LTE-Advanced | CA | DC

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

# Carrier Aggregation Enhancement and Dual Connectivity Promising Higher Throughput and Capacity

*In 3GPP Release 10 of LTE-Advanced, CA was introduced as a promising way to increase user throughput and it is being introduced commercially around the world. In Release 12, new functionalities were specified to further increase user throughput and capacity and to realize more flexible deployment: CA between LTE carriers using different duplex modes, RF requirements for CA with more LTE carriers, and DC, which enables a UE to connect with multiple base stations simultaneously.*

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## 1. Introduction

As smartphones have spread, traffic on wireless networks has increased. To increase the capacity of wireless networks and handle this increase, the 3GPP has been studying Heterogeneous Networks (HetNets)*1, which offload macro cell*2 radio traffic to small cells*3 with relatively low transmission power. NTT DOCOMO has been proposing a technology for and planning the deployment of "add-on cell" operation, which applies Carrier Aggregation (CA)*4 on HetNets, as specified in the Release 10 specification, to realize increased radio capacity using small cells while maintaining stable communication [1]. NTT DOCOMO is actively studying how to expand the regions where add-on operation is used, and other companies in the 3rd Generation Partnership Project (3GPP) are also actively studying how to achieve higher throughput using multiple LTE carriers and more-flexible operation. Based on this background, the Release 12 standard specifies TDD-FDD CA which aggregates LTE carriers using different duplex modes, Frequency Division Duplex (FDD)*5 and Time Division Duplex (TDD)*6, and the Radio frequency (RF) requirements for CA using more LTE carriers. It also specifies a new technology called Dual Connectivity (DC), with which UE is connected to multiple evolved NodeBs (eNBs)*7 using multiple LTE carriers. This article describes these technologies.

## 2. CA Extensions

### 2.1 CA between LTE Carriers with Different Duplex Modes

Release 12 specifies a TDD-FDD CA for CA between LTE carriers with different duplex modes, FDD and TDD, so



*1 **HetNet:** A network deployment that overlays nodes of different power. It typically mixes-in, links and integrates base stations of lower transmission power than conventional base stations.

*2 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

that a wider variety of frequency bands can be aggregated by CA. The FDD and TDD specifications are mostly compatible, but some control signaling procedures specifying transmission/reception timing are designed differently, such that they fit with their respective frame structures. It is difficult to perform CA with both FDD and TDD carriers utilizing such duplex-mode specific operation, since CA requires coordination between Component Carriers (CCs)*8, so a new control signaling procedure was specified for TDD-FDD CA.

The control schemes for both FDD and TDD in LTE, as well as TDD-FDD CA are described below.

1) FDD and TDD

A conceptual diagram of FDD and TDD in LTE is shown in **Figure 1**. With FDD, different frequencies are used for the UpLink (UL) and DownLink (DL) (pair band). Conversely, with TDD, the UL and DL use the same frequency, but transmitting and receiving switches in time, between the DL and the UL. Note that when switching from DL to UL, a Special subframe*9 is inserted, incorporating a DL reception period Downlink Pilot Time Slot (DwPTS), a Guard Period (GP), and an UL transmitting period Uplink Pilot Time Slot (UpPTS). In LTE, seven UL/DL configurations with different subframe up-down ratios and different UL/DL switching periods are specified (**Table 1**).

As mentioned earlier, the frame structures for FDD and TDD are different, with FDD allowing transmission and reception at any time, while TDD has constraints on such timing. For this reason, differences arise with control signalling procedure that requires specific timing, such as Hybrid Automatic Retransmission reQuest (HARQ)*10. With HARQ control, the User Equipment (UE) attempts to receive data on the Physical Downlink Shared CHannel (PDSCH)*11 allocated to itself, and transmits the decoding result (ACKnowledgement (ACK)*12 or NACK) as a HARQ feedback signal in a prescribed UL subframe. In CA aggregating multiple LTE carriers, the HARQ feedback signals for data received on a Primary Cell (PCell)*13 and Secondary Cell (SCell)*14 in the DL are sent together on the Physical Up-

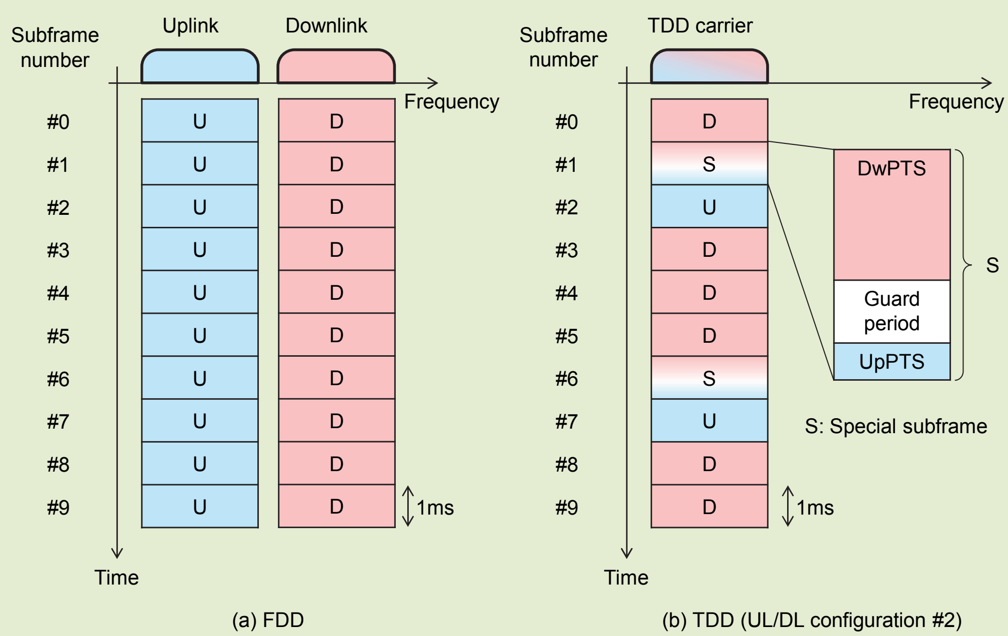


**Figure 1 Frame structures for FDD and TDD**

*3 **Small cell:** A general term for cells that transmit with power that is low compared to that of a macro cell transmitting at higher power.

*4 **CA:** A technology that achieves high-speed communications through wider bandwidth while maintaining backward compatibility with existing LTE by performing simultaneous transmission and reception using multiple component carriers.

*5 **FDD:** A scheme for transmitting signals using different carrier frequencies and bands in the uplink and downlink.

*6 **TDD:** A scheme for transmitting signals using the same carrier frequencies and bands in the uplink and downlink. It switches time slots for uplink and downlink.

*7 **eNB:** A base station for the LTE radio access system.

*8 **CC:** Term denoting each of the carriers used in CA.

*9 **Subframe:** A unit of radio resources in the time domain consisting of multiple OFDM symbols (typically 14 OFDM symbols).

link Control CHannel (PUCCH)*15 of the PCell. With an FDD carrier (or CA among FDD carriers), the HARQ feedback signal for data received on the DL is sent uniformly 4 ms later in the PCell UL subframe (**Figure 2**(a)). In contrast, with a TDD carrier (or CA among TDD carriers), the HARQ feedback timing depends on the DL subframe in which the data was received, since only certain subframes can be used for UL in the PCell. Specifically, as illustrated in Fig. 2(b), one or more HARQ feedback signals are sent in a particular PCell UL subframe at least 4 ms after the DL data is received.

Thus, the HARQ feedback timing is uniquely determined based on the respective FDD and TDD frame structures.

2) TDD-FDD CA

The timing of the HARQ feedback signal specified for TDD-FDD CA is described using an example below.

(1) PCell is FDD carrier

In the case that the PCell is an FDD carrier (FDD PCell) and conventional TDD HARQ feedback timing applies for a TDD carrier added as an SCell (TDD SCell), HARQ feedback delay will be the same as for conventional TDD, even though

**Table 1 TDD UL/DL configurations specified in LTE**

| Uplink-downlink configuration | Downlink-to-Uplink switch-point periodicity | Subframe # | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0 | 5ms | D | S | U | U | U | D | S | U | U | U |
| 1 | 5ms | D | S | U | U | D | D | S | U | U | D |
| 2 | 5ms | D | S | U | D | D | D | S | U | D | D |
| 3 | 10ms | D | S | U | U | U | D | D | D | D | D |
| 4 | 10ms | D | S | U | U | D | D | D | D | D | D |
| 5 | 10ms | D | S | U | D | D | D | D | D | D | D |
| 6 | 5ms | D | S | U | U | U | D | S | U | U | D |

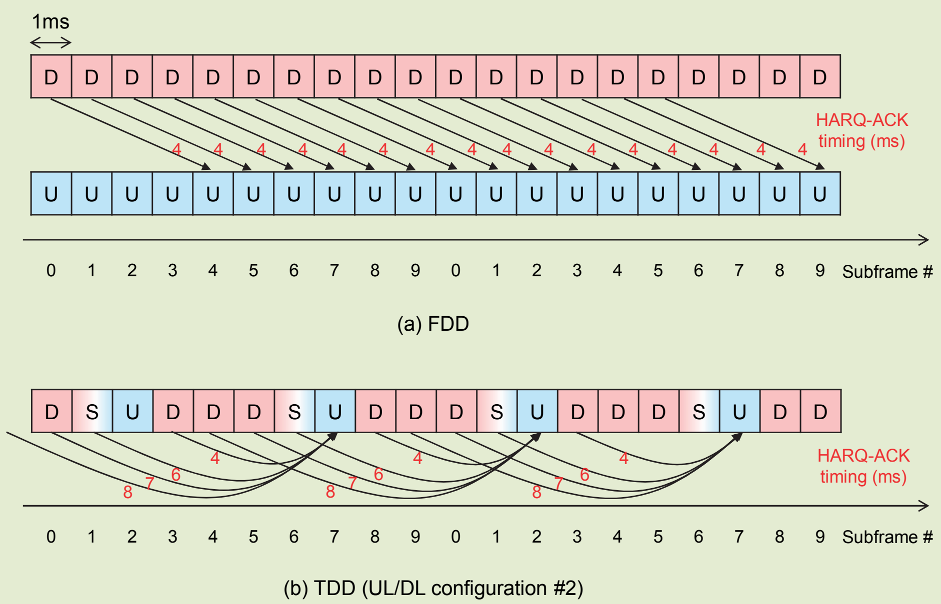


**Figure 2 DL HARQ-ACK transmission timing for FDD and TDD**

*10 **HARQ:** A technology that combines Automatic Repeat reQuest (ARQ) and error correcting codes to improve error-correcting performance on a retransmission and reduce the number of retransmissions. A packet retransmission method that improves reception quality and achieves efficient transmission by combining the retransmitted data with previously received data.

*11 **PDSCH:** A shared channel used in DL data transmission in LTE.

*12 **ACK:** An acknowledgement feedback from the receiving node to the transmitting node when a data frame has been received successfully.

*13 **PCell:** A cell that maintains the connection between UE and network in CA.

*14 **SCell:** A cell that provides radio resources in addition to a PCell.

*15 **PUCCH:** Physical channel used for sending and receiving control signals in the UL.

the FDD has the advantage that there is opportunity for UL transmission in every subframe. To take the advantage of the FDD frame structure, HARQ feedback signals for the TDD SCell can be sent utilizing the same timing as for the FDD carrier. Specifically, HARQ feedback signals corresponding to DL received data on a TDD SCell are sent 4 ms after the subframe, as with an FDD PCell (**Figure 3**(a)). Thus, since HARQ response signals are sent with the same timing as for FDD and CA among FDD carriers, HARQ feedback delay for TDD SCells is comparable to that for FDD. In other words, HARQ transmission control can be applied to TDD SCells, as if the SCells were FDD carriers.

(2) PCell is TDD carrier

On the other hand, in the case that PCell is a TDD carrier (TDD PCell), the same constraint as with conventional TDD applies; UL transmission can be performed only in a limited number of PCell UL subframes. Accordingly, there are cases when there is no UL subframe 4 ms after DL data is received on an FDD carrier added as an SCell (FDD SCell). In order to be able to schedule all DL subframes on FDD SCells, a new DL HARQ feedback timing was specified for FDD SCells (Fig. 3(b)). The timing for transmitting HARQ feedback

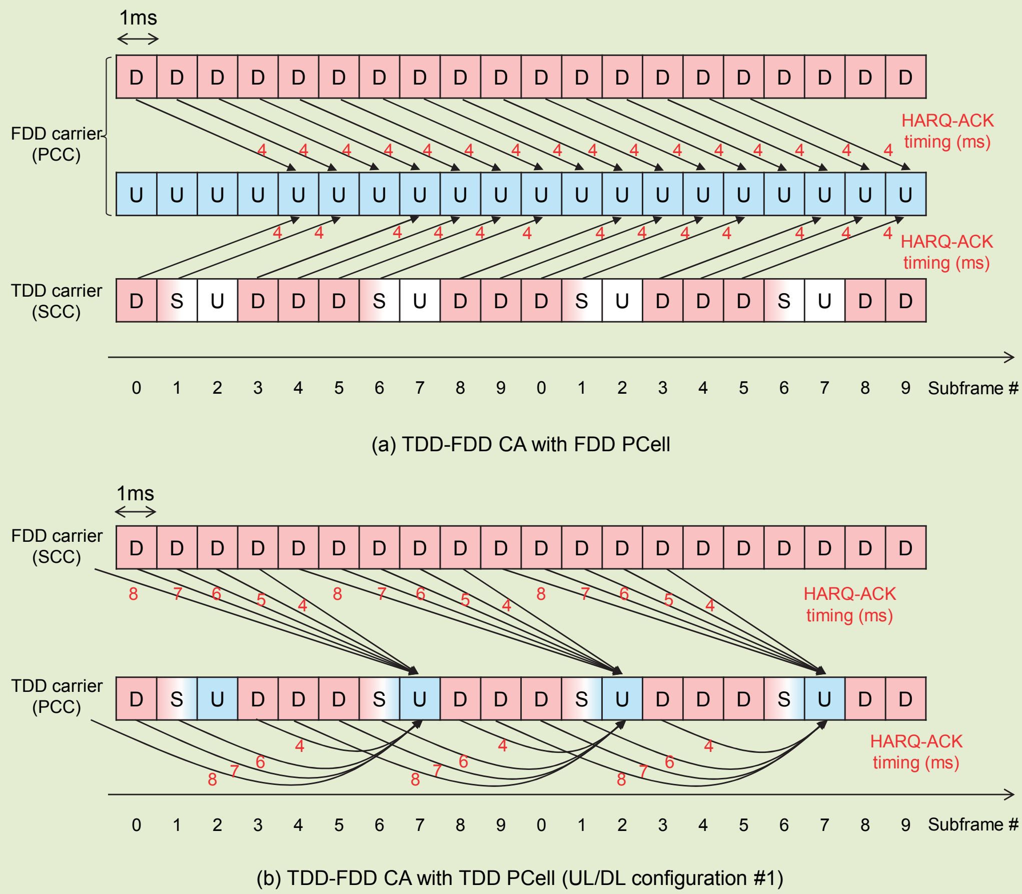


**Figure 3　DL HARQ-ACK transmission timing for TDD-FDD CA**

signals for FDD SCells is determined based on the UL/DL configuration of the TDD PCell. Thus, with a TDD PCell, HARQ transmission control for the TDD carrier can be applied to FDD SCells, as if the SCells were TDD carriers.

### 2.2 RF Requirements for CA Supporting More Carriers

As specified in the Release 10, up to five LTE CC can be aggregated in CA to realize 100 MHz bandwidth communication. However, the RF requirements for CA operation (e.g., reference sensitivity requirements, spurious emission requirements*16, etc.) are quite different and diverse depending on frequency band, number of CCs and bandwidth of CCs. For this reason, to develop UE that supports specific CA band combinations, it is first necessary to specify corresponding RF requirements in 3GPP specifications. 3GPP specifies such RF requirements according to demand from operators and in Release 10 and 11, requirements for CA band combinations consisting of two CCs were specified. In Release 12, to achieve even higher throughput using more CCs, new RF requirements for CA band combinations consisting of three CCs on the DL were specified. This will enable development of UE which can serve higher throughput thanks to a total of 60 MHz aggregated bandwidth.

Moreover, 3GPP is working to achieve such higher throughput due to CA in the UL as well. Up to Release 11, the requirements for CA band combinations consisting of only two CCs in the same frequency band had been specified. In Release 12, those for CA band combinations consisting of two different frequency bands are specified.

## 3. DC

As mentioned in the first article [2] of this special feature, a new technology called DC has been specified. This feature increases user throughput by aggregating multiple CCs from different eNBs connected by a backhaul*17 with non-negligible delay, considering that such backhauls can be provided with relatively lower cost and are used in many countries and regions. Compared with conventional CA, which aggregates CCs from a single eNB, the following issues had to be studied in order to aggregate carriers from different eNBs.

(1) Network architecture for aggregating carriers from different eNBs
- U-plane data routing to the different eNBs
- Termination point of Control Plane (C-plane)*18 and User Plane (U-plane)*19 protocols
- Coordination between Master eNB (MeNB) and Secondary eNB (SeNB)

(2) Physical layer functions for simultaneous connection to different eNBs
- Transmission of control signals
- Transmission power control*20 for simultaneous transmission

(3) Supporting synchronous and asynchronous networks

How each of these issues was resolved to specify DC is described below.

### 3.1 Network Architecture for Aggregating Carriers from Different eNBs

1) U-plane Data Routing to the Different eNBs

DC in Release 12 utilizes the radio resources*21 from two eNBs, called MeNB and SeNB. To achieve throughput comparable to that with CA, the user data from one bearer*22 needs to be transmitted from two eNBs. There are two architecture options defined in DC. In the first architecture, the MeNB acts as an anchor point for splitting user data, and the DL data delivered via an S1 interface*23 from the Serving Gateway (S-GW)*24 is transmitted on the MeNB carrier or forwarded via X2 interface*25 to the SeNB and then transmitted on the SeNB carrier (**Figure 4**(a)). The second architecture is defined for deployments emphasizing the off-loading effects rather than the throughput enhancement, which is the first architecture's main focus. In this architecture the user data from the bearer is transmitted on only the SeNB carrier (Fig. 4(b)). In this case, the DL data arrives at the SeNB directly from the S-GW without going through the MeNB. Note that for both architec-

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*16 **Spurious emission requirement:** Requirement to avoid interference from unnecessary radio emissions.

*17 **Backhaul:** Indicates the route connecting a wireless base station to the core network.

*18 **C-plane:** The protocol used for transmitting control signals for connection establishment and other procedures.

*19 **U-plane:** The protocol used for transmitting user data.

*20 **Toransmission power control:** A technique of controlling transmission power such that the signal-to-noise ratio (SNR) and signal-to-interference and noise ratio (SINR) at the receiver exceed the required values.

*21 **Radio resource:** General term for resources needed to allocate radio channels (frequencies).

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

*23 **S1 Interface:** An interface connecting an MME or S-GW to eNB.

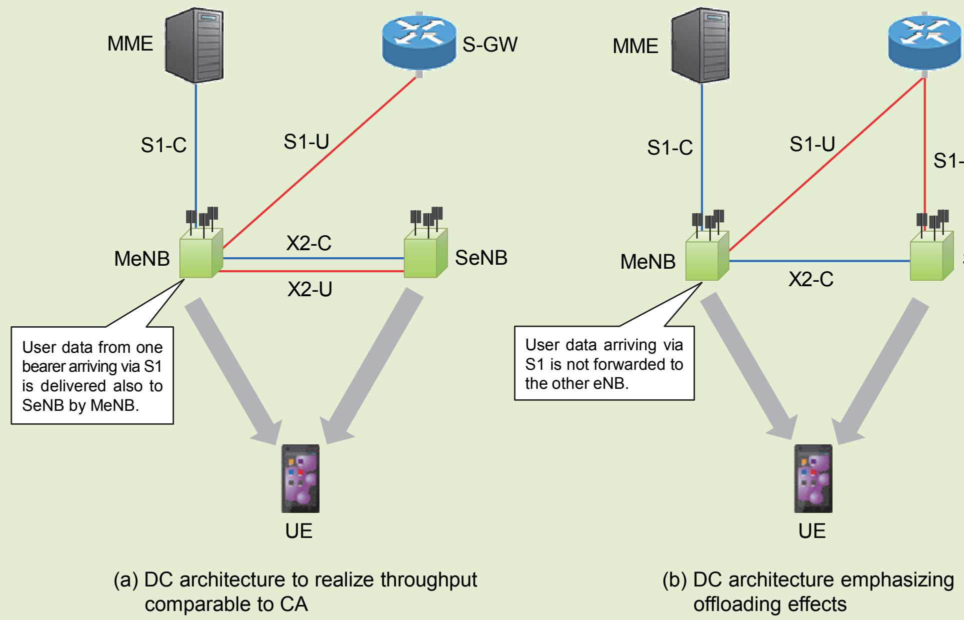


**Figure 4 DC architectures**

tures, only the MeNB establishes a connection with the Mobility Management Entity (MME).

In this article, we focus on the first architecture, which emphasizes user throughput enhancement. Note that in Release 12, such throughput enhancement by utilizing the radio resources of two eNBs is supported only for the DL, and for the UL, user data transmission is handled by only one of the eNBs.

2) Terminating C-plane Protocols

In LTE networks, a UE first establishes a Radio Resource Control (RRC)*26 connection with an eNB, and then uses this connection to receive radio resource configuration and measurement configuration for handover*27 from the eNB and transmit measurement reports. For DC, this conventional RRC connection concept is utilized, an RRC connection is established with the MeNB only, and the SeNB connection is controlled through the MeNB. Several procedures are specified specifically for DC, such as SeNB Addition, to configure the UE for a carrier provided by a SeNB, and SeNB Release or Change of SeNB, to remove a carrier.

With DC, it is assumed that the macro cell is covered by the MeNB and the small cells are covered by SeNBs. In such a configuration, the add-on cell concept can be applied, even when aggregating multiple CCs from different eNBs that are connected by a backhaul with non-negligible delay. Even if the user moves across multiple SeNBs, the degradation of mobility performance caused by handover can be avoided with RRC control, using SeNB Addition, SeNB Release and Change of SeNB.

3) Terminating U-plane Protocols

Conventional LTE uses a protocol stack on eNB and UE as shown in **Figure 5**, consisting of, from higher to lower, a Packet Data Convergence Protocol (PDCP)*28 layer, a Radio Link Control (RLC)*29 layer, a Medium Access Control (MAC)*30 layer and a physical layer. In contrast, with DC, since multiple eNBs communicate with the UE, the protocol stacks split below the PDCP layer in the MeNB on the network side, such that both MeNB and SeNB have their own protocol stacks that are the same as the conventional stack from the

*24 **S-GW:** A packet switch that processes user data in an LTE network.
*25 **X2 Interface:** An interface for connecting between eNBs.
*26 **RRC:** A protocol for controlling radio resources on a radio network.
*27 **Handover:** The technique of switching from one base station to another without interrupting communication when a terminal moves between base stations.
*28 **PDCP:** One of the sublayers in Layer 2 of the radio interface in LTE that provides protocols for ciphering, integrity protection, header compression and the like.
*29 **RLC:** One of the sublayers in Layer 2 of the radio interface in LTE that provides protocols for retransmission control, duplicate detection, reordering and the like.
*30 **MAC:** One of the sublayers of layer 2 of the radio interface in LTE, providing protocols for radio resource allocation, mapping data to TBs, and performing HARQ retransmission control.

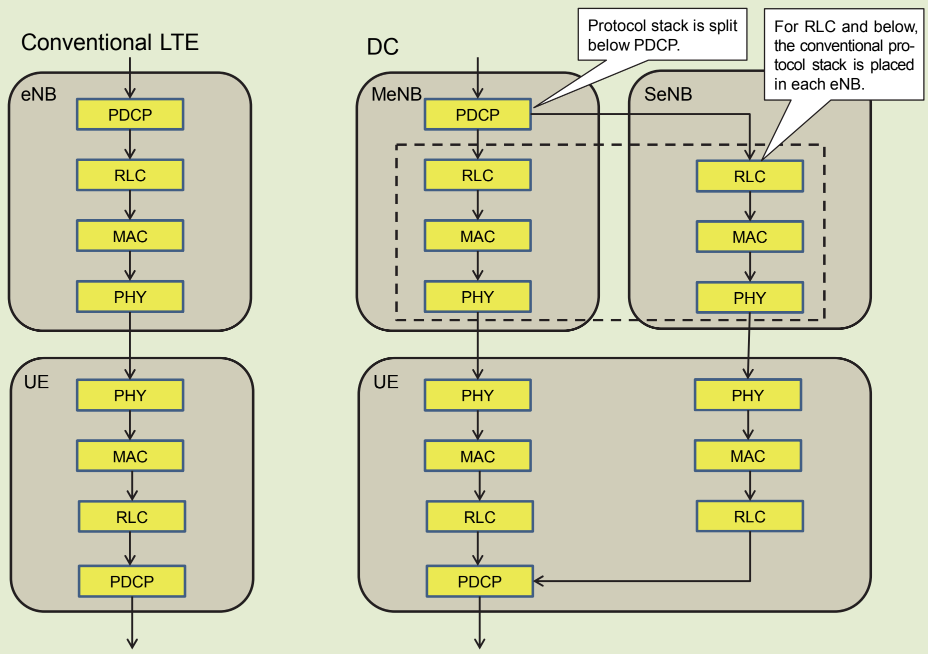


**Figure 5 Protocol stacks for conventional LTE and DC**

RLC layer down. The UE side has the corresponding protocol layers.

4) Coordination Between MeNB and SeNB

When splitting the data as described in 1), the MeNB needs to split the user data appropriately between its own carrier and the SeNB carrier. A flow control function is defined for this purpose, enabling the SeNB to feedback acknowledgement of data transmitted from the SeNB to the UE and to notify the MeNB of available buffer size in the SeNB.

Also, to enable configuration of radio resources for the UE as mentioned in 2), procedures for sending information on radio resources allocated by the SeNB to the MeNB via the X2 interface are defined. The SeNB Addition procedure for DC is shown in **Figure 6**. The UE first connects to the eNB acting as the MeNB and reports to the MeNB when the quality of the cells under a neighbour eNB is good. If the reported quality satisfies a certain threshold, then the MeNB configures DC with the relevant neighbor eNB (which is refered to SeNB) with the following procedure.

(1) MeNB sends SeNB a request to configure DC (SeNB Addition Request).
(2) SeNB responds to the DC configuration request, sending MeNB a SeNB Addition Request Acknowledgement containing radio parameter information for the SeNB cell.
(3) MeNB receives the response from the SeNB and sends a radio resource configuration signal (RRC connection reconfiguration) to the UE.
(4) The UE sends the MeNB a RRC connection reconfiguration complete message, and starts the random access procedure for the SeNB. Upon the completion of the procedure, the connection with the SeNB is established.
(5) When the MeNB receives the completion message from the UE, it informs SeNB of the completion (SeNB reconfiguration complete), completing the DC configuration procedure. Thereafter, the MeNB starts forwarding DL user data arriving from the S-GW to the SeNB.

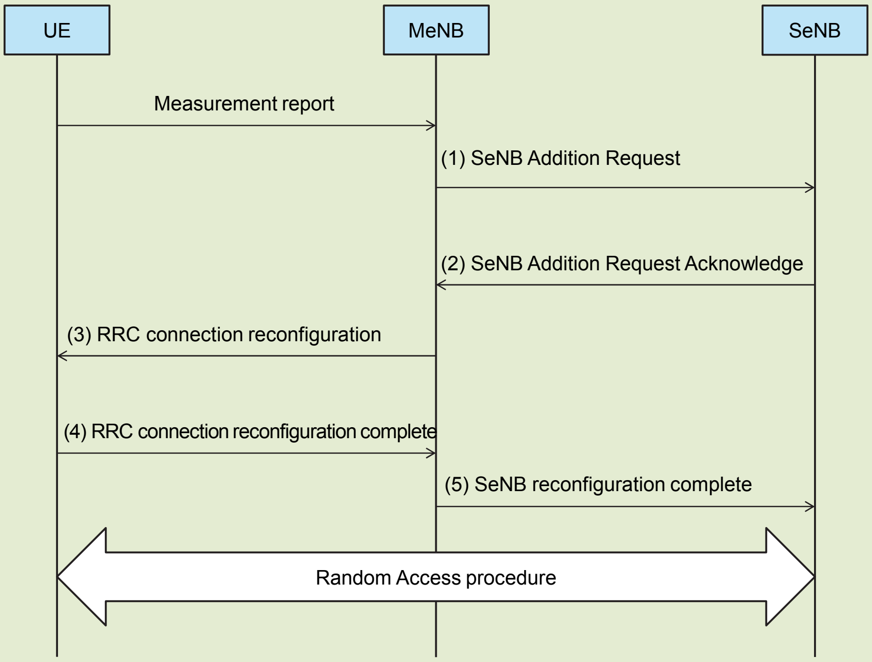


**Figure 6 SeNB addition procedure**

### 3.2 Physical Layer Mechanism for Simultaneous Connection to Different eNB

For CA, aggregated carriers are managed and scheduled by a single eNB. For this reason, information regarding each of the carriers is known in real time by that eNB. On the other hand, since carriers aggregated with DC are managed and scheduled by two eNBs that could be connected by a backhaul with non-negligible delay, it is difficult for the eNBs to share information about each carrier in real time. To solve this issue, advanced physical layer mechanisms were introduced.

1) Transmission of Control Signals

The PCell for CA supports all physical channel*31 functions in Release 8, while SCells only support some of them. For example, PUCCH and Contention Based Random Access (CBRA) are not supported on SCells, and transmission of UL Control Information (UCI), such as HARQ feedback signals, channel quality information feedback, and UL scheduling requests to the eNB, are basically handled by the PCell.

With DC, there can be non-negligible delay between the eNBs of the aggregated carriers, making it difficult for eNBs to share information such as UCI and scheduling requests through the backhaul in real-time, so that scheduling can be carried out taking them into account. Thus, in DC, in addition to the PCell, one carrier under the SeNB is used as the Primary SCell (PSCell) supporting PUCCH transmission and CBRA, and UCI and scheduling requests for carriers under the SeNB are sent directly from the UE to the SeNB (**Figure 7**). This allows communication with multiple eNBs to be implemented without being affected by delay between the eNBs. The PSCell also provides functionality such as Radio Link Monitoring, which was only supported by the PCell earlier.

DC UEs can be configured with CA within MeNB and/or SeNB to increase throughput. In this case, the UE transmits the UCI of the carriers under the MeNB in the PUCCH of the PCell and the UCI of the carriers under an SeNB

*31 **Physical channel:** A generic term for channels that are mapped onto physical resources such as frequency or time, and transmit control information and other higher layer data.

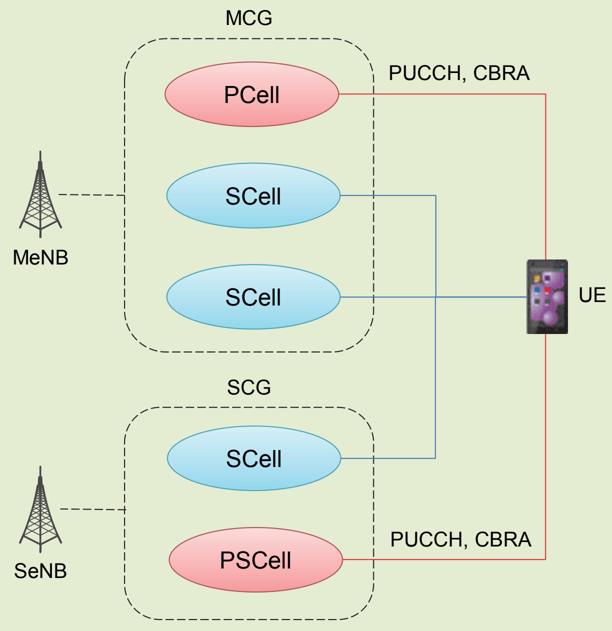


**Figure 7 Cell-Groups in DC**

in the PUCCH of the PSCell. In this way, each carrier configured for the UE is associated with a PCell or PSCell, forming a Cell-Group (CG). For this reason, the CG under the MeNB is called a Master Cell-Group (MCG) and a CG under an SeNB is called a Secondary Cell-Group (SCG). MAC layer and physical layer control, such as scheduling, is performed per CG.

2) Transmission Power Control for Simultaneous Transmission

Conventionally, when multiple UL carriers are configured for a UE, the eNB manages the transmission power for the UE, allocating resources of each carrier and adjusting transmission power so that the transmit power does not exceed a certain value (called maximum transmit power in this article). The transmit power can be controlled dynamically in Transmission Time Interval (TTI)*32 units. However, with DC, it is difficult for each eNB to know and control the transmission power of each carrier in real time, and it is inevitable that the total UE transmit power, the sum of UL transmit power for all the carriers over the two eNB, will at times exceed the maximum transmit power per UE. If the UE has UL transmission which will result in excessive transmission power, the UE itself reduces (scales) the power of the UL signal to keep the transmit power within the allowable range. However, if scaling of control information and other important UL signals occurs often, user throughput could be degraded. Thus, with DC, power control was introduced that guarantees a minimum transmission power for each CG, to maintain minimum UL coverage with each eNB and prevent important UL signals from being scaled. Specifically, the UE allocates certain transmission power for each CG to guarantee a minimum transmission power, according to the Maximum Guaranteed Power (MGP) configured by the eNB. If the total required transmission power of both CGs exceeds the maximum transmit power per UE, the UE allocates transmit power to the UL signals for each CG at least until the MGP value for the CG.

Since DC supports both synchronous and asynchronous operation as mentioned in section 3.3, two power control modes

*32 **TTI:** The time interval at which signals are transmitted.

were specified. With synchronous DC operation (mode 1), MCG and SCG subframe boundaries coincide closely (**Figure 8**(a)). Therefore, the UE can calculate transmission power allocated for each CG at the same time. Thus, if the maximum transmission power per UE is expected to be exceeded, the UE re-calculates the transmission power for each CG so that the transmission power not guaranteed by MGP is allocated for UL transmission based on channel type. Then, transmission power scaling is applied starting with lower priority channels as for CA. This can avoid scaling of high-priority signals, even if the power allocated is not being guaranteed by MGP.

On the other hand, with asynchronous DC operation (mode 2), MCG and SCG subframe boundaries can differ significantly (Fig. 8(b)). Therefore, the transmission power to be allocated for each CG is determined based on the transmission timing. For this reason, the transmission power not guaranteed by MGP is allocated sequentially, in the order UL transmission is performed. If the maximum transmit power is expected to be exceeded, the transmission power for the UL transmission of the CG having later transmission is restricted, regardless of the channel type. Since it is not necessary to compute the transmit power of the UL transmission between MCG and SCG having large timing difference at the same time, the UE computational complexity can be alleviated.

### 3.3 Supporting Synchronous and Asynchronous Networks

Since all CCs configured for CA are accommodated in the single eNB and these CCs are synchronized to each other, UE supporting conventional CA are implemented under assumption of synchronization among CCs. However, CCs accommodated in different eNB are not always synchronized even if they are on the same network. For this reason, a UE implemented assuming the CCs are synchronized may not be able to operate DC in an unsynchronized network, which will limit where DC can be deployed. Thus, to implement more flexible DC operation, in addition to DC operation assuming synchronization between eNBs, an asynchronous DC operation, which

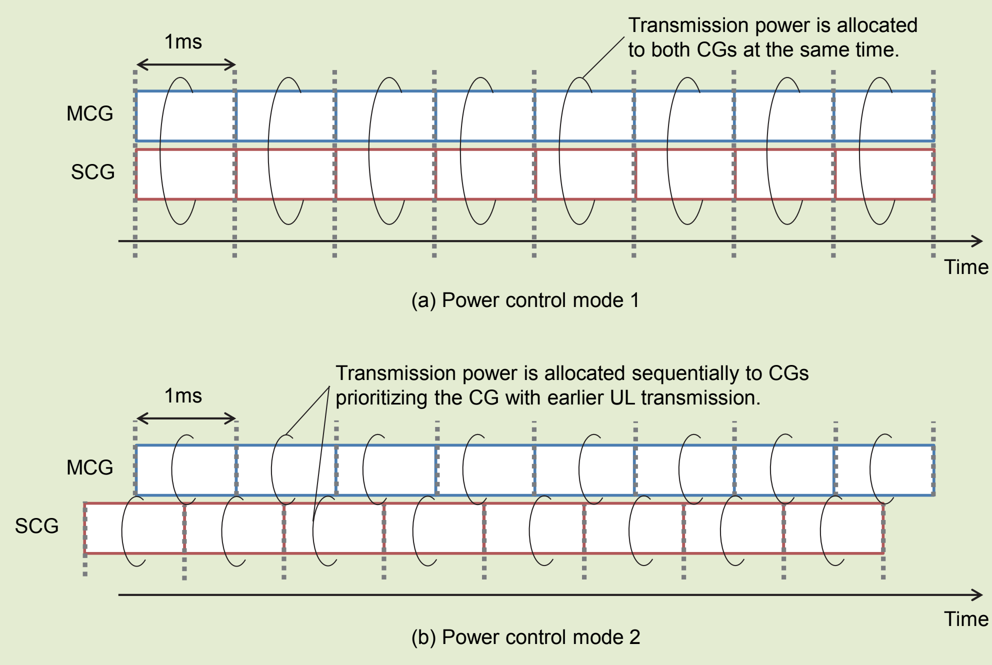


**Figure 8 Power control modes for synchronous and asynchronous DC operation**

does not assume synchronization between CCs, has been specified. Thus, UE supporting DC is implemented assuming these two types of operations.

For synchronous DC operation, CCs are assumed to be synchronized as those for CA. This means that although it can be operated only on synchronized networks, UE supporting DC can be implemented reusing the CA implementation. On the other hand, for asynchronous DC operation, although UEs need to be able to handle signals of different carriers arriving with a large delay, operators can apply DC without synchronization between eNBs and flexible deployment can be achieved.

## 4. Conclusion

In this article, we have described the functional characteristics and basic operations of TDD-FDD CA, RF requirements for CA using more CCs, as well as DC as specified in 3GPP Release 12. With these functions, higher throughput can be served in a larger expanded area by more flexible add-on cell deployment.

To further accommodate traffic as it continues to increase, in Release 13 we are studying further enhancement of CA utilizing bandwidths exceeding 100 MHz and enhancement of DC which increases user throughput in the UL as well.

### References

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