Technology Reports
5G | LTE-NR DC | Front-haul Open Interface
Special Articles on 5G Standardization Trends Toward 2020

5G Radio Access Network Standardization Trends

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Aiming for an early deployment of the fifth-generation mobile communications system (5G), studies of component technologies for a radio access network satisfying 5G requirements are well under way at 3GPP RAN. A SI was completed in March 2017 as a foundation for the full-scale drafting of specifications that began in April 2017. This article presents the results of this SI and describes upper-layer component technologies targeted for standardization.

1. Introduction

The opening article of this issue's Special Articles presented an overview of Non-Standalone operation for New Radio (NR) studied at the 3rd Generation Partnership Project (3GPP) with the aim of achieving an early and efficient deployment of the fifth-generation mobile communications system (5G) [1]. In this article, we focus on the technologies required for Non-Standalone operation among the component technologies making up the upper layer*1 of NR studied at 3GPP. Specifically, we take up the simultaneous use of the LTE and NR radio links*2 called LTE-NR Dual Connectivity (DC)*3 and the functional split and open interface between the Central Unit (CU) and Distributed Unit (DU) nodes in Centralized Radio Access Network (C-RAN)*4 architecture, explaining the background and purpose of studying these technologies. We also describe the 5G RAN configuration and Layer 2 and Layer 3

*1 Upper layer: All layers positioned above the physical layer, namely, layers such as MAC (see *22), RLC (see *26), PDCP (see *25), S1AP, and X2AP.

*2 Radio link: A logical link between the mobile terminal and cells (access points in a radio access network).

protocols for achieving the CU-DU functional split and open interface and briefly describe the RAN configuration and Layer 2 and Layer 3 protocols for subsequent deployment of NR Standalone operation.

2. LTE-NR DC

2.1 Overview

Technology for providing NR through Non-Standalone operation combined with LTE is LTE-NR DC. Here, DC is a technology specified for LTE in Release 12 specifications for the purpose of improving user throughput by bundling multiple LTE carriers*5 between evolved NodeB (eNB) base stations and performing data transmission and reception simultaneously (see [2] for details on DC technology). In short, LTE-NR DC is a technology that extends LTE DC for use between LTE and NR that have different radio technologies.

2.2 Functional Extensions of Radio Protocol

The following three functional extensions have been specified in LTE and NR radio protocol.

1) Split Bearer*6 Extension for Transmitting/Receiving User Data to/from Two eNBs

To achieve higher throughput in LTE DC, Release 12 specifies the Master Cell Group (MCG) split bearer as shown in **Figure 1** (a) [2]. For the MCG split bearer the Master Node (MN)*7 is the splitting point, where downlink data from the Core Network (CN)*8 to User Equipment (UE) is transferred by an MN carrier or is transmitted to the Secondary Node (SN)*9 through an X2 interface*10

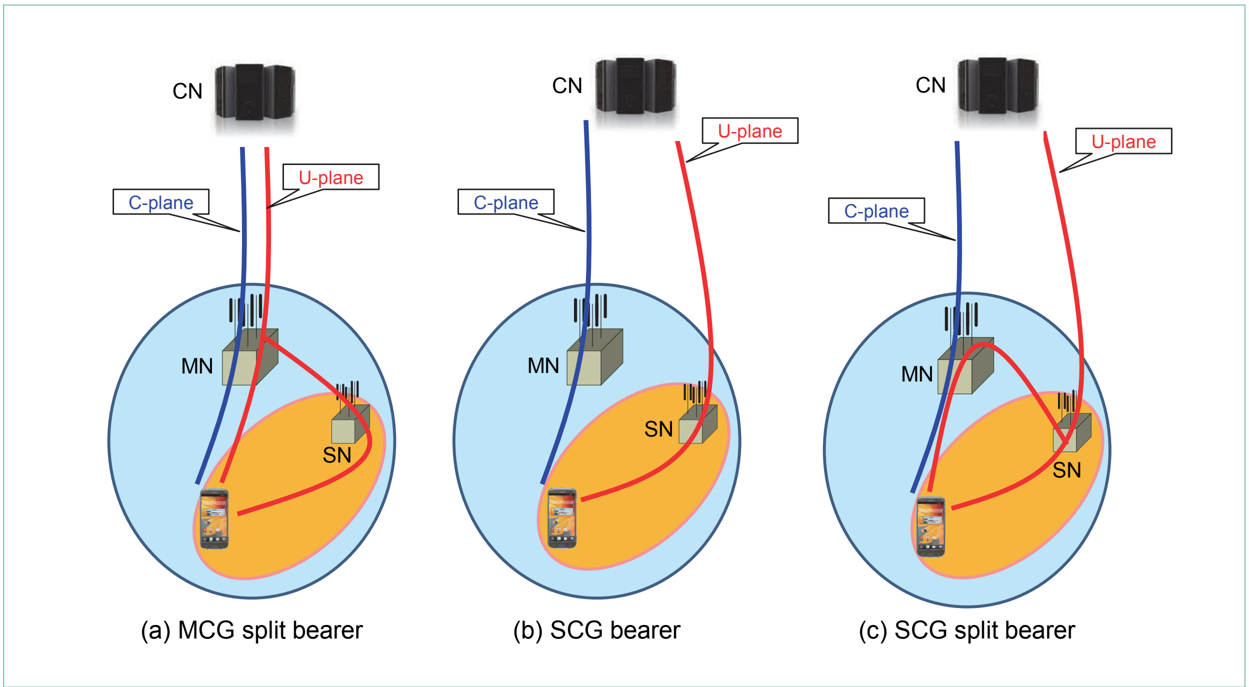

Figure 1 U-plane bearer type in LTE-NR DC

*3 DC: A technology that achieves wider bandwidths by connecting two base stations in a master/secondary relationship and performing transmission and reception using multiple component carriers supported by those base stations.

*4 C-RAN: A radio access network having a configuration that consolidates the baseband processing sections of base station equipment and controls the radio sections of that equipment through optical fiber connections.

*5 Carrier: A radio signal (carrier wave) that is modulated to transmit information.

*6 Split bearer: In DC, a bearer that is transmitted and received via both the master and secondary base stations.

*7 MN: In DC, the base station that establishes an RRC (see *11) connection with the UE. In LTE-NR DC, this could be the LTE base station (eNB) or the NR base station (gNB (see *31)).

and then transferred by an SN carrier.

Now, in LTE-NR DC operation in which the LTE eNB is the MN, it would be necessary to enhance processing power and buffer size in the LTE eNB to support this MCG split bearer as the bandwidth on the NR side increases. This, however, would increase equipment development and operation costs. Consequently, to minimize LTE eNB upgrading while avoiding limitations in throughput due to the processing capacity of such equipment, Secondary Cell Group (SCG) split bearer was specified for LTE-NR DC as shown in Fig. 1 (c) so that the user-data splitting point could be configured at the SN. In this regard, the SCG split bearer extends the SCG bearer in Release 12 specifications, which transfers user data only by an SN carrier as shown in Fig. 1 (b), by utilizing an MN carrier as well thereby enabling simultaneous transmission of user data over both types of carriers. As shown in Fig. 1, the MCG split bearer and SCG split bearer represent different data splitting points as seen from the network side. However, from the UE side, these split bearers appear to be the same when performing data transmission with the MN and SN base stations. With this in mind, discussions are now being held on defining the MCG/SCG split bearers as an equivalent single bearer for the UE function to reduce in specifications the types of bearers that the UE must support.

2) Independent Control of LTE-NR Radio Resource Control (RRC)[*11] in DC

In LTE DC, RRC protocol is established between the MN and UE enabling RRC messages to be transmitted and received only between the MN and UE as shown in **Figure 2** (a). In a DC state, however, the two base stations (MN and SN) connected to the UE each performs Radio Resource Management (RRM) on its own. For example, in the event that an SN is added or modified, the SN itself allocates resources and coordinates with the MN via an X2 interface. The UE then receives RRC messages containing SN resource settings from the MN. Now, in LTE-NR DC, each node performs its own RRM the same as in LTE DC, but in this case, RRC protocol as well exists independently at MN and SN, which have different Radio Access Technology (RAT)[*12], and an RRC connection is established independently between the UE and MN and between the UE and SN. In other words, an RRC message containing resource allocation settings not requiring coordination with the MN can be transmitted directly from the SN to the UE as shown in Fig. 2 (b). In addition, this independent establishment of RRC connections means that the MN and SN can independently set RRC measurements (target frequencies for measurement, measurement events, measurement content) to the UE. However, the UE's RRC connections and context are stored and managed at the MN, which means that the SN cannot release the UE's RRC connection nor have the UE make a transition to RRC_IDLE[*13] state.

3) Transmit Diversity[*14] of C-plane[*15] Signal (RRC Diversity)

In LTE-NR DC for the case in which NR rollout in the network is achieved with small cell[*16] base stations, an NR base station is often a SN. In such a case, the distance between the UE and NR base station is relatively short compared with the distance between the UE and LTE base station so that the path loss between the UE and NR base

*8 **CN**: A network consisting of switching equipment, subscriber information management equipment, etc. Mobile terminals communicate with the core network via the radio access network.

*9 **SN**: A base station that provides a UE in DC with radio resources in addition to those provided by the MN. In LTE-NR DC, the SN is an NR base station (gNB (see *31)) if the MN is an LTE base station (eNB) and an LTE base station (eNB) if the MN is an NR base station (gNB (see *31)).

*10 **X2 interface**: An interface for connecting between eNBs.

*11 **RRC**: A protocol for controlling radio resources on a radio network.

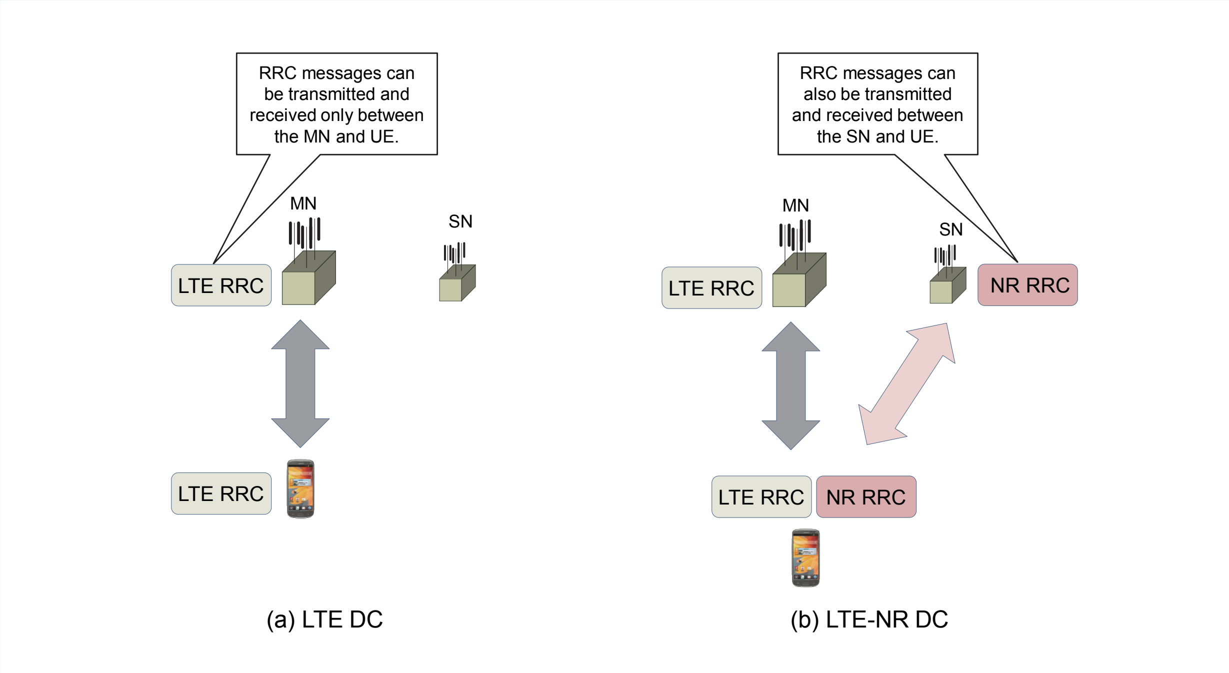

Figure 2 Independent control of LTE-NR RRC in DC

station is small. Under these conditions, the probability of successfully receiving an RRC message at the UE is higher when transmitted from the SN. In LTE DC, as described above, RRC messages are transmitted only from the MN while the mechanism for splitting and transmitting data from both the MN and SN targets only user data. In short, LTE DC is constrained in that RRC messages cannot be transmitted from the SN. In LTE-NR DC, though, to improve the reliability of transmitting signaling data, this constraint is removed and a split bearer for signaling data is supported. As a result, an RRC message generated by the MN can be duplicated so that the same message can be transmitted from the MN and SN to the UE to improve the success rate of receiving RRC messages at the UE. In this way, a diversity effect (RRC diversity) can be expected as shown in **Figure 3**.

3. CU-DU Functional Split and Open Interface

In LTE, C-RAN has already been adopted as a RAN architecture that configures multiple distributed nodes from a single aggregating node thereby suppressing CN signaling associated with user mobility and improving performance through inter-cell coordination [3]. Given these advantages, it has been assumed that NR would likewise use this type of architecture.

In present C-RAN based on LTE, the Common Public Radio Interface (CPRI)*17 standard is widely used as a front-haul interface between the aggregating node and distributed nodes. The CPRI

*12 RAT: A radio access technology such as NR, LTE, 3G, GSM, and Wi-Fi.

*13 RRC_IDLE: A UE RRC state in which the UE has no cell-level identity within the base station and the base station stores no UE context. The core network stores UE context.

*14 Transmit diversity: Technology that utilizes the differences in channel fluctuation between transmission antenna channels to obtain diversity gain.

*15 C-plane: Protocol for transferring control signals to establish and cut off communications.

*16 Small cell: A general term for the transmission area covered by base station transmitting at low power compared to a macro cell base station.

*17 CPRI: Internal interface specification for radio base stations. CPRI is also the industry association regulating the specification.

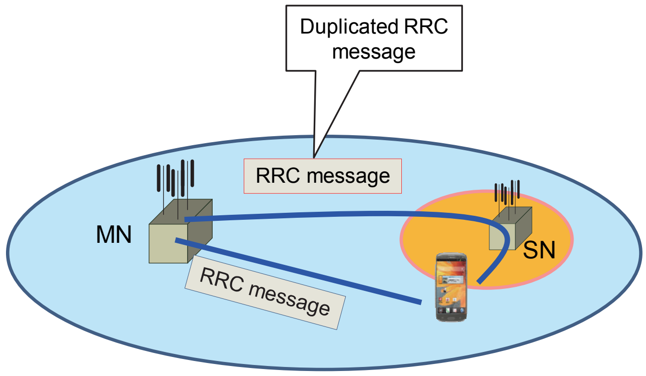

Figure 3 Transmit diversity of C-plane signal

standard specifies the format of Layer 2*18 signals transmitted by the front-haul, but Layer 3*19 signals (data, control signals) carried above that are vendor-specific. Therefore, to achieve multivendor C-RAN that can connect aggregating and distributed nodes from different vendors, it has been necessary to make inter-vendor adjustments individually.

For NR, taking into account the desire expressed by operators for a more open multivendor C-RAN, studies are being performed at 3GPP on defining the aggregating node as the Central Unit (CU) and distributed nodes as Distributed Units (DUs) and specifying a CU-DU interface.

Additionally, as CPRI transmits the radio signals transmitted and received by each antenna as digital signals over the front-haul, the transmission bandwidth required for the front-haul depends on the radio frequency bandwidth and the number of antennas. In this regard, it is assumed that NR will apply a broader frequency bandwidth than LTE and Massive Multiple Input Multiple Output (Massive MIMO)*20 technology that uses many antennas. Consequently, if the existing CPRI standard were to be used with NR, the required front-haul transmission bandwidth would become dramatically larger. Taking, for example, a typical configuration at initial LTE deployment (20 MHz system bandwidth, 2 transmit/receive antennas, 2 MIMO transmission layers, and 64 Quadrature Amplitude Modulation (QAM)*21), the required front-haul transmission bandwidth would be about 2 Gbps for a user data rate of about 150 Mbps. On the other hand, for a typical configuration used in NR studies (100 MHz system bandwidth, 32 transmit/receive antennas, 8 MIMO transmission layers, and 256QAM), a front-haul transmission bandwidth of approximately 160 Gbps would be required for a user data rate of about 4 Gbps. To resolve this issue, a study was performed on reducing the required transmission bandwidth by re-evaluating the functional split between CU and DU and moving some functions to the DU side. For example, in the downlink function, the function for extending the signals

*18 **Layer 2**: The second layer (data link layer) in the Open Systems Interconnect (OSI) reference model.

*19 **Layer 3**: The third layer (the network layer) in the OSI reference model.

*20 **Massive MIMO**: A generic term for MIMO transmission technologies using very large numbers of antennas.

*21 **QAM**: A modulation method using both amplitude and phase. In 64QAM, 64 (2^6) symbols exist, so this method allows for the transmission of 6 bits at one time, while in 256QAM, 256 (2^8) symbols exist, which allows for the transmission of 8 bits at one time.

of each MIMO transmission layer to the signals of each antenna can be placed on the DU, which results in signal transmission for each MIMO transmission layer on the front-haul instead of signal transmission for each antenna. This has the effect of reducing the required front-haul transmission bandwidth by a ratio of "number-of-antennas/number-of-MIMO-transmission-layers." In addition, if placing the entire function of the PHYsical (PHY) layer on the DU, that is, if splitting the CU and DU between the Media Access Control layer (MAC layer)*22 and PHY layer, the result would be transmission of the user-data bit string before encoding over the front-haul instead of transmission of quantized In-phase and Quadrature (IQ)*23 signals. This would have the effect of reducing the required front-haul transmission bandwidth to an amount equivalent to the user data rate.

The NR Study Item (SI)*24 has included discussions on an open CU-DU interface with the aim of achieving this new CU-DU functional split and multivendor connectivity. NTT DOCOMO has been actively contributing to these discussions. Considering support for various types of transmission networks used for the front-haul, two types of CU-DU functional splits referred to as "lower layer split" and "higher layer split" have been studied according to the envisioned amount of front-haul delay (**Figure 4**). First, taking up the lower layer split shown in Fig. 4 (a), a functional split between the MAC layer and PHY layer or within the PHY layer itself has mainly been studied as it can improve radio performance through advanced inter-cell coordination including the MAC scheduler and PHY processing while reducing the required front-haul transmission bandwidth. In this lower layer split, the MAC layer and PHY layer that perform processing on a Transmission Time Interval (TTI) basis straddles the CU and DU, so it is assumed

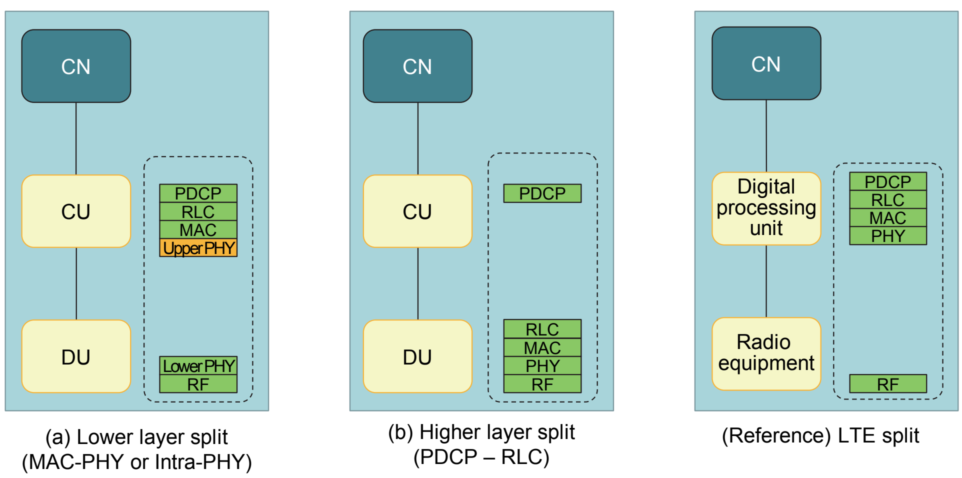

Figure 4　Examples of CU-DU functional split configurations

*22　**MAC layer:** One of the sublayers of Layer 2 providing protocols for allocating radio resources, mapping data, and controlling retransmission.

*23　**IQ:** The in-phase and quadrature components of a complex digital signal.

*24　**SI:** The work of "studying feasibility and broadly identifying functions that should become specifications."

that the transmission network used here for the front-haul would satisfy high requirements for latency. Next, turning to the higher layer split shown in Fig. 4 (b), agreement has been reached on including in Release 15 specifications a functional split between the Packet Data Convergence Protocol (PDCP)*25 layer and Radio Link Control (RLC)*26 layer and an interface between the CU and DU with that functional split as an F1 interface. This functional split enables the aggregation benefits of C-RAN to be enjoyed while reducing the required front-haul transmission bandwidth, even when a transmission network with a relatively long delay is used for the front-haul.

4. 5G Radio Access Network

This section presents the 5G RAN configuration for achieving LTE-NR DC and the CU-DU functional split and open interface and describes the U-plane*27 and C-plane radio protocols.

4.1 RAN Configuration

Non-Standalone operation and Standalone operation for NR in 3GPP is described in the opening article of this issue's Special Articles [1]. The 5G RAN configuration corresponding to each of these operations is shown in **Figure 5**. In NR Non-Standalone operation, the NR base station denoted as en-gNB*28 connects to the LTE base station denoted as eNB via an X2 interface. Although the X2 interface has

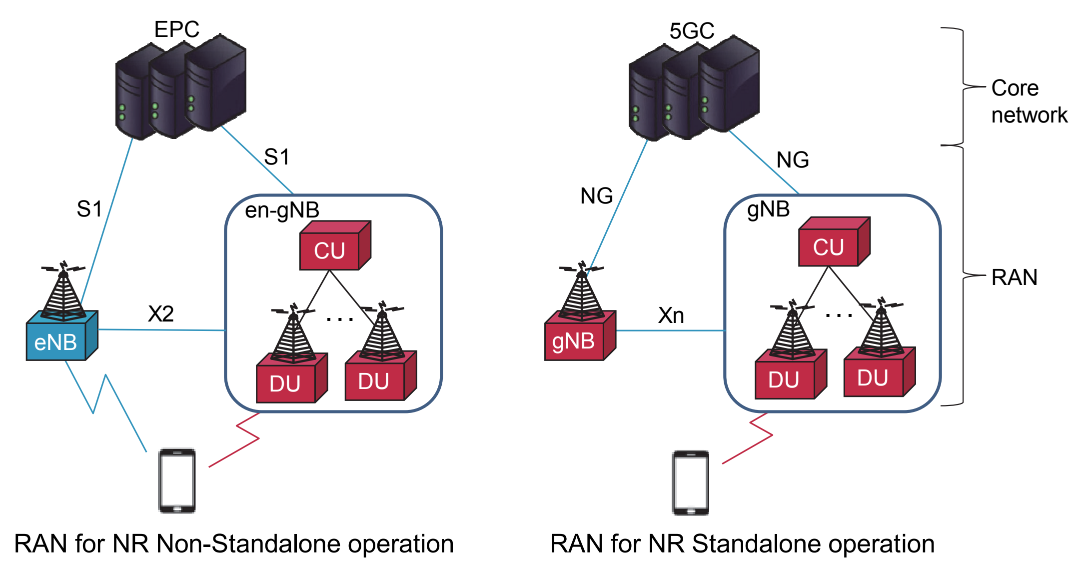

Figure 5 5G RAN configurations

*25 PDCP: A sublayer of Layer 2. A protocol for ciphering, validation, ordering and header compression, etc.

*26 RLC: A protocol for controlling retransmission and other functions as a sublayer of Layer 2.

*27 U-plane: A path for the transmission of user data to the C-plane, which is a control signal transmission.

*28 en-gNB: A radio base station providing NR signals in RAN for NR Non-Standalone operation.

been used up to now to connect eNBs, Release 15 extends the interface for use in connecting an eNB and en-gNB in the RAN for NR Non-Standalone operation. In addition, the RAN for NR Non-Standalone operation connects to the Evolved Packet Core (EPC)*29 network using an S1 interface*30.

On the other hand, RAN for NR Standalone operation enables service to be provided solely on the basis of gNB*31, which connects to the new 5G core network (5GC) described in the opening article of this issue's Special Articles [1]. In this RAN configuration, gNBs connect to each other using an Xn interface while a gNB connects to 5GC using an NG interface.

4.2 U-plane Radio Protocol

The LTE U-plane protocol stack*32 consists of PDCP, RLC, and MAC layers. It has provided flexible specifications supporting a wide range of terminals from low-end terminals such as Machine Type Communication (MTC) terminals to high-end terminals achieving high data rates in excess of 1 Gbps. For 5G, this LTE protocol stack has served as a basis for design work and extensions have been made to support 5G requirements and new use cases.

1) Main Extensions for NR U-plane

In LTE, QoS control*33 is performed per Evolved Packet System (EPS)*34 bearer, so EPS bearers and radio bearers have a one-to-one relationship. When accommodating Non-Standalone NR by EPC using LTE-NR DC [1], the Layer 2 protocol stack is the same as that of LTE.

In contrast, the new 5G CN enables QoS control on the basis of IP flow instead of EPS bearers to achieve more flexible and finer QoS control. Specifically, it enables multiple IP flows flowing through a single Protocol Data Unit (PDU)*35 Session Tunnel established between the CN and base station to be individually subjected to radio bearer mapping. In NR Layer 2, a new Service Data Adaptation Protocol (SDAP) layer has been introduced above the PDCP layer to perform mapping between such IP flows and radio bearers as shown in **Figure 6** (a). In the SDAP layer, IP packets are encapsulated and the header contains an identifier indicating the QoS for those packets.

As for the PDCP layer and below, changes have been made to support even lower delay and higher data rates in RAN regardless of the connecting CN. For example, to enable a large amount of user data to be transmitted in the short Hybrid Automatic Repeat reQuest (HARQ)*36 Round Trip Time (RTT)*37, more Layer 2 processing must be performed before the determination of the transport block size*38 and more processing must be performed in parallel. To this end, it has been made possible to complete RLC PDU generation processing before scheduling by not supporting the RLC concatenation function that multiplexes the data in the same bearer based on the transport block size. In addition, the LTE MAC PDU takes on a format in which information on MAC Service Data Unit (SDU) multiplexing is indicated at the beginning of the MAC PDU, which means that the MAC PDU cannot be submitted to the PHY layer until MAC multiplexing has been completed. However, for the NR MAC PDU, a format has been defined that indicates information on MAC SDU multiplexing immediately before each MAC

*29 **EPC:** An IP-based core network standardized by 3GPP for LTE and other access technologies.

*30 **S1 interface:** An interface connecting EPC and eNBs.

*31 **gNB:** A radio base station providing NR signals in RAN for NR Standalone operation.

*32 **Protocol stack:** Protocol hierarchy.

*33 **QoS control:** Technology to control communication quality such as priority packet transfer.

*34 **EPS:** Generic term for an IP-based packet network specified by 3GPP for LTE or other access technologies.

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

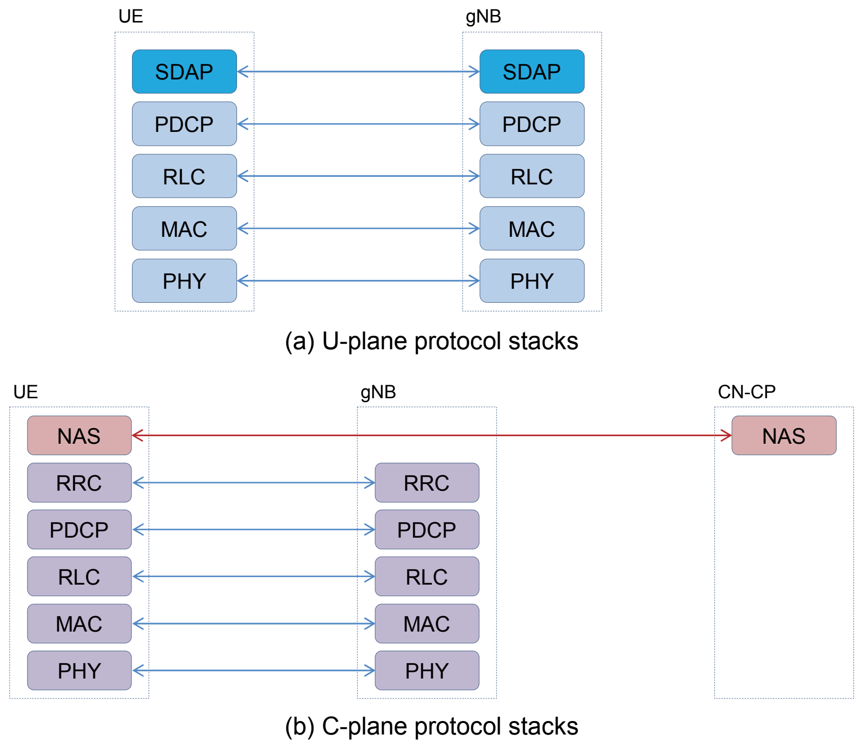

Figure 6　NR radio-interface protocol stacks

SDU so that PHY layer processing in relation to MAC SDU can be executed even before completing multiplexing processing in the MAC layer. An example of a data frame configuration in NR is shown in **Figure 7**. Here, IP packets received from an upper layer are subjected to radio bearer mapping on the SDAP layer according to QoS and then processed on the PDCP and RLC layers according to the radio bearer. Finally, the MAC layer multiplexes multiple RLC PDUs of multiple radio bearers as multiple MAC SDUs into the same MAC PDU and passes the result to the PHY layer.

2) Extensions for Achieving High-reliability Communications

In the standardization of NR upper layers, a duplicate transmission scheme on the PDCP layer has been discussed as a technology for improving the reliability of communications in RAN to achieve the 5G feature of Ultra-Reliable and Low Latency Communications (URLLC). Since radio conditions can change dynamically due to radio quality, congestion in RAN, etc., it may not be possible to achieve high-reliability communications via a single cell. It has therefore been discussed that frequency

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*36 HARQ: A technique that compensates for errors in received signals through a combination of error-correcting codes and retransmission.

*37 RTT: The delay required for round-trip transmission between a base station and terminal. In a higher layer split, the MAC layer managing HARQ resides in the DU, so the delay between the DU and terminal may be treated as RTT, but in a lower layer split, the MAC layer managing HARQ resides in the CU, so the delay spanning the CU, DU, and terminal must be treated as RTT.

*38 Transport block size: The amount of information that can be transmitted per unit time when transmitting data on the physical layer.

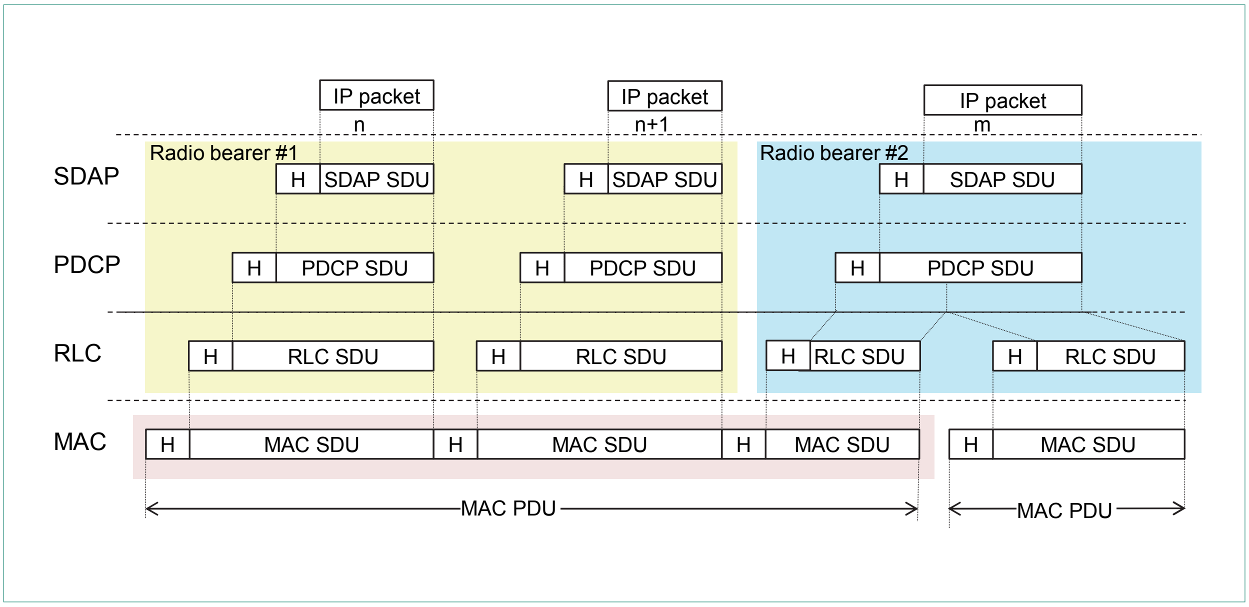

Figure 7 U-plane data frame configuration

diversity*39 be used to improve communications reliability in RAN by applying Carrier Aggregation (CA)*40 and Multi-Connectivity (MC)*41 that use multiple Component Carriers (CCs)*42 to a single terminal. As shown in **Figure 8**, the radio protocol architecture for achieving this places multiple RLC layers below a single PDCP layer. Here, a packet processed and duplicated on the PDCP layer is transferred to each RLC entity*43 and logical channel*44 and transmitted via the associated CCs. The PDCP layer on the receiving side processes the packet that arrives earlier while discarding the delayed packet as a duplicate. Transmitting the same data over multiple radio links in this way enables data to be delivered over a good radio link in the event that the radio environment of the other radio link deteriorates. This scheme makes for high-reliability communications.

4.3 C-plane Radio Protocol

The RRC protocol used in the NR C-plane protocol is the same as that used in LTE. The NR C-plane protocol stack is shown in Fig. 6 (b). The basic functions of NR RRC are essentially the same as that of LTE. They include terminal-specific call control, RRC state management, and the broadcasting of common information for a terminal to connect to a cell (frequency information, information on neighboring cells of the same and different frequencies, access restrictions, etc.). Here, terminal-specific call control is achieved by providing, for example, functions for RRC connection establishment, Admission Control*45, and RRM. Furthermore, to improve efficiency of resources used for System Information*46, studies are examining a mechanism for notifying a terminal of service-specific and contract-specific System Information that does not require constant broadcasting in an on-demand

*39 Frequency diversity: A diversity method for improving reception quality by using different frequencies. Diversity improves reception quality by using multiple paths and selecting the one with the best quality.

*40 CA: A technology for increasing bandwidth and data rate by simultaneously transmitting and receiving signals for one user using multiple carriers.

*41 MC: A connection configuration in which a terminal communicates with multiple base stations simultaneously.

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

*43 RLC entity: A functional section that performs RLC-layer processing in units of bearers.

*44 Logical channel: Channels classified by the type of information (e.g., user data, control information) that they transmit via the radio interface.

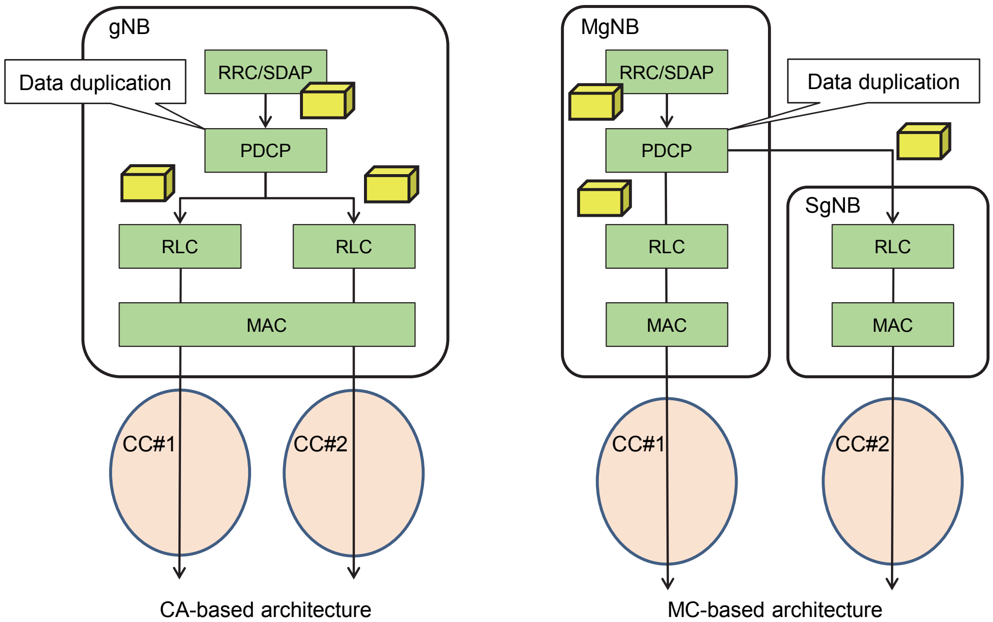

Figure 8 Layer 2 data flow in PDCP duplicate transmission

manner only when needed.

Next, in RRC state management, the plan is to specify an RRC_INACTIVE state beginning in Release 15 specifications, the first 3GPP Release to specify NR. Taking into account a variety of Internet of Things (IoT) scenarios, the purpose of this state is to reduce connection delay in small-data communications and stationary terminals and reduce the number of signals for establishing a connection.

In NR, this RRC_INACTIVE state has been added to those states corresponding to RRC_IDLE and RRC_CONNECTED*47 in LTE making for a total of three terminal states in NR. These NR RRC terminal states are shown in **Figure 9**.

In RRC_INACTIVE state, the RRC and Non Access Stratum (NAS)*48 context are stored in the terminal, base station, and core network, but since this terminal state is nearly the same as RRC_IDLE, power savings can be expected. Additionally, storing terminal context at each node in the RRC_INACTIVE state helps to reduce the number of signals required for returning to the RRC_CONNECTED state.

Finally, for NR Non-Standalone operation described above, RRC protocol functions will be extended to support LTE-NR RRC independent control and RRC diversity in DC.

5. Conclusion

This article described main component technologies

*45 Admission Control: A function for controlling the acceptance of calls.

*46 System Information: Various types of information broadcast from base stations per cell, such as the location area code required for judging whether location registration is needed by a mobile terminal, neighboring cell information, and information for restricting and controlling outgoing calls.

*47 RRC_CONNECTED: A UE RRC-layer state in which the UE is known on the cell level within the eNB and UE context is stored in the eNB.

*48 NAS: The functional layer between the mobile terminal and core network located above the Access Stratum (AS).

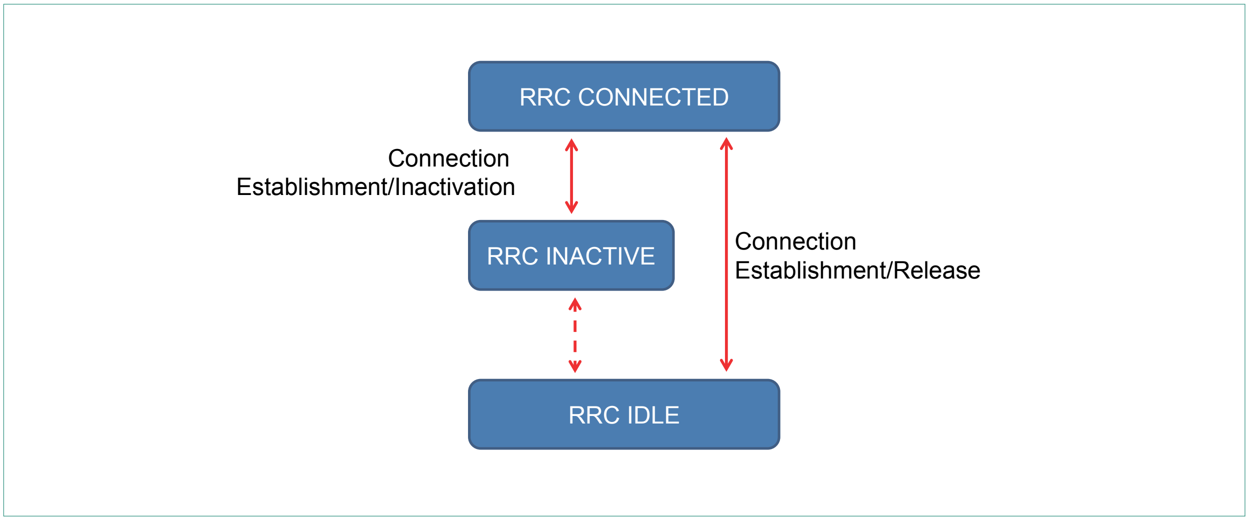

Figure 9 NR RRC states

of the 5G upper layer targeted for standardization based on the results of an SI at 3GPP. Work continues at 3GPP with the aim of completing specifications for Non-Standalone operation and Standalone operation by December 2017 and June 2018, respectively. As a member of the 3GPP RAN Working Group (WG), NTT DOCOMO will continue to take a proactive role in proposing technologies and contributing to the completion of these specifications.

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