first subframe of a burst since they are located after the fifth OS within a subframe. For the same reasons, no changes are required for control channel design when DL bursts start from the first OS, with regard to PDCCH and the enhanced PDCCH (EPDCCH). If a 7-symbol partial subframe is used at the start of a burst, the PDCCH and PDSCH resource mapping is the same as in the first slot of a regular full-length subframe, while the start symbol of the EPDCCH is offset by 7 OFDM symbols. For the partial subframe of various lengths at the end of a burst, the reference signal mappings are based on existing mappings defined for the downlink pilot time slot (DwPTS) used in TDD special subframes.

Finally, the physical multicast channel (PMCH) and physical broadcast channel are not included in Release 13 LAA, since single-frequency operation and transmission without a licensed carrier are not in the scope of the feature.

Control Signaling

In Release 10 CA, an SCell may carry scheduling grants for UEs served on that same SCell (referred to as self-scheduling), or UEs on a par-

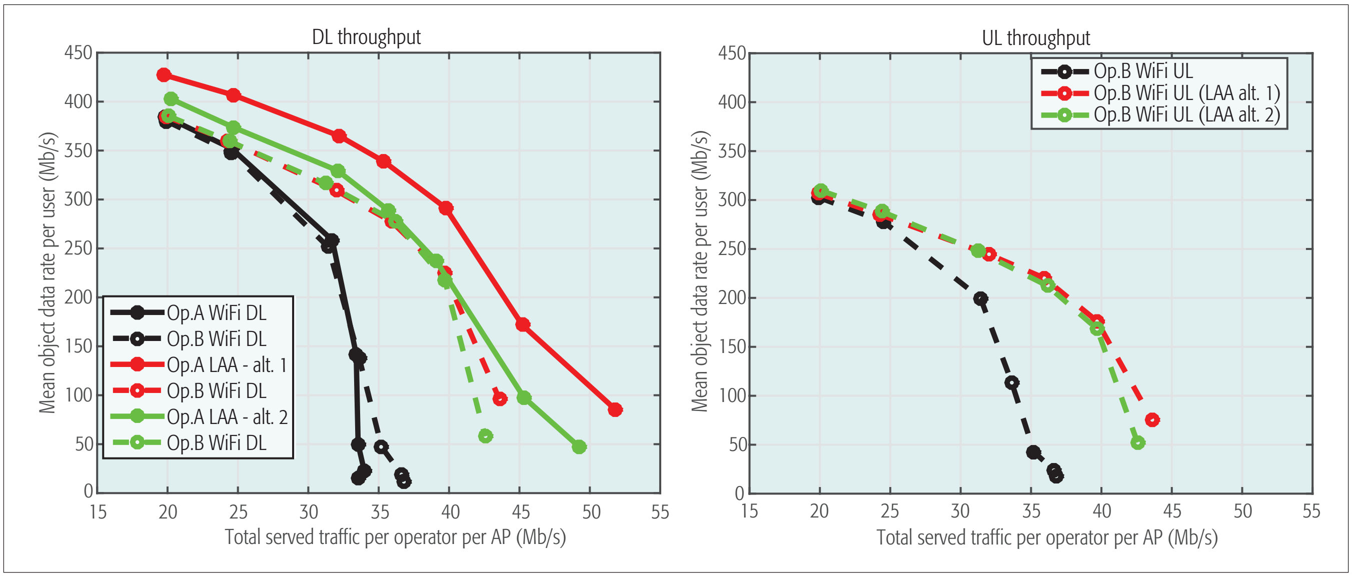

Figure 4. Mean user throughput vs. served traffic per AP per operator for the indoor multi-carrier deployment scenario with FTP traffic using up to 80 MHz transmission bandwidth. The non-replaced WiFi network is operator B. Left and right plots correspond to DL and UL per user throughput results, respectively.

ticular SCell may be scheduled from the PCell or another SCell via cross-carrier scheduling configuration. To support self-scheduling on the LAA SCell, either the PDCCH or the EPDCCH can be used to send DL resource assignments. Therefore, the physical control format indicator channel (PCFICH) may also be transmitted on LAA SCells to indicate how many OFDM symbols are allocated for PDCCH in a subframe. However, as discussed earlier, the physical HARQ indicator channel (PHICH) will not be used to convey HARQ ACK/NACKs for UL transmissions. Both PCFICH and PHICH resources will continue to span the system bandwidth in the first OFDM symbol of each DL subframe, as in Release 12 LTE.

Following the LTE CA framework, the physical uplink control channel (PUCCH) carrying HARQ-ACK and CSI for all aggregated cells should be sent on the UL PCell. Since the PUCCH resources on the PCell are reserved and always available (unlike the LAA SCell), sending UCI on the PUCCH is one important advantage of the LAA LTE PHY layer over the WiFi PHY layer. The LTE PUCCH is designed for coverage and reliability via very low rate coding (rate-1/3 convolutional coding), repetition, and frequency hopping. Transmitting on the licensed PCell further allows the UE to transmit at higher powers and at lower carrier frequencies (with lower path losses). WiFi control frames for both UL and DL utilize binary phase shift keying (BPSK) rate-1/2 convolutional coding, and the frame acknowledgment design requires substantially more bits than the LTE design, although the gap between data transmission and ACK reception is significantly lower for WiFi. In all, the WiFi control frame has been designed to provide coverage in localized areas such as indoor deployment and is less suitable for outdoor deployment. The LTE control channel design in comparison enables reliable outdoor deployment and a larger coverage area.

Component	Release 13 LAA	Release 12 LTE
PDSCH	Can start at slot boundaries	Start at subframe boundaries
PDCCH	Up to first three symbols of a slot	Up to first four symbols of a subframe
EPDCCH	Can occupy one slot	Can occupy last 11 OS
PHICH	Not used for UL HARQ feedback	Used for UL HARQ feedback
PBCH/PMCH	Not supported	Supported
CRS	1- or 2-symbol CRS in up to 8 out of 10 subframes per frame allowed	1- or 2-symbol CRS in up to 6 out of 10 subframes per frame allowed
PSS/SSS	Can appear outside subframe 0/5	Appear only in subframe 0/5

Table 1. Summary of PHY changes in Release 13 LAA.

Radio Resource Management and CSI Measurements

The combination of the LBT and maximum transmission burst duration functionalities of LAA implies that LTE reference signals are not guaranteed to be transmitted with a fixed periodicity on LAA SCells. This can affect the methods by which RRM, CSI measurements and feedback, and time-frequency tracking are currently supported in LTE. Similarly, RRM measurements form the basis for cell selection and mobility management, and closed-loop link adaptation is not feasible without accurate CSI measurements and feedback.

In Release 12, periodic transmission of primary/secondary synchronization sequences (PSS/SSSs), CRSs, and CSI-RSs are generally used to achieve these objectives. Since periodic reference signal transmission is no longer feasible on LAA SCells, this raises the question if PCell reference signals can be utilized for at least coarse time-frequency synchronization and automatic gain control (AGC) adjustment on the SCells. While coarse timing synchronization may be possible using the PCell RS in a co-located scenario, AGC

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adjustment would not be feasible due to the PCell potentially operating on a carrier (e.g., 2 GHz) that has substantially different characteristics and path loss compared to LAA SCells in the 5 GHz band. This difference in long-term channel properties also rules out using PCell RS for channel estimation filter adjustment on LAA SCells.

Based on the above discussion, the Release 13 solution is to transmit constant-power discovery reference signals (DRSs) on the LAA SCells, subject to a single CCA duration of 25 μs without random backoff. The signals comprising the LAA DRSs are the same as symbols 0–11 of the Release 12 DRS, which comprised PSS/SSS/CRS and was designed for small cell PHY enhancements. The transmission burst containing LAA DRSs cannot exceed 1 ms in duration, and will be attempted to be sent periodically every 40 ms or so. UEs will be configured with a discovery measurement timing configuration (DMTC) of six subframes, within which they can attempt to detect and measure DRSs of serving and adjacent LAA cells.

Moreover; CSI-RSs together with CSI-IMs (or other known unused resource elements) can be used to derive CSI reports from the UE when they are available. Due to the unpredictable availability of the unlicensed carrier, the most practical approach would be to rely only on aperiodic CSI reports for the LAA SCell, as opposed to periodic CSI reports. Furthermore, the CRS and CSI-RS power will be the same within a burst but may be varied across transmission bursts; therefore, UEs should not average CRS/CSI-RS measurements across bursts.

Evolution beyond Release 13

The initial DL-only LAA framework developed in Release 13 is amenable to several potential enhancements in future releases in order to create a full-fledged LAA design with both DL and UL transmissions and support for aggregation of a large number of unlicensed channels.

Uplink LAA

Several aspects of UL LAA, such as HARQ and UL LBT, were discussed during Release 13. It was agreed that UL HARQ should follow an asynchronous protocol, similar to LAA DL HARQ. In other words, UL retransmissions are explicitly rescheduled by the eNB, as opposed to automatic retransmission 4 ms after an eNB NACK as in Release 12.

With regard to the framework of UL LBT, it was recognized that UL LBT imposes an additional LBT step for UL transmissions that were scheduled by an LAA SCell (self-scheduling), since the UL grant itself requires a DL LBT by the eNB. Therefore, Release 13 LAA recommended that the UL LBT for self-scheduling should use either a single CCA duration of at least 25 μs (similar to DL DRS) or a random backoff scheme with a defer period of 25 μs including a defer duration of 16 μs followed by one CCA slot, and a maximum contention window size between three and seven.

The exact specification of UL LBT and enhancements to UL scheduling, PUCCH design, and data transmission are expected to be finalized in a Release 14 work item.

LAA with 32 Carriers

Wideband transmissions are a key feature for enabling high user data rates, and this is especially true as we evolve toward 5G. As discussed earlier, IEEE 802.11ac currently supports transmission bandwidths of up to 160 MHz, and further improvements may be made in 802.11ax. In contrast, Release 13 LAA can aggregate up to 100 MHz on the downlink by aggregating five DL carriers. Therefore, LAA should be enhanced to support system bandwidths similar to 802.11ac in unlicensed spectrum. In Release 13, a separate 3GPP work item specified aggregation of up to 16 or 32 carriers, which is a natural candidate for application to LAA. With 32 aggregated carriers, LAA will then be able to support a transmission bandwidth of 640 MHz to a single UE. This would impact a number of PHY-layer aspects, such as the need to support PUCCH on LAA SCells to reduce control overhead on the PCell, and enhancements in scheduling with such a large number of available carriers.

Dual Connectivity Support

To allow additional deployment scenarios for LTE that utilize unlicensed spectrum, it is important to extend the applicable deployment scenarios beyond those enabled by carrier aggregation with licensed spectrum and the associated stringent time synchronization requirements. It is therefore proposed to extend the design to also allow for dual connectivity (DC) operation between LTE in licensed and unlicensed spectrum with non-ideal backhaul in Release 14, which would have much looser synchronization requirements compared to CA. Supporting DC would necessitate the introduction of PUCCH and random access channels on the LAA UL, in addition to changes in radio link monitoring of the unlicensed secondary carriers.

Conclusions

This article presents an overview of licensed assisted access in Release 13 LTE for operation in unlicensed spectrum. It is shown how the introduction of new functionalities such as DTX and LBT necessitates numerous changes in the DL physical channels, HARQ feedback procedures, scheduling, RRM mechanisms, and CSI acquisition. Detailed system-level simulation results are presented to show that fair coexistence between LAA and WiFi can be achieved in a range of single-carrier and multi-carrier scenarios. Finally, an overview of desirable enhancements for LAA in future LTE releases was presented.

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