LTE-Advanced Bandwidth Extension CA

Technology Reports

Special Articles on LTE-Advanced Technology
—Ongoing Evolution of LTE toward IMT-Advanced—

CA for Bandwidth Extension in LTE-Advanced

The standardization of LTE-Advanced as an enhanced form of LTE is now underway at 3GPP. To achieve greater throughput while maintaining backward compatibility with LTE, LTE-Advanced introduces CA technology that uses multiple LTE carriers simultaneously and treats bandwidths supported by LTE Rel. 8 (maximum 20 MHz) as basic bandwidth units.

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1. Introduction

To achieve a high-speed, high-function and economical wireless network, NTT DOCOMO is developing a next-generation mobile communications system for commercial use based on 3GPP Rel. 8 specifications [1] standardized in the spring of 2009. LTE*1 Rel.8 features a radio access system using Orthogonal Frequency Division Multiple Access (OFDMA)*2 in the downlink and Single Carrier (SC)-FDMA*3 in the uplink with a spectrum efficiency*4 three to four times that of W-CDMA.

However, the spread of large-capacity content services like video sharing and instant messaging is expected to drive up traffic volume to new levels, and to keep up with this growing demand, NTT DOCOMO is promoting the standardization of LTE-Advanced (LTE Rel. 10) with an eye to raising the transmission speed of the radio access network even higher. At 3GPP, an LTE-Advanced study item [2] with NTT DOCOMO as rapporteur was approved in March 2008 and technical studies for LTE Rel. 10 were begun. At present, detailed specification of Carrier Aggregation (CA) as a major elemental technology for increasing transmission speed in LTE Rel. 10 is proceeding. In CA, communication is achieved through the simultaneous use of multiple LTE carriers called “Component Carriers (CCs)” enabling broadband transmission exceeding 20 MHz. In LTE Rel. 10, the use of CA with multi-antenna transmission will achieve maximum transmission speeds of 1 Gbit/s in the downlink and 500 Mbit/s in the uplink. In December 2009, a work item [3] for CA was approved at 3GPP, and the drafting of standard specifications is now progressing rapidly with the aim of completing specifications by the end of 2010.

In this article, we focus on CA for bandwidth extension and describe the basic concept of CCs, frequency arrangements when using CCs, and probable CA usage scenarios. We also explain the radio access system, the

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*1 **LTE**: Extended standard for the 3G mobile communication system studied by 3GPP. Achieves faster speeds and lower delay than HSPA.

*2 **OFDMA**: A radio access scheme that uses Orthogonal Frequency Division Multiplexing (OFDM). OFDM uses multiple low data rate multi-carrier signals for the parallel transmission of wideband data with a high data rate, thereby implementing high-quality transmission that is highly robust to multipath interference (interference from delayed waves).

configuration of the physical layer including layer 1 and layer 2 control channels, the configuration of layer 2, and radio protocol including Radio Resource Control (RRC)*5.

2. Bandwidth Extension by CA

2.1 Bandwidth Extension using CCs

LTE Rel. 8 supports transmission bandwidths from 1.4 MHz to a maximum of 20 MHz, but to meet the requirements of IMT-Advanced [4], even broader bandwidths will be needed. But to achieve a smooth transition from Rel. 8 to Rel. 10, it is desirable that the wireless interface have backward compatibility so as to support both Rel. 8 and Rel. 10 User Equipment (UE) within the same system band. To this end, LTE Rel. 10 supports bandwidth extension up to a maximum of 100 MHz using CA (**Figure 1**). CA is a method for achieving bandwidth extension by arranging basic frequency blocks called CCs on the frequency axis [5]. Here, the bandwidth of each CC is a bandwidth supported by LTE Rel. 8 (1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz or 20 MHz) to maintain backward compatibility with LTE Rel. 8. By making the bandwidths available to each CC the same as those of Rel. 8, it becomes possible to appropriate the eNode B (eNB) and Radio Frequency (RF) specifications*6 associated with LTE Rel. 8 (such as specifications for Adjacent Channel Leakage power Ratio (ACLR)*7, Spectrum Emission Mask (SEM), spurious emissions, receiver sensitivity, Adjacent Channel Selectivity (ACS) and blocking) and thus affect a smooth transition to LTE Rel. 10. Furthermore, considering that Rel. 10 UE will generally support both Rel. 8 and Rel. 10, and given that the Rel. 10 system bandwidth will be the same as that of Rel. 8, it will be possible to minimize redundant functions, which is a great advantage in terms of implementation. In this way, Rel. 10 UE will transmit and receive multiple CCs simultaneously achieving higher transmission speeds than Rel. 8. In this regard, CA can be classified into three types according to the way in which CC frequencies are arranged (**Figure 2)**.

1) Intra-band Contiguous CA

In this type of frequency arrangement, communications are performed by a contiguous band larger than 20 MHz. This scenario can be applied, for example, to broadband allocation in the 3.5-GHz band.

2) Inter-band Non-contiguous CA

In this case, communications are performed using different carrier frequency bands, such as the 2-GHz band

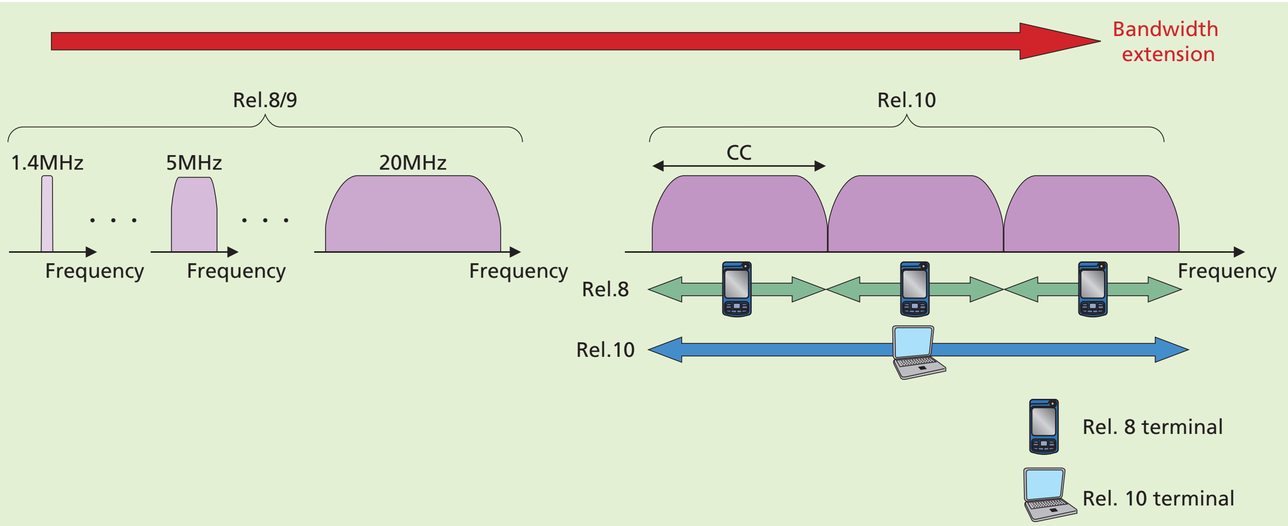

Figure 1 Bandwidth extension by CA

*3 **SC-FDMA**: A method that allows multiple user access by allocating consecutive frequency bandwidths for each user within the same frequency band.

*4 **Spectrum efficiency**: The number of data bits that can be transmitted per unit time and unit frequency band.

*5 **RRC**: Layer 3 protocol for controlling radio resources.

*6 **RF specifications**: Radio-related characteristics such as spurious emissions and receiver sensitivity.

*7 **ACLR**: Ratio of one's signal power to that of unnecessary waves sent to an adjacent channel when a modulated signal is transmitted.

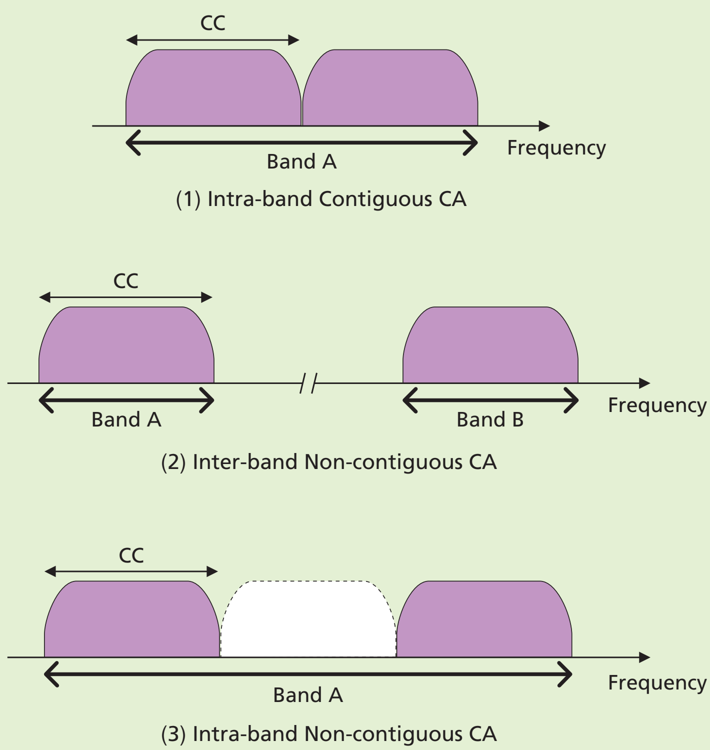

Figure 2 Frequency arrangements for CCs

and the 800-MHz band. The use of two carriers can improve throughput in communications, and the use of multiple carriers with different propagation environments can improve stability.

3) Intra-band Non-contiguous CA

Here, communications are performed using multiple carriers in the same frequency band. This scenario could be applied when frequency bands are allocated to operators in a fragmentary manner as in Europe and the United States, or when network sharing is performed among multiple operators.

2.2 CA Usage Scenarios

Examples of CA usage are shown in **Figure 3** [6]. In addition to a configuration that allocates a contiguous band and provides identical coverage using multiple CCs (Fig. 3(a)), we can consider a configuration that uses CCs of greatly different frequencies resulting in different coverage between those CCs (Fig. 3(b)), a configuration in which the sectors of a certain CC are oriented toward the boundaries of another CC's sectors (Fig. 3(c)), and a configuration that secures macro coverage with a certain frequency (usually a low frequency) while absorbing traffic from hotspots[*8] using Remote Radio Head (RRH)[*9] units with another frequency (usually a high frequency) (Fig. 3(d)).

3. Physical Layer Configuration

3.1 Radio Access

1) Downlink

In the downlink, LTE-Advanced will adopt an OFDMA-based radio access system the same as Rel. 8. When extending bandwidth using CA, the Synchronization Signal (SS), which is used to detect the cell that UE must connect to (cell search), is transmitted on the center frequency of each CC using a signal format common with LTE Rel. 8 (**Figure 4**). The Physical Broadcast Channel (PBCH) is multiplexed in the same way. Here, the center frequency of each CC is arranged on a 100-kHz channel raster[*10]. In this way, SS and PBCH can be used in all CCs and access from both Rel. 8 and Rel. 10 UEs can be supported. This arrangement of multiple SSs is also useful in shortening the time required for cell search in the case of a very wide bandwidth such as a 100-MHz band. On the Physical Downlink Shared Channel (PDSCH), Adaptive Modulation and Coding (AMC)[*11] and Hybrid Automatic Repeat reQuest (HARQ)[*12] are performed independently in each CC in units of transport blocks and then mapped to a single CC. As a result, the frequency diversity[*13] effect obtained through channel coding is limited to the

*8 **Hotspot**: A place where traffic is generated in concentrated form such as a plaza or square in front of a train station.

*9 **RRH**: Base-station antenna equipment installed at a distance from the base station using optical fiber or other means.

*10 **Channel raster**: Minimum unit for determining a carrier's center frequency. For a channel raster of 100 kHz, center frequency can be set in units of 100 kHz.

*11 **AMC**: A method for adaptively controlling transmission speed by selecting an optimal data modulation scheme and channel coding rate according to reception quality as indicated, for example, by the signal-to-interference power ratio.

*12 **HARQ**: An error-correction technology combining channel coding and ARQ.

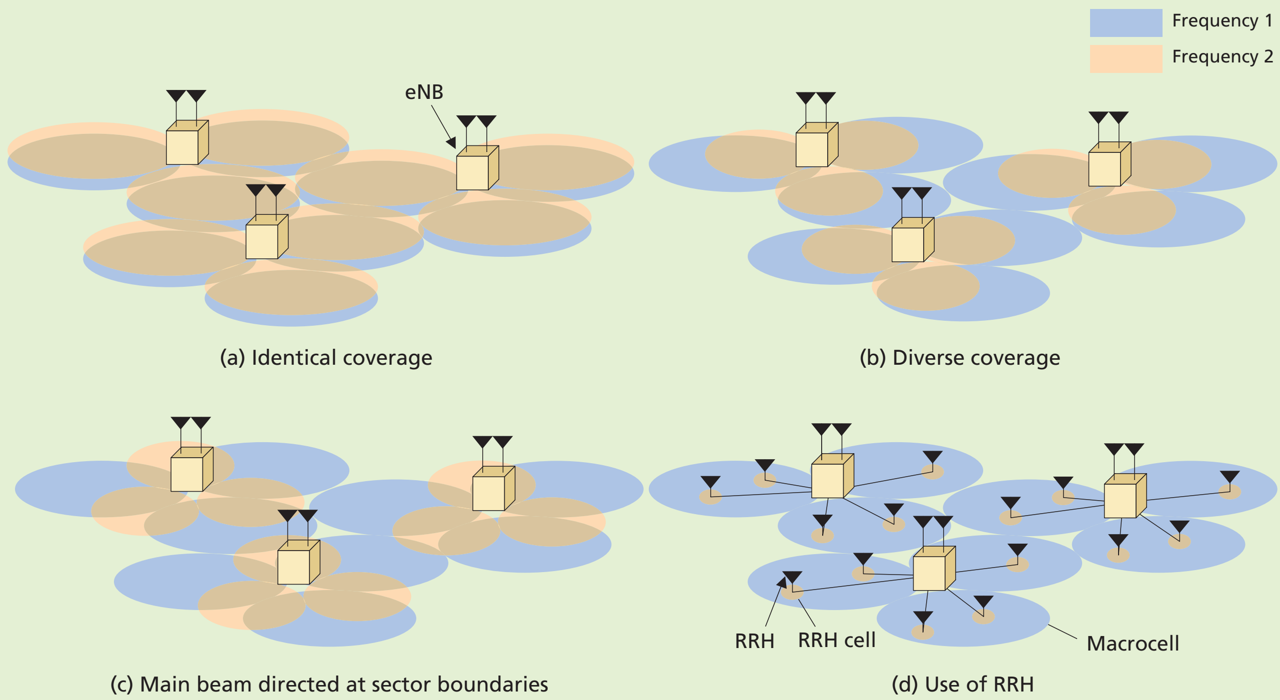

Figure 3 CA usage scenarios

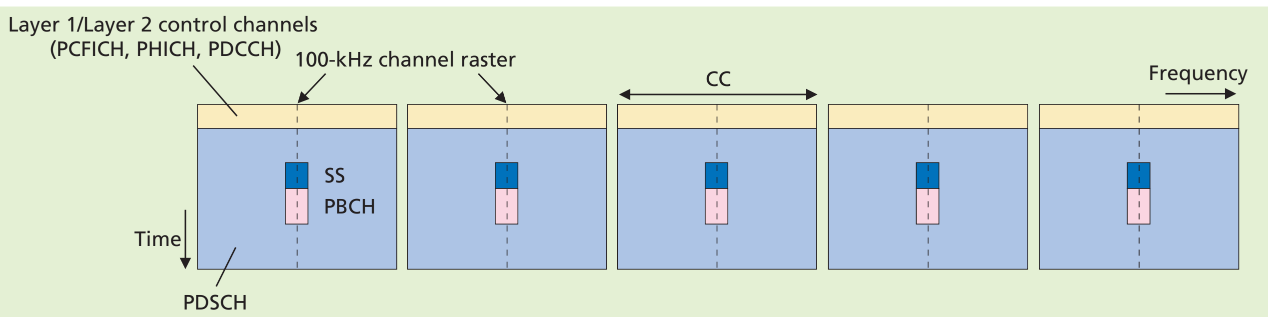

Figure 4 Physical channel arrangement in the downlink

CC bandwidth [7]. On the other hand, specifications related to Rel. 8 transport blocks can be reused. In addition, in the case that coverage, interference power, etc. of each CC differs according to the CA scenario in use as described in Section 2.2, different transmission modes can be set for each CC even for the same UE.

2) Uplink

In the uplink, the SC-FDMA system, which can keep the Peak-to-Average Power Ratio (PAPR)*14 low, will be adopted, and Discrete Fourier Transform Spread (DFTS)-OFDM*15 will be used to generate SC-FDMA signals in the frequency domain [8]. However, in the case of bandwidth extension using CA, a Physical Uplink Control Channel (PUCCH) will be multiplexed at both ends of each CC to maintain backward compatibility with LTE Rel. 8. Thus, to avoid the PUCCH areas when achieving broadband transmission using N

*13 **Frequency diversity**: A diversity method for improving reception quality by using different frequencies. Diversity, in general, aims to improve reception quality by using, for example, multiple paths (mainly via multiple antennas) and selecting those paths having good reception quality.

*14 **PAPR**: As the ratio of maximum power to average power, an index expressing the peak magnitude of the transmit waveform. If this value is large, the amplifier power back-off has to be large to avoid nonlinear distortion, which is particularly problematic for mobile terminals.

*15 **DFTS-OFDM**: A method for achieving single-carrier transmission in OFDM by incorporating DFT in the pre-stage of the Inverse Fast Fourier Transform (IFFT). It is adopted as an uplink transmission method in LTE.

CCs, N SC-FDMA signals will be transmitted in parallel (**Figure 5**). This transmission method is also called "N-times DFTS-OFDM" since it results in a configuration having N DFTs. It effectively corresponds to the introduction of a multi-carrier scheme in units of CCs. The PAPR therefore increases compared to DFTS-OFDM of LTE Rel. 8. At the same time, since the mapping of transport blocks is performed in units of CCs while avoiding PUCCH areas, LTE Rel. 8 specifications can be reused to the utmost here the same as in the downlink.

Furthermore, Clustered DFTS-OFDM[*16] is used here as a transmission method for achieving flexible Resource Block (RB) allocation within a CC. This method allows non-contiguous RB allocation of a Physical Uplink Shared Channel (PUSCH) [9], which has been shown by system-level simulations to improve cell throughput[*17] by more than 10% [10]. Non-contiguous RB allocation, however, increases PAPR compared to contiguous RB allocation, which means that non-contiguous RB allocation should be avoided at cell edge where severe limitations on transmit power are imposed.

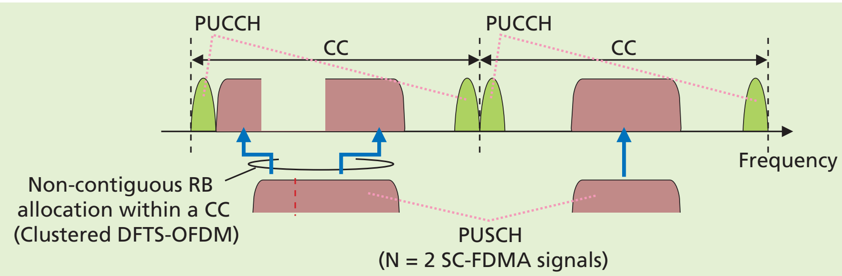

Figure 5 Uplink radio access

3.2 Layer 1/layer 2 Control Signals

1) Downlink

In the downlink, layer 1/layer 2 control channels are configured in the same way as Rel. 8 in each CC for the sake of compatibility. As shown in Fig. 4, layer 1/layer 2 control channels in the downlink are multiplexed on the first 1 - 3 OFDM symbols in each CC depending on the amount of resources. The number of symbols is notified in each CC via the Physical Control Format Indicator Channel (PCFICH). The Physical HARQ Indicator Channel (PHICH) that notifies of Acknowledgement (ACK) / Negative ACK (NACK) signals with respect to PUSCH is also configured in the same way as Rel. 8.

In addition, AMC and HARQ operate independently in each CC, as described in Section 3.1. Thus, the Physical Downlink Control Channel (PDCCH) that indicates the allocation of PDSCH and PUSCH in a CC is also transmitted to each CC (**Figure 6**(a)).

A mixture of eNBs combining a macro eNB with low-power base stations such as picocell eNBs (pico eNBs)[*18] or femtocell eNBs (femto eNBs)[*19] may also be used. In such a heterogeneous network[*20] [5], interference on a pico eNB from a macro eNB is significant due to differences in transmit power. Since retransmission cannot be applied to PDCCH, this could significantly increase the possibility that the PDCCH of a pico eNB is not correctly received. To rectify this situation, the method shown in Fig. 6(b) can be used. Here, by making use of interference coordination, the CC subject to small interference from the macro eNB is used to transmit the PDCCH that notifies of PDSCH allocation in the CC subject to large interference from the macro eNB. To implement this method, agreement was reached on adding a 3-bit Carrier Indicator Field (CIF) to indicate which CC the PDSCH allocation in PDCCH is for.

2) Uplink

In the uplink, PUCCH multiplexed at both ends of each CC is used to transmit layer 1/layer 2 control information consisting of ACK/NACK signals, Scheduling Request (SR) signals, and Channel Quality Indicator (CQI) signals. As in layer 1/layer 2 control information in the downlink, this uplink control information in each CC has the same configuration as that in Rel. 8.

In LTE-Advanced, low PAPR is an extremely important requirement for

*16 **Clustered DFTS-OFDM**: While DFT output has been allocated to contiguous subcarriers in DFTS-OFDM adopted by LTE, this technique can increase the frequency-domain scheduling effect by allowing non-contiguous allocation although producing an increase in PAPR.

*17 **Cell throughput**: The amount of data that can be transmitted within one cell per unit time.

*18 **Pico eNB**: A small base station with a maximum cell radius of several tens of meters for use in underground shopping malls, public facilities, etc.

*19 **Femto eNB**: A small base station with a maximum cell radius of several tens of meters for use in the home, office, etc. Access rights are limited to specific users.

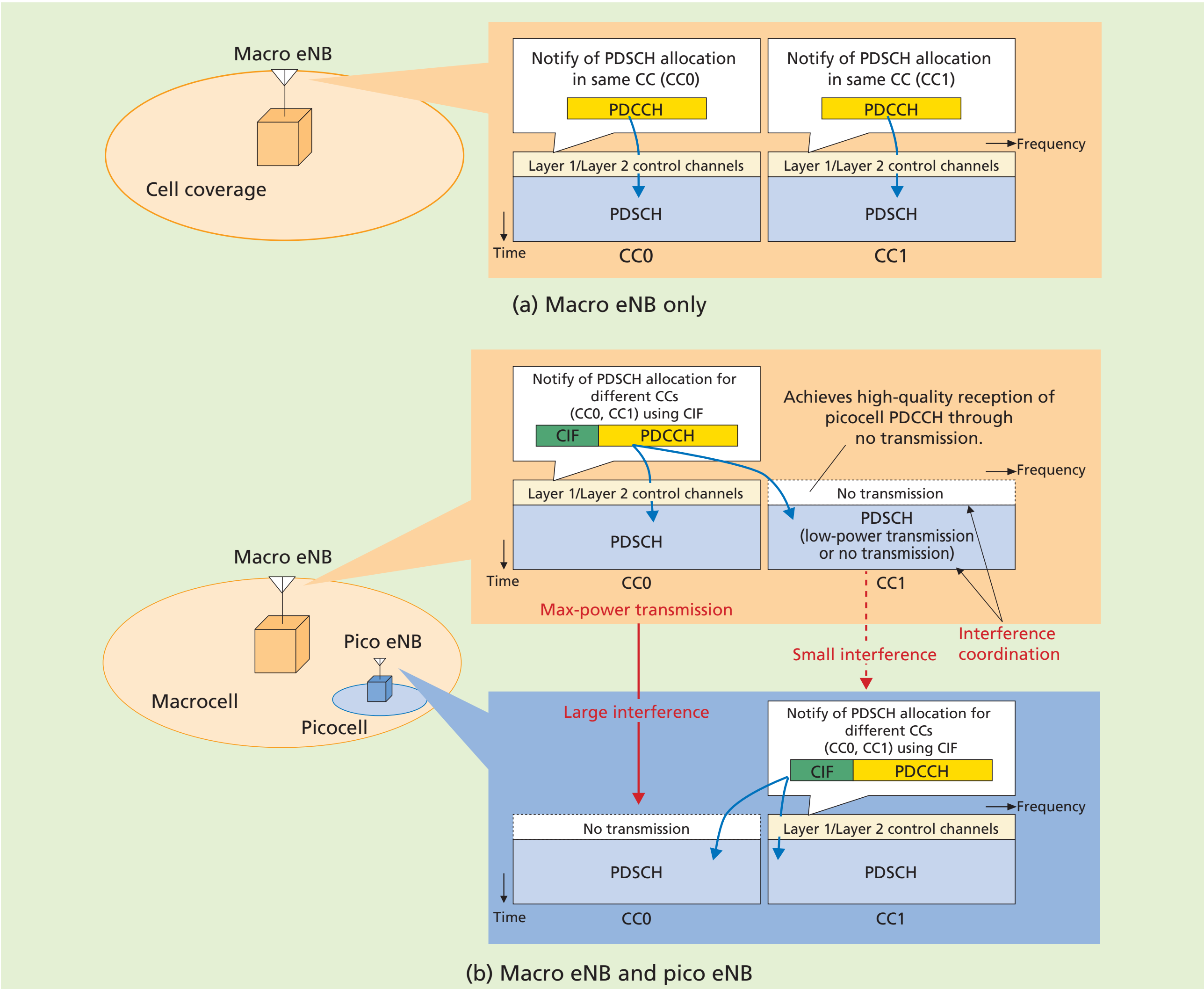

Figure 6 Transmission of PDCCH in a heterogeneous network

control channels especially in the uplink from the viewpoint of good coverage. Furthermore, in UE that allows for the transmission of PUSCH by multiple CCs through CA, the simultaneous transmission of PUCCH 180-kHz narrow-band signals by multiple CCs can result in the generation of very strong spurious signals[*21] due to intermodulation distortion[*22] [11]. In response to this issue, it was agreed for Rel. 10 that PUCCH would be transmitted using only one CC allocated in each UE.

4. Radio Protocol Configuration

4.1 Layer 2 Control

1) Architecture

The layer 2 architecture is shown in **Figure 7** [6]. As can be seen, layer 2 consists of a Medium Access Control (MAC)[*23] sublayer, Radio Link Control (RLC)[*24] sublayer, and Packet Data Convergence Protocol (PDCP)[*25] sublayer, the same as in Rel. 8.

The MAC sublayer consists of multiple HARQ entities, where one HARQ entity is assigned per CC. In other words, a transport block is generated for each CC and HARQ retransmission

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

*21 **Spurious signal**: Unintended radio signals emitted from the transmitter such as harmonics, subharmonics, and parasitic emissions.

*22 **Intermodulation distortion**: The distortion of signal waveform when inputting signals of different frequencies into a non-linear circuit such as an amplifier and generating unwanted frequency components caused by the combination of those input frequencies.

*23 **MAC**: A protocol in layer 2 for performing HARQ operations, random access procedures, logical channel to transport channel mapping, etc.

is confined within each CC. Here, HARQ retransmission control is based on that specified in Rel. 8. Thus, the operation of each HARQ entity is equivalent to that of Rel. 8.

The RLC and PDCP sublayers, meanwhile, consist of an RLC and PDCP entity per radio bearer[*26], the same as in Rel. 8. That is to say, the RLC and PDCP sublayers are CC agnostic. Thus, RLC and PDCP processing is based on that specified in Rel. 8.

2) Discontinuous Reception (DRX) Control[*27] and CC Activation/Deactivation Control

Even though a UE may have an RRC connection established, it may be given opportunities to omit transmit/receive processing in accordance with the ebb and flow of data to be received and transmitted by the UE. The UE can therefore save power at such times. To provide such power-saving opportunities, DRX control and CC activation/deactivation control are being studied.

The DRX control used here follows Rel. 8 specifications. The UE makes transitions between active time and non active time according to 3GPP MAC operation specifications. Some processing like PDCCH detection may be omitted during non active time. Thus, as the UE does not monitor PDCCH during non active time, the eNB avoids allocation by PDCCH with respect to that UE. The alignment of active time in each CC in the case of CA is being studied.

CC activation/deactivation is a mechanism unique to CA. In this process, the eNB can perform frequent activation/deactivation of individual CCs configured for a UE through the use of MAC control signals (MAC control elements). The UE can omit processing such as PDCCH monitoring, PDSCH reception, and CQI measurement/reporting for a deactivated CC.

Only necessary CCs need be activated according to the amount of UE data residing in the eNB buffer. Thus, by deactivating excessive CCs, power consumption in the UE can be reduced.

The concept of active time in DRX control is valid only for an activated

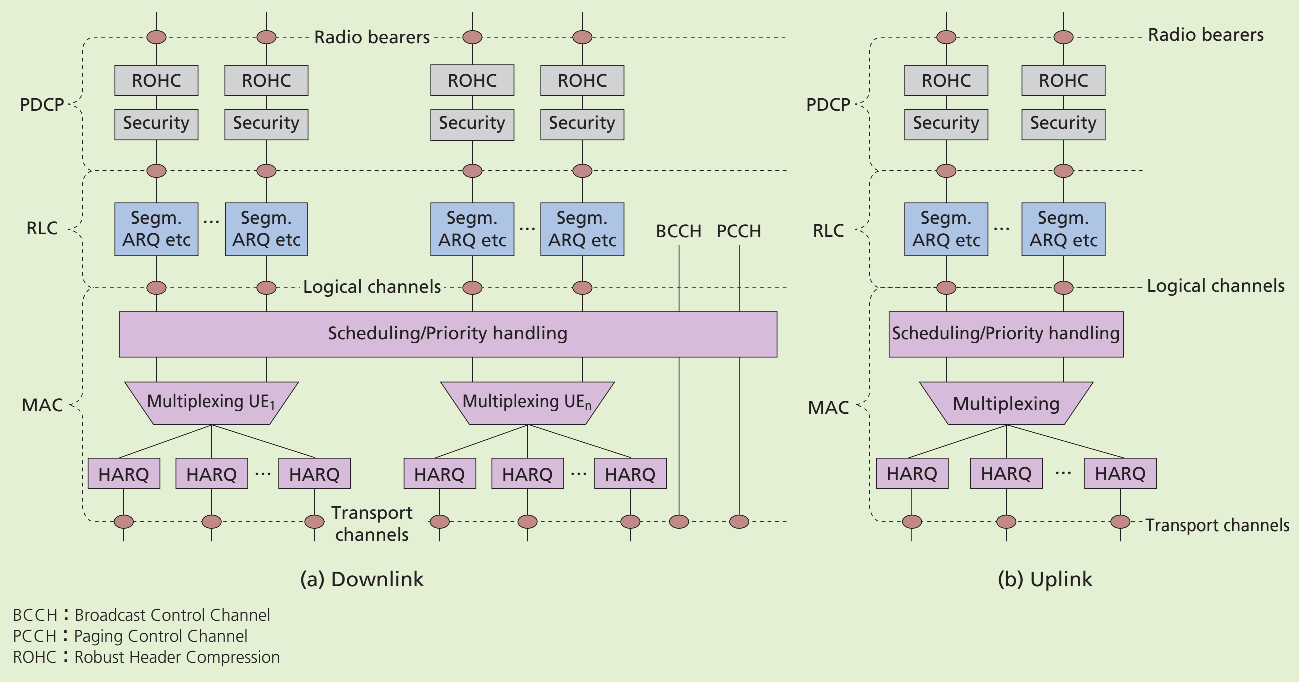

Figure 7 Layer 2 architecture

*24 **RLC**: A protocol in layer 2 for performing ARQ operations, etc.

*25 **PDCP**: A protocol in layer 2 for performing security functions, header compression, etc.

*26 **Radio bearer**: Logical data flow established between a UE and eNB which serves as the minimum granularity of QoS control in wireless communications.

*27 **DRX control**: Intermittent reception control used to reduce power consumption in UE.

CC, and the UE may omit certain processing such as PDCCH monitoring in a deactivated CC even during active time (**Figure 8**).

There is concern, however, that the introduction of CC activation/deactivation control will increase system complexity, and for the case that CC activation/deactivation control is not supported, an alternative proposal in which DRX control is performed independently for each CC is being studied.

3) Timing Advance (TA) Control

Uplink access is based on DFTS-OFDM, and to maintain orthogonality between signals received from users, uplink signal receive timing from each UE must be coordinated at the eNB. This can be achieved by TA control in which the eNB adjusts UE transmission timing. The mechanism for TA control has already been provided by Rel. 8.

In Rel. 8, as there is only one carrier for UE transmissions, it was sufficient to have only one TA controlled per UE. However, in the case of CA in the uplink, the need arises for controlling TA, that is, for controlling transmission timing, for each CC configured for the UE or for each set of CCs. The means for achieving this is now being discussed at 3GPP. To give a specific example of this need, we consider the case shown in Fig. 3(d) in which CA is performed between RRH cells and a macro cell. Since the location of the receive antenna differs from one cell to another, transmission timing must be controlled independently in each cell. However, as CA in the uplink in Rel. 10 will likely be limited to CCs within the same band, it appears that this kind of control will not be supported by Rel. 10 but will be promoted in Rel. 11 and beyond.

4.2 RRC Control

1) RRC Connection Model

When applying CA, communications are performed between a UE and eNB using multiple CCs simultaneously. As in LTE Rel. 8, the UE has only one RRC connection established with the eNB. The same procedure as specified in LTE Rel. 8 is used to establish a RRC connection, using a single CC. A second or later CC can then be configured from

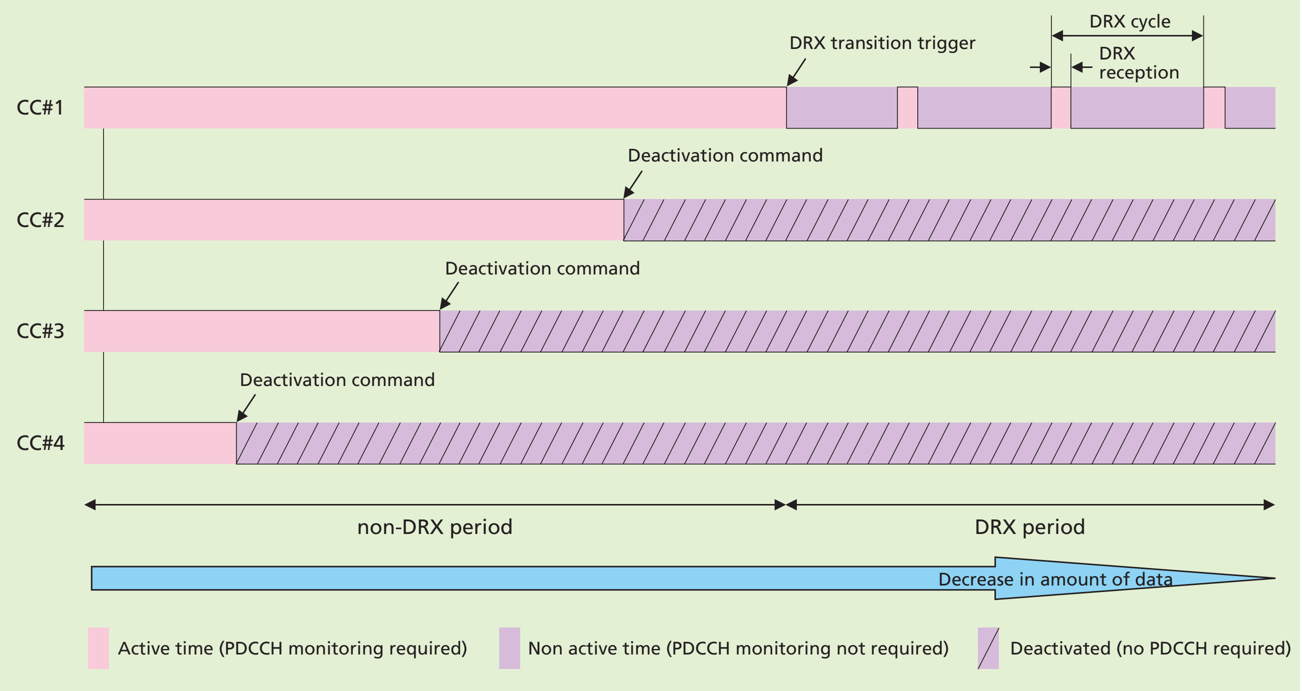

Figure 8 DRX control and CC activation/deactivation control

the eNB.

The CC for which the RRC connection is initially established is called the Primary CC (PCC), on which the UE receives PDCCH and PDSCH and transmits PUCCH, PUSCH, and Physical Random Access Channel (PRACH). A second or later CC is called a Secondary CC (SCC), on which no PUCCH or PRACH transmissions are made.

It is also possible to perform PCC switching while communication is ongoing, but this would require resetting of the PDCP layer and below to update security keys (to ensure ciphering and prevent data tampering).

2) Broadcast Control

Each CC broadcasts only system information relevant to its own carrier, including bandwidth, common-channel settings, and other attributes. When adding an SCC, system information that is needed for using that SCC is provided from the eNB by dedicated signaling.

In case system information changes on the PCC, the UE can detect such a change in the same manner as in LTE Rel. 8, that is, by receiving a change notification by paging or by receiving a value tag that indicates the version of system information. In contrast, to avoid the UE having to read system information directly from the SCC broadcast, all changes to system information on the SCC are delivered to the UE by dedicated signaling.

3) Measurement Control

When applying CA, measurement control becomes essential for efficient control of handover due to mobility and of CC addition and deletion. Especially in CA scenarios like those shown in Fig. 3(b), (c) and (d), the locations where quality deteriorates can differ for each CC and the optimum cell that the UE should connect to can be different as well. For these reasons, it is possible for the UE to measure the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) for the serving cell and neighboring cells on each CC, and to report to the eNB of the measurement results whenever certain reporting conditions (events) are satisfied. Furthermore, to control the switching of a PCC and SCC or to switch a PCC or SCC to a non-configured CC having better quality, extensions are being studied such as reporting to the eNB whenever the quality difference between CCs satisfies specific conditions.

4) Radio Link Failure

As described above, the locations where quality deteriorates can differ for each CC when applying CA. In particular, deterioration in the quality of the PCC can hinder continuous communication, and in such a case, the UE will temporarily suspend the User-Plane (U-Plane)[*28], select another cell, and try to re-establish connection. This re-establishment attempt is performed via a single CC (PCC), and if re-establishment is successful and SCCs again added, communications using CA will continue. Triggers for initiating a re-establishment attempt include deterioration in PCC receive quality in the downlink, failure of the Random Access (RA) procedure, and reaching the maximum number of allowed retransmissions in the RLC layer. Deterioration in an SCC will basically be handled by the eNB through appropriate control measures (such as SCC removal), but the need for the UE itself to autonomously halt the uplink transmission of an SCC is also being studied.

5. Conclusion

This article described CA technology for application to LTE-Advanced, which is now being standardized at 3GPP as LTE Rel. 10. CA is a useful technology for improving peak transmission rates, and special attention is being given to ensuring its smooth introduction as an extension of LTE Rel. 8/9 such as by maintaining backward compatibility with those releases and supporting a variety of deployment scenarios. Completion of LTE Rel. 10 specifications is scheduled for the spring of 2011, and until then, we plan to discuss control details and remaining issues dealing, for example, with RF specifications and UE capabilities. Additionally, we plan to discuss further enhancements in Rel. 11 and beyond to support more flexible deployments and to improve performance, such as paral-

*28 **U-Plane**: The protocol for transmitting user data.

lel transmission timing control for uplink transmission on multiple CCs.

Looking forward, we will continue to promote standardization of the radio access network toward even higher levels of performance, functionality and economy.

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