CA | DC | Unlicensed Frequency Utilization

Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

# Broadband Frequency Technologies in LTE-Advanced Release 13

*To accommodate the surge in traffic, the key LTE-Advanced technologies such as CA and DC were specified in 3GPP up to Release 12. CA achieves broadband communication by utilizing multiple LTE carriers simultaneously, while DC enables UE to connect with multiple eNBs simultaneously utilizing multiple LTE carriers. This article describes new technologies defined in 3GPP Release 13 including advanced CA and DC technologies, and LAA and LWA technologies that utilize unlicensed frequency bands.*

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## 1. Introduction

In recent years, there have been growing demands for higher speed and larger capacity networks to cope with the rapid increase in mobile data from services such as high-definition video and video calling accompanying the spread of smartphones and tablet devices. The 3rd Generation Partnership Project (3GPP) Release 10 specifies Carrier Aggregation (CA) technologies that achieve high data rates utilizing multiple LTE carriers simultaneously. These technologies have already been deployed by many mobile network operators all around the world. In March 2015, NTT DOCOMO launched LTE-Advanced services based on CA technologies called PREMIUM 4G. These services offered a maximum downlink speed of 300 Mbps in October of that year, which rose to 375 Mbps in June 2016. In 3GPP standardization, NTT DOCOMO has been proactive in studying further expansion of high-speed CA data communications with other participating companies such as telecommunication operators and vendors. 3GPP discussed enhanced technologies to enable higher-speed communications with multiple LTE carriers and more flexible operations in recent releases, and specified Time Division Duplex (TDD)*1-Frequency Division Duplex (FDD)*2 CA technologies that aggregate multiple LTE carriers with different duplex modes



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*1 **TDD:** A scheme for transmitting signals using the same uplink and downlink carrier frequency. It switches time slots for uplink and downlink.

*2 **FDD:** A scheme for transmitting signals using different uplink and downlink carrier frequencies.

and Dual Connectivity (DC) technologies that enable simultaneous communications with multiple evolved Node B (eNB)*3 in Release 12.

Then, 3GPP Release 13 specified advanced CA technology for higher throughput*4 by aggregating even more LTE carriers, and advanced DC technology for enhancing uplink throughput. In addition, Release 13 also specifies Licensed Assisted Access (LAA) and LTE Wireless Local Area Network (LTE-WLAN) Aggregation (LWA) technologies to enhance throughput by utilizing conventional LTE and unlicensed frequency bands*5 simultaneously. This article describes these Release 13 technologies.

## 2. Advanced CA Technologies

### 2.1 CC Number Extension

Up to Release 12 CA, a maximum of 5 LTE carriers called "Component Carriers" (CCs)*6 could be configured for a User Equipment (UE) [1] - [3]. This enables a maximum 100 MHz bandwidth for data communications, which achieves a theoretical peak data rates of approximately 4 Gbps, assuming eight Multiple Input Multiple Output (MIMO) layers*7 and 256 Quadrature Amplitude Modulation (QAM)*8 for downlink, and 1.5 Gbps assuming four MIMO layers and 64QAM*9 for uplink.

In Release 13, the maximum number of CCs that can be configured for a UE simultaneously was increased to 32 to archive higher data transmission rates with wider bandwidths. This enables a maximum 640-MHz bandwidth for data transmission, achieving peak data rates of approximately 25 Gbps for downlink with 8 MIMO layers and 256QAM, and 9.6 Gbps for uplink with 4 MIMO layers and 64QAM.

### 2.2 PUCCH on SCell

Since CA aggregates multiple independent LTE carriers for parallel and simultaneous communications, scheduling and data transmission/reception are done independently by each CC. Hence, most of the conventional and non-CA LTE functions can be reused for each CC. On the other hand, in Release 12 CA, only the Primary Cell (PCell)*10 supports the Physical Uplink Control CHannel (PUCCH)*11 that transmits Uplink Control Information (UCI)*12 such as ACKnowledgement (ACK)*13/ Negative ACK (NACK)*14 for all the downlink CCs and Channel State Information (CSI)*15 for all the downlink CCs, and Scheduling Requests (SR)*16 for uplink. This is to avoid mandating more than one uplink CC in CA. Furthermore, having PUCCH on PCell only allows UE to use the unified UCI transmission framework regardless of its uplink CA capability. However, if a certain LTE carrier is used as the PCell for many UEs configured with CA, there can be a shortage of uplink radio resources*17 due to the increased PUCCH load on that carrier. A typical example is CA operating on heterogeneous networks*18 where many small cells*19 are deployed in the coverage of a macro cell. The relatively low-powered small cells are deployed in high traffic areas with different frequencies from that of the macro cell. In areas where these small cells are overlaid on the macro cell, UE can be configured with CA for the small cells and the macro cell (**Figure 1**).

In order to solve this issue, Release 13 introduced the new function to enable PUCCH configuration for a Secondary Cell (SCell)*20 in addition to the PCell in uplink CA. When CA is performed with this function, CCs are grouped together either with the PCell or SCell with PUCCH (PUCCH-SCell). UE sends UCI for CCs within each group by using the PCell or PUCCH-SCell. With this new function, uplink radio resource shortages can be resolved by offloading UCI from macro cell to the small cells while keeping the macro cell as the PCell.

### 2.3 Two Types of PUCCH Formats

Up to Release 12, different PUCCH formats were designed to suit numbers of CCs or multiplexed UCI classes/ payloads*21. All of these formats use Code Division Multiplexing (CDM)*22

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*3 **eNB:** A base station in LTE radio access systems.

*4 **Throughput:** The effective amount of data received without error per unit time.

*5 **Unlicensed frequency band:** A frequency band usable without the need for an official license and not limited to a particular telecommunications operator.

*6 **CC:** A term denoting each of the carriers in CA.

*7 **MIMO layer:** In MIMO, the multiplex number when multiplexing different signals with spatial multiplexing on the same radio resources with different antennas.

*8 **256QAM:** A type of modulation scheme. 256QAM modulates data bits through 256 different amplitude and phase signal points. A single modulation can transmit 8 bits of data.

*9 **64QAM:** A type of modulation scheme. 64QAM modulates data bits through 64 different amplitude and phase signal points. A single modulation can transmit 6 bits of data.

*10 **PCell:** The carrier essential to keep the connection with multiple carriers in CA. Also referred to as the primary cell.

*11 **PUCCH:** The physical channel used to send and receive UCI.

*12 **UCI:** A term denoting uplink control information such as ACK/NACK, CSI and SR.

*13 **ACK:** A reception confirmation signal to notify the transmitting node that the receiving node has received (decoded) the data correctly.

to multiplex different users on PUCCH into a single Physical Resource Block (PRB)*23 to suppress overheads. However, to achieve CA with maximum 32 CCs, UCI with size of tens to hundreds of bits need to be accommodated on PUCCH. For this reason, two types of new PUCCH formats (PUCCH formats 4 and 5) were introduced in Release 13 (**Table 1**, **Figure 2**).

(1) The PUCCH format 4 can accommodate very large payloads without any spreading (no CDM support). Furthermore, it enables setting more than one PRB to further increase payloads.

(2) Applying the spreading factor 2 to PUCCH format 5 enables CDM for up to two users on PUCCH, which supports larger payloads than the conventional PUCCH formats.

Apart from the CDM supporting and

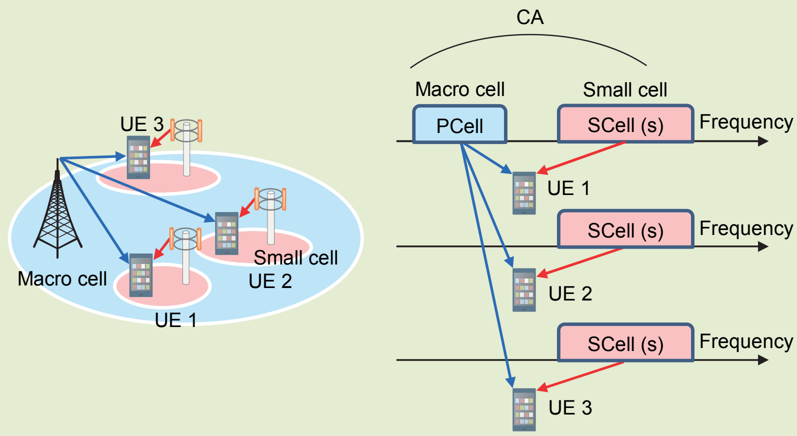



**Figure 1 CA operations with macro and small cells**

**Table 1 Structure of PUCCH formats 4 and 5**

| | PUCCH format 4 | PUCCH format 5 |
|---|---|---|
| Spreading factor | 1 (no spreading) | 2 |
| No. of PRBs | 1 - 8 | 1 |
| No. of bits per PRB | 288 | 144 |
| UCI classes | Any combination of ACK/NACK, SR, CSI measurement information | |
| No. of CRC bits | 8 | |
| Encoding scheme | Tail biting convolutional coding | |
| Frequency hopping | Yes | |

Tail biting convolutional coding: A type of convolutional coding. These encoders match the initial shift register state with the end. Convolutional coding is a type of error correction encoding. Consisting of a shift register and a bit adder, these encoders use input bits and internal state of the shift register to produce an output. Maximum likelihood decoding based on the Viterbi algorithm is known as a decoding method.

*14 **NACK:** A reception confirmation signal to notify the transmitting node that the receiving node was unable to receive (decode) the data correctly.

*15 **CSI:** The channel state information of the radio channel.

*16 **SR:** A signal from the user to the base station requesting radio resource allocation for uplink.

*17 **Radio resources:** A general term for resources needed to allocate radio channels (frequencies).

*18 **Heterogeneous network:** In this article, a network configuration that overlays nodes of different power, which typically includes picocell and/or femtocell base stations whose transmit power is smaller than that of ordinary base stations.

*19 **Small cell:** A general term for cells that transmit with lower power than macro cells.

*20 **SCell:** Carriers other than the PCell with multiple carriers in CA. Also referred to as the secondary cell.

*21 **Payload:** In this article, this denotes the number of UCI data bits transmitted on a PUCCH.

*22 **CDM:** Multiplexing signals using mutually different orthogonal spreading sequences when transmitting multiple signal sequences on the same radio system band.

*23 **PRB:** A unit for allocating radio resources consisting of one subframe and 12 subcarriers.

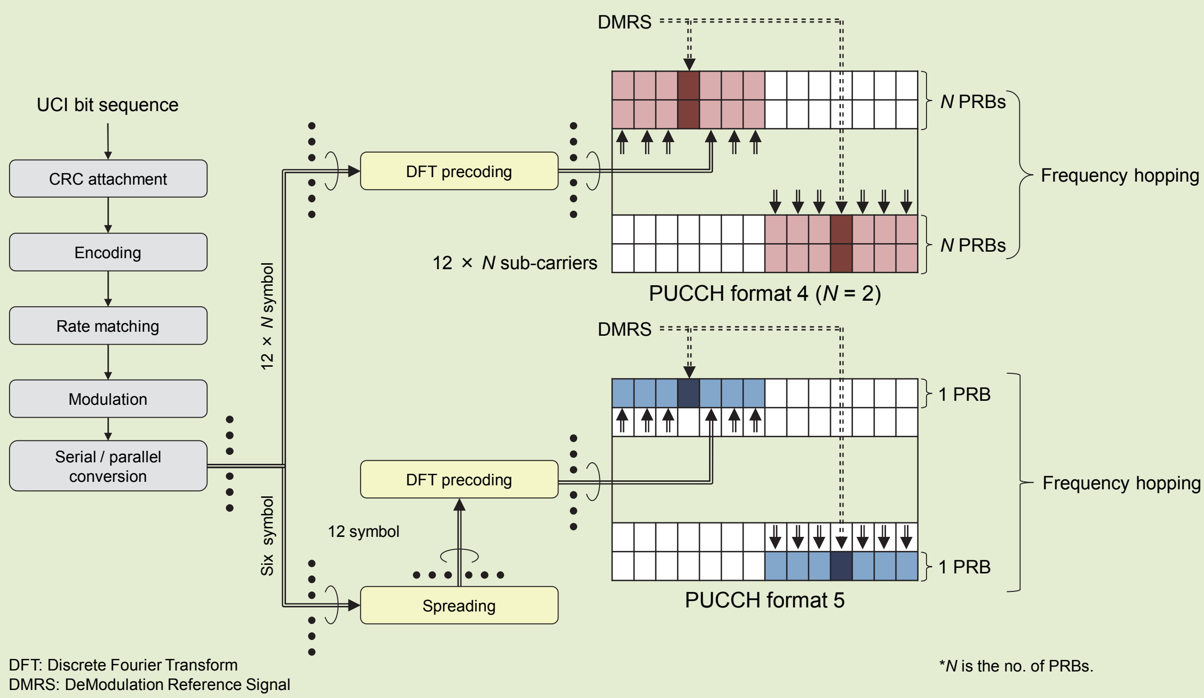



**Figure 2 Structure of PUCCH formats 4 and 5**

the number of PRBs, these two PUCCH formats have many commonalities in the physical layer, such as the number of Cyclic Redundancy Check (CRC) bits, encoding scheme, and multiplexed UCI classes.

## 3. Advanced DC Technologies

Release 12 designed DC to achieve user throughput comparable with that of CA by aggregating multiple CCs across two eNBs. In release 13, DC was further enhanced with higher uplink throughput and more flexible deployment.

### 3.1 Uplink Throughput Improvements

1) DC Uplink Resource Allocation Issues

In DC, separate eNBs allocate uplink resources independently for a UE. Hence, Release 13 addresses how to allocate adequate uplink resources on multiple CCs for UE.

Typically, eNB calculates the required uplink resources based on the uplink buffer amount reported from UE. In DC, since both eNBs calculate the amount of uplink resources based on the report and allocate them to the UE independently, excess uplink resource allocation over actual amount of remaining data will occur. In particular, with small data packets, if resources are allocated by both eNBs, the UE may send all data to only one of them, and send padding (meaningless bit strings) to the other eNB, which wastes radio resources.

2) Data Amount-based Buffer Size Report/Uplink Data Transmission Control

To prevent the excess uplink resource

allocation for the small data packets described above, new uplink transmission control methods were introduced. In Release 13 DC, UE buffer status reporting and uplink data transmission are controlled based on the amount of uplink data buffered in the UE. As shown in **Figure 3**, if the amount of the buffered data is smaller than the threshold configured by the eNB, the UE performs buffer status reporting and uplink data transmission only to one of the eNBs, just like DC in Release 12. In contrast, if the amount of the buffered data is larger than the threshold, the UE transmits to both eNBs. This buffer size-based mechanism solves the uplink resource over-allocation problem since only one eNB is aware of the buffered data and allocates resources when the amount of the buffered data is small.

## 3.2 Controls for More Flexible Operations

1) The Issue of Acquiring Difference Information for SFN/Subframe Numbers between eNBs

Release 12 specifies two kinds of DC operation - synchronous DC (requiring synchronization between eNBs), and asynchronous DC (not requiring synchronization between eNBs). When DC is deployed on an unsynchronized NW where each eNB manages System Frame Number (SFN)*24/subframe numbers*25 independently, UE is configured with the multiple CCs of which SFN/subframe numbers are not aligned. In this case, both eNBs must control the UE considering the SFN/subframe number differences (e.g. measurement gap control*26) (**Figure 4**).

In Release 12 DC, it was assumed that the difference information of SFN/subframe numbers between eNBs would be acquired by Operation, Administration and Management (OAM)*27. However, several potential issues were identified with this assumption in 3GPP standardization. Specifically, this OAM based acquisition is hard to apply to eNBs operating under separate OAMs. Another issue is the increased operational workload such that when an eNB is newly installed, the operator needs to obtain and set the difference information for every neighboring eNB. Consequently,

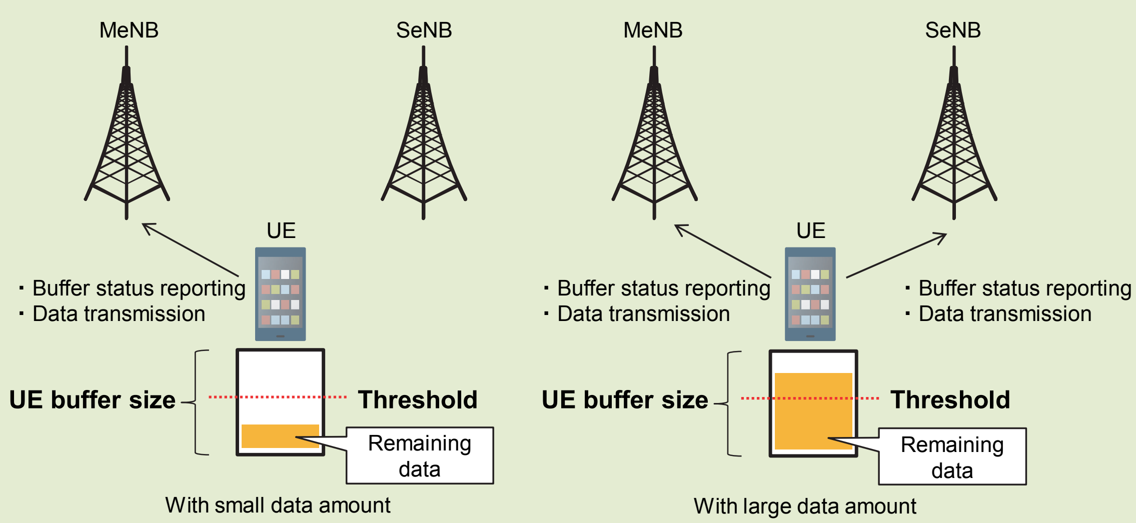



**Figure 3 Uplink data amount-based buffer size report & transmission controls in DC**

*24 **SFN:** The number allocated to each radio frame. Values are from 0 to 1,023.

*25 **Subframe number:** The number allocated to each subframe. Values are from 0 to 9.

*26 **Measurement gap control:** Management control in periods for measuring frequencies other than the serving frequency.

*27 **OAM:** Functions for maintenance and operational management on a network.

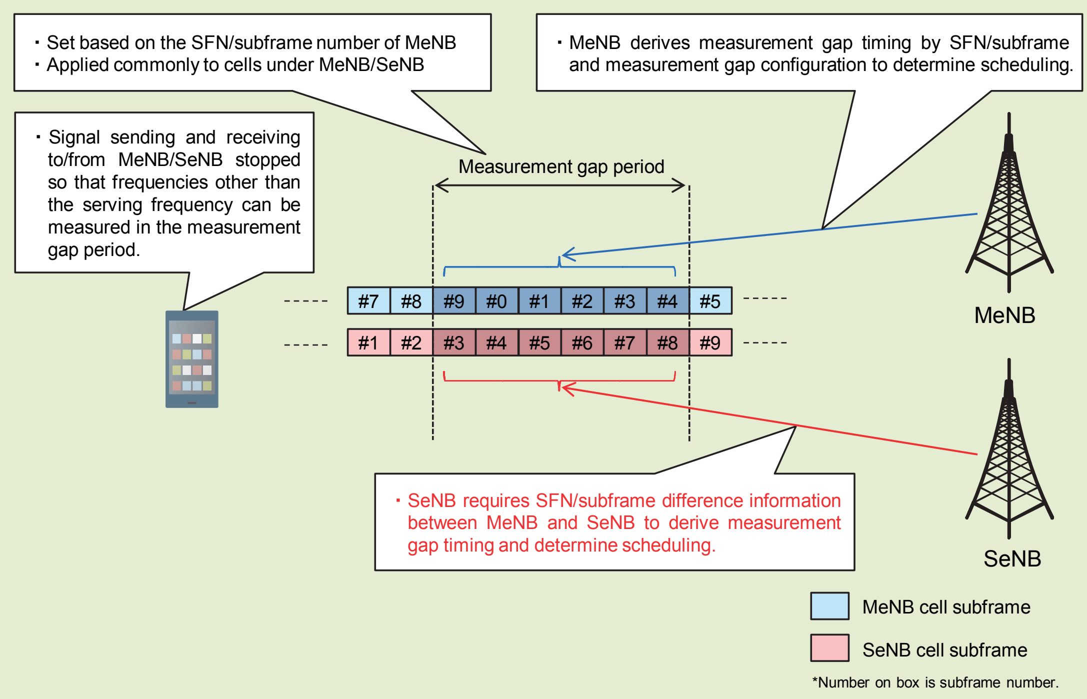



**Figure 4 Example of SFN/subframe number differences necessity in asynchronous DC (measurement gap control)**

DC deployment is limited to certain areas.

2) UE Measuring and Reporting of SFN/Subframe Number Difference

To solve the issues above, Release 13 specified UE-based acquisition of the difference information of SFN/subframe numbers. Specifically, UE calculates the differences of SFN, subframe numbers and subframe start timing between Master eNB (MeNB)*28 and Secondary eNB (SeNB)*29 cells, and then reports the information to the eNB as measurement result. With this new UE based acquisition mechanism, operators can deploy DC more flexibly, i.e., regardless of OAM implementation and without increasing operational load.

## 4. Unlicensed Frequency Band Technologies

In hot spot areas where high data traffic can be expected, many telecommunications operators are providing WLAN services using Wi-Fi®*30 with unlicensed frequency bands in addition to their cellular communication services such as 3G/LTE provided on specially allocated frequencies (licensed frequency bands). Unlicensed frequency bands in hot spot areas can greatly improve the quality of the user experience. However, using two different Radio Access Technologies (RAT)*31, i.e. LTE with licensed frequency bands and Wi-Fi with unlicensed frequency bands, could inconvenience users, since RAT switching, re-connection and re-authentication would be necessary as users move to different coverage areas. Hence, 3GPP studied and specified LAA and LWA technologies to eliminate this inconvenience and facilitate efficient use of unlicensed frequency bands. LAA enables users to use unlicensed frequency bands without any

*28 **MeNB:** eNB in DC that manages UE-network connectivity.

*29 **SeNB:** eNB in DC that provides radio resources in addition to MeNB.

*30 **Wi-Fi®:** The name used for devices that interconnect on a wireless LAN using the IEEE802.11 standard specifications, as recognized by the Wi-Fi Alliance. A registered trademark of the Wi-Fi Alliance.

*31 **RAT:** Radio access technologies such as LTE, 3G, GSM and Wi-Fi.

inconvenient operations by using a single LTE-based RAT for both licensed and unlicensed frequency bands. On the other hand, LWA utilizes DC designed to enhance user throughput by adding WLAN connections while maintaining mobility with connection to LTE.

## 4.1 LAA Technology

Release 13 defines LAA technologies for LTE carriers using a 20-MHz bandwidth on the 5-GHz unlicensed band as a supplemental downlink SCell in CA. Essential channel access technologies for unlicensed frequency bands are described below.

1) Channel Access Based on LBT

Since radio stations using unlicensed frequency bands can be set up by any operator or user, interference from the radio stations in the vicinity could degrade the quality of data communications. For this reason, Japan and Europe require Listen-Before-Talk (LBT) mechanisms in radio systems working on the 5-GHz unlicensed band. These mechanisms prevent interference by allowing transmission only when it is confirmed as result of carrier sensing*32 that the channel is unused by the other systems in the vicinity, and limiting the transmission period to a predetermined amount of time (4 ms in Japan) [4] [5].

3GPP specifies LBT mechanisms as LAA downlink channel access methods (**Figure 5**) for fair coexistence with WLAN. LAA base stations use collision avoidance mechanisms similar to those of WLAN, which are based on random back-off*33 and Contention Window Size (CWS)*34 adjustment with variable length. Carrier sensing is performed and the back-off counter is decremented when the channel is idle. Then, when the back-off counter reaches 0, channel access opportunity for transmission can be obtained. Furthermore, there is a low power detection threshold in LAA for

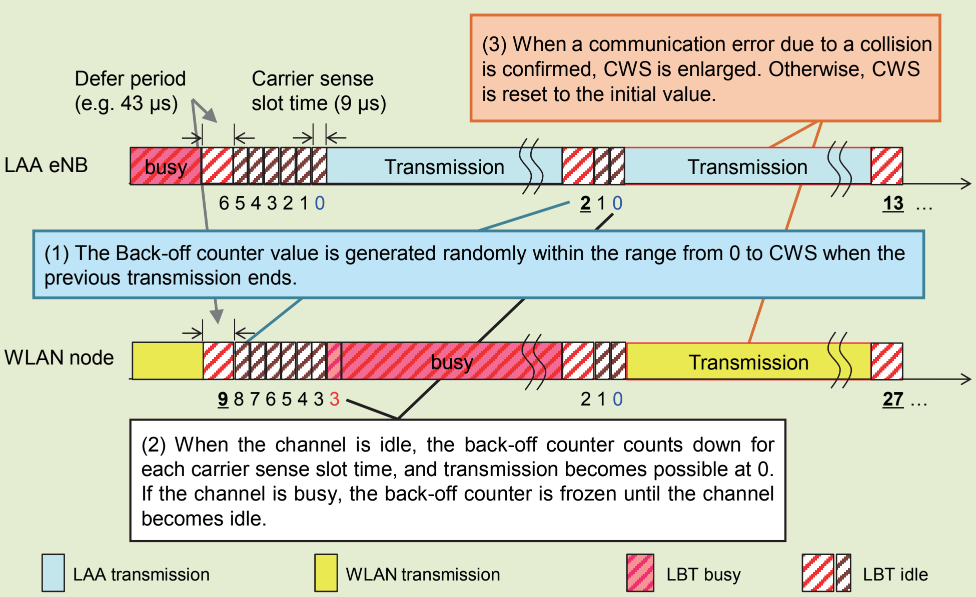



**Figure 5 LAA and WLAN coexistence based on LBT**

*32 **Carrier sensing:** Technology to confirm that a frequency carrier is not in use by another communication before commencing transmission.

*33 **Random back-off:** Technology to prevent collisions due to multiple simultaneous transmissions that uses periods of randomly set length in which it must be confirmed that a frequency carrier is not used before transmitting.

*34 **CWS:** The range of values that can be set randomly in random back-off technology.

coexistence with WLANs so that other nearby WLAN performance is not degraded [6]. There is also a set of configurations (LBT priority class) for the combination of LBT parameters and maximum transmission time, which are described in **Table 2**. For example, to send a small amount of data with minimum delay, the LBT time can be shortened with LBT priority class 1 in exchange for decreasing the maximum transmission time (Maximum Channel Occupancy Time (MCOT)).

2) Partial Subframe Transmission

In LTE, subframes with length of 1 ms are used as the basic Transmission Time Interval (TTI)*35 for data transmission and reception. Therefore, radio signal transmission or reception is performed for 1 ms from the beginning of the subframe. However, with the LAA channel access method, when transmission or reception becomes possible, i.e. when the back-off counter is at 0, in most cases the corresponding timing does not match the beginning of the subframe, which may limit opportunities for sending or receiving data.

Here, in LAA, initial partial subframe and ending partial subframe transmissions are supported as functions to enable transmission of control and data signals in start and stop positions other than the subframe boundaries. The initial partial subframe is the data transmission structure from the middle to the end of the subframe, while ending partial subframe is the data transmission structure from the beginning to the middle of the subframe. This function improves LAA transmission efficiency and throughput by increasing the amount of data sent in the same transmission time. Furthermore, since the LAA transmission time for a certain traffic amount is reduced, the time spent competing for channels with other systems is reduced, which enables improved coexistence with other systems in neighboring LAA areas [7].

Also, UE can identify normal subframes or partial subframes and recognize continuous transmission (bursts*36) cut-off points by decoding common control information from eNB to get the number of valid Orthogonal Frequency Division Multiplexing (OFDM) symbols in the subframe.

## 4.2 LWA Technology

In addition to LAA technology, Release 13 also specifies LWA technologies that enhance user throughput by utilizing LTE and WLAN radio resources simultaneously.

**Figure 6** describes LWA network architecture and LTE/WLAN protocol stack*37 adaptation.

1) LWA Network Architecture

LWA network architecture is based on the DC architecture defined in Release 12. LWA achieves radio capacity improvements without degrading UE mobility performance by utilizing LTE eNB as the MeNB due to its more reliable transmissions while using WLAN-AP (Access Point)*38 as SeNB for more capacity. Also, LWA utilizes the user plane data transmission paths defined for DC in Release 12, as shown in Fig. 6 (a). Release 13 specifies an interface (Xw IF) between eNB and WLAN-AP and inter-node procedures for this architecture.

**Table 2 LBT parameter set in LAA**

| LBT priority class | Defer period | CWS set (underlined is initial CWS value.) | MCOT |
|---|---|---|---|
| 1 | 16 + 9 × 1 = 25 μs | {<u>3</u>, 7} | 2 ms |
| 2 | 16 + 9 × 1 = 25 μs | {<u>7</u>, 15} | 3 ms |
| 3 | 16 + 9 × 3 = 43 μs | {<u>15</u>, 31, 63} | 8 or 10 ms* |
| 4 | 16 + 9 × 7 = 79 μs | {<u>15</u>, 31, 63, 127, 255, 511, 1,023} | 8 or 10 ms* |

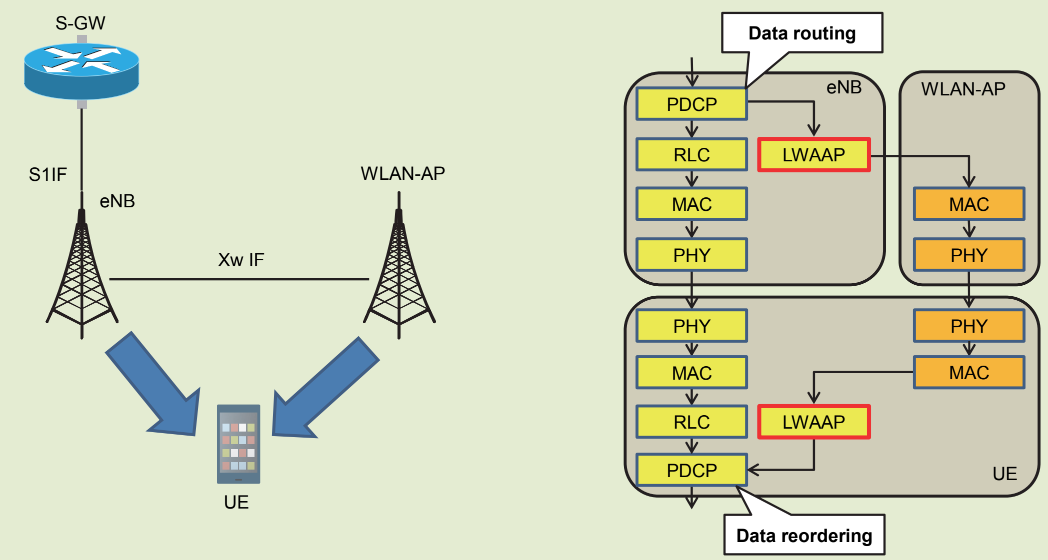
*10 ms is applied if RAT other than LAA is guaranteed not to coexist on the same frequency by regulations etc. In other cases, 8 ms is applied.

*35 **TTI:** Transmission time per data item transmitted via a transport channel.

*36 **Burst:** Temporally successive transmissions based on one LBT.

*37 **Protocol stack:** Protocol hierarchy.

*38 **WLAN-AP:** Nodes that transmit and receive using WLAN radio resources.




(a) LWA network architecture (b) LWA protocol stack adaptation

**Figure 6 LWA network architecture and protocol stack adaptation**

2) LTE/WLAN Protocol Stack Adaptation

In the same way as DC, the LWA protocol stack is split under the Packet Data Convergence Protocol (PDCP)*39 layer. Downlink data from Serving Gate-Way (S-GW)*40 arriving at eNB via S1 interface is processed in the PDCP layer in eNB, then either passed to LTE Radio Link Control (RLC)*41 layer to be sent to UE using LTE radio resources, or transferred to WLAN-AP to be sent to UE using WLAN resources.

However, because bearer*42-aware (de-) multiplexing is not done in WLAN as it is in LTE, if data of multiple bearers are sent via WLAN, the receiving UE is not be able to identify which received data belongs to which bearer, and consequently is not be able to perform reordering with the data received via LTE.

In order to solve this problem, a new adaptation layer (LWAAP, LTE-WLAN Aggregation Adaptation Protocol) is introduced under the PDCP layer in LWA, as shown in Fig. 6 (b). LWAAP layer performs capsuling on PDCP Protocol Data Units (PDUs)*43, and attaches the identity of the corresponding bearer to the header to enable the UE to identify the data.

## 5. Conclusion

This article has described the functional characteristics and basic operations specified in 3GPP Release 13 including advanced CA technologies for expanding maximum bandwidth and offloading uplink control information, advanced DC technologies for high uplink throughput and operational flexibility, and LAA/LWA technologies for communications on unlicensed bands. These functions enable further broadband communications, higher user throughput, and more flexible operations. To accommodate further traffic increases, Release 14 is studying enhanced LAA for higher uplink throughput and next-generation radio technologies with even wider bandwidths.

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*39 **PDCP:** One of the sublayers in Layer 2 of the radio interface in LTE that provides protocols for ciphering, integrity protection, header compression etc.

*40 **S-GW:** The area packet gateway accommodating the 3GPP access system.

*41 **RLC:** One of the sublayers in Layer 2 of the radio interface in LTE that provides protocols for retransmission control, duplicate detection, reordering etc.

*42 **Bearer:** A logical user-data packet transmission path established along P-GW, S-GW, eNodeB, and UE.

*43 **PDU:** A unit of data processed by a protocol layer/sublayer.

## References


[1] N. Miki et al.: "CA for Bandwidth Extension in LTE-Advanced," NTT DOCOMO Technical Journal, Vol.12, No.2, pp.10-19, Sep. 2010.

[2] Y. Kishiyama et al.: "Heterogeneous Network Capacity Expansion Technology for Further Development of LTE/LTE-Advanced," NTT DOCOMO Technical Journal, Vol.15, No.2, pp.9-17, Oct. 2013.

[3] T. Uchino et al.: "Carrier Aggregation Enhancement and Dual Connectivity Promising Higher Throughput and Capacity," NTT DOCOMO Technical Journal, Vol.17, No.2, pp.36-46, Oct. 2015.

[4] ETSI EN301 893 V1.8.1: "Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN," Harmonized European Standard, Mar. 2015.

[5] ARIB STD-T71 Ver. 6.1: "Broadband Mobile Access System (CSMA)," Mar. 2014.

[6] 3GPP TR36.889 V13.0.0: "Study on Licensed-Assisted Access to Unlicensed Spectrum (Release 13)," Jul. 2015.

[7] Y. Jiang, H. Harada, L. Liu, H. Jiang and S. Nagata: "Investigation on Partial Subframe Transmission for Licensed-Assisted Access to Unlicensed Spectrum," IEICE general conference, Mar. 2016.