Technology Reports

5G | NR | NR Higher Layer

Special Articles on Release 15 Standardization
—Advancements in the Completed Initial 5G and LTE/LTE-Advanced Specifications—

Specifications of NR Higher Layer in 5G

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In June 2018, the 3GPP finalized the NR specifications of wireless communication for 5G networks. This paper describes the specifications of the NR higher layer that are required for non-standalone operation (by NR in combination with existing LTE/LTE-Advanced systems) and standalone operation (by NR alone). First, we describe a standardized architecture and a bearer type defined for non-standalone operation involving the simultaneous use of LTE and NR radio links. Then, among the main functions of the higher layer, we describe the layer 2/3 protocol functions not mentioned in the special issue of October 2017, and also explain the network interface used in the base stations providing NR.

1. Introduction

Since March 2016, the 3rd Generation Partnership Project (3GPP) has been studying 5th Generation (5G) mobile communication systems. A feature article in 2017 outlined the discussions of the Study Item (SI)*1 on feasibility studies [1] [2]. In March 2017, 3GPP shifted to the Work Item (WI)*2 phase based on the issues considered and agreed upon at the SI stage, and work began on the actual standard specification process.

The Release 15 standard specifications include

*1 SI: Work on a feasibility study and an identification of high-level features to be specified.

*2 WI: Work that involves determining all functions to be specified and formulating detailed specifications for those functions.

one for non-standalone operation, in which New Radio (NR) and existing LTE/LTE-Advanced networks are combined, and one for standalone operation, in which NR can be operated alone. They were released in December 2017 and June 2018, respectively. This article describes NR's higher layer specifications as standardized by 3GPP.

2. Standardized Architecture and Bearer Types

2.1 Architecture

As stated above, 3GPP Release 15 provides specifications for both non-standalone operation and standalone operation for NR. Non-standalone operation is where services are provided in combination with existing LTE/LTE-Advanced networks. In contrast, stand-alone operation is where NR services can be operated alone. **Figure 1** shows the configuration of a Radio Access Network (RAN)*3 for these operations. In the Core Network (CN)*4, the Evolved Packet Core (EPC)*5, which was conventionally used for LTE, is used for non-standalone operation, while a new 5G Core (5GC) is used for standalone operation.

To address the demands from operators wishing to introduce 5G as early as possible, 3GPP released the 5G standard specifications in several

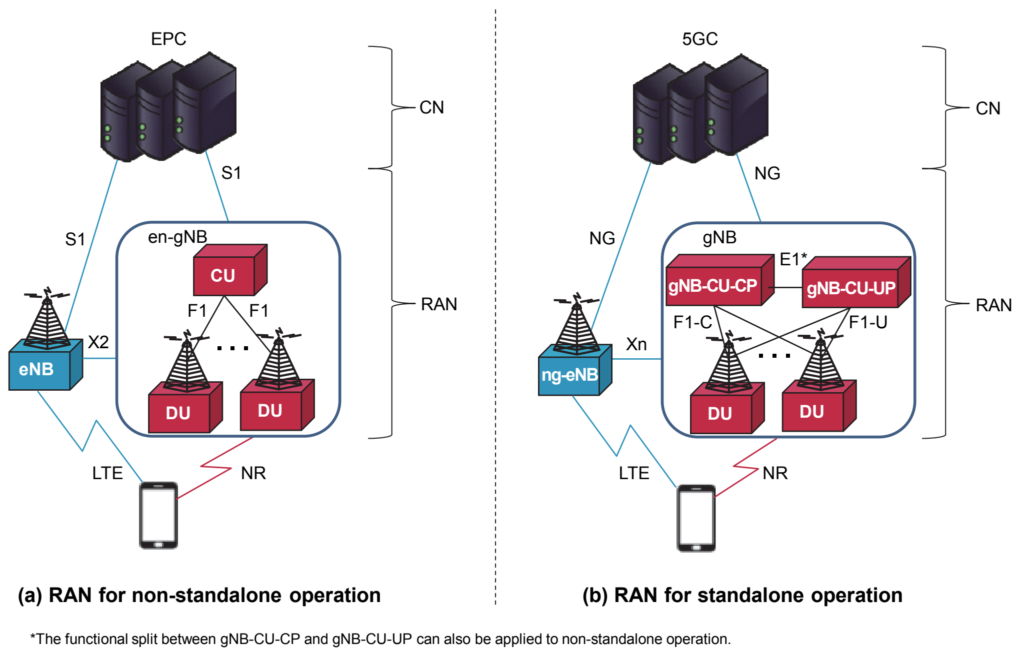

Figure 1 5G RAN configurations

*3 RAN: A network consisting of radio base stations and radio-circuit control equipment situated between the CN (see*4) and mobile terminals.

*4 CN: A network comprising switching equipment, subscriber information management equipment, etc. A mobile terminal communicates with the core network via a radio access network.

*5 EPC: A core network that can accommodate diverse radio access systems including LTE.

stages. First, for non-standalone operation, the specifications for higher layer*6 functions and the network interface*7 between LTE base stations (evolved Node B (eNB)) and NR base stations (gNB) were released in December 2017. Then in June 2018, for standalone operation, specifications for the additional functions and network interfaces were released, together with an LTE extension for connecting to 5GC via LTE. In December 2018, the specifications for a terminal that simultaneously communicates with multiple RAN nodes (LTE-NR Dual Connectivity (DC)*8 and NR-NR DC) with 5GC were released.

2.2 Bearer Types in Non-standalone Operation

The bearer type in non-standalone operation is based on what was specified for DC in Release 12 LTE and was extended to facilitate bearer control with greater flexibility. **Figure 2** shows the bearer types prescribed for non-standalone operation.

In LTE-DC, a split bearer is defined as one that simultaneously uses the radio resources*9 of multiple base stations (Master Nodes (MN)*10 and Secondary Nodes (SN)*11). However, in this case, the node terminating the bearer on the network side is limited to MN [2]. In non-standalone operation,

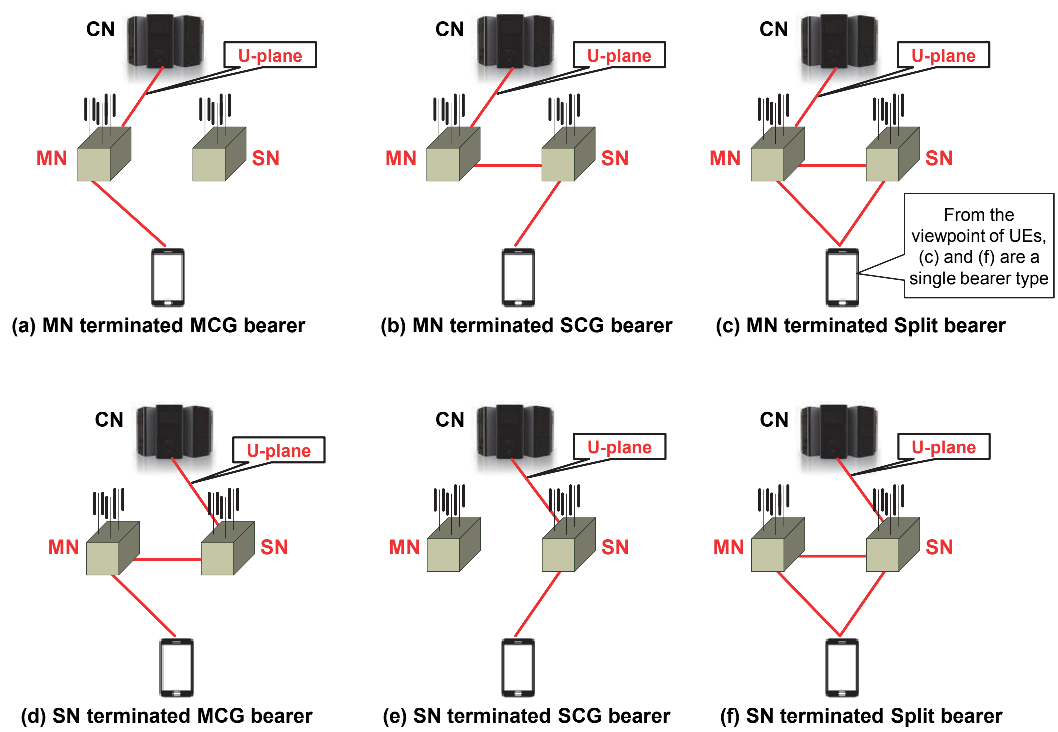

Figure 2 Bearer types in non-standalone operation

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*6 **Higher layer**: All layers positioned above the physical layer, namely, layers such as MAC (see *44), PDCP (see *22), RLC (see *20), S1AP, and X2AP.

*7 **Network interface**: An interface used in RAN, between RAN-CN, and in CN (X2, S1, Xn, NG, F1, E1, etc.).

*8 **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.

*9 **Radio resource**: General term for resources needed to allocate radio channels (frequencies). This can include radio transmission power, TRX resources, BB channels, and RLC (see *20) resources.

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

eNB is used as the MN to ensure connectivity between the terminal and the network via LTE wireless communication. However, if the same definition as the split bearer in LTE-DC is used for non-standalone operation, all the U-plane*12 data transmitted and received in LTE and NR will have to be processed and routed by eNB. In the standardization discussions, it was pointed out that this approach is likely to limit the wireless transmission rate due to a bottleneck in the processing performance of eNB equipment. To mitigate this issue, a new split bearer that terminates the bearer in SN (the Secondary Cell Group (SCG) split bearer in Fig. 1 of Reference [2]) was specified. In order to introduce this new bearer type, further discussions were held regarding the unification of bearer types in order to reduce the variation of bearer types from the viewpoint of the User Equipment (UE) and further expansion to facilitate more efficient operation.

1) Bearer Type Unification

With the introduction of a new bearer type, the specifications now define four bearer types from the viewpoint of the UE. When different operators can choose different bearer types and multiple bearer types are implemented to meet the needs of these multiple operators, the cost of the UE increases. Therefore, in order to minimize the variation of bearer types, an attempt was made to unify the types. Specifically, the U-plane protocol stacks*13 used in split bearers terminated by MN (Fig. 2 (c)) and SN (Fig. 2 (f)) are almost identical in terms of the functions and operations provided at Layer 2. In this sense, from the viewpoint of UE, there is no need to distinguish between them and they can be regarded as the same bearer type. By specifying these as a single split bearer type in the standard specification, it becomes possible to reduce the variation of bearer types as seen from the viewpoint of UE.

2) Configuration of Bearers in the Network for Efficient Operation

In a split bearer terminated with SNs (Fig. 2 (f)), EN-DCs*14 are set up and released when the user enters or leaves an SN area, whereupon the bearer termination nodes on the network side are switched between MN and SN. Every time this happens, control signaling for the path switch*15 is generated between the base station and CN, which is one of the issues discussed in the standardization process. In particular, during the early stage of the introduction of NR, since it is assumed that NR would be operated at hotspots*16 using high-frequency millimeter wave*17 signals, this sort of switching is likely to occur frequently. In an attempt to avoid these path switches, a plan was considered whereby even if a user leaves an SN area, the base station does not release the EN-DC configuration from the UE and keeps the bearer termination in the SN on the network side (with the U-plane data being transmitted and received on the LTE side). However, in this case, since the UE continues to search for an NR cell*18 outside the NR area, its battery power will be wasted.

Therefore, an inter-network procedure*19 was specified such that bearer termination nodes can be freely set on the network side, regardless of whether an EN-DC is configured for the UE. For example, when using a split bearer (Fig. 2 (f)) terminated by SN in EN-DC, the radio bearer is ter-

*11 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) if the MN is an LTE base station (eNB) and an LTE base station (eNB) if the MN is an NR base station (gNB).

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

*13 Protocol stack: Protocol hierarchy.

*14 EN-DC: An architecture for NR non-standalone operation. Performs RRC connection with LTE wireless, and also uses NR as an additional wireless resource.

*15 Path switch: The process of changing paths taken by routes used to transmit/receive data between CNs and base stations.

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

*17 Millimeter waves: Radio frequency band with wavelengths in the range of 1 to 10 mm.

minated at the SN. When the UE leaves the SN area, the base station deletes the radio resource setting (up to the Radio Link Control (RLC)*20 layer) on the SN side of the UE, whereby the UE can only use LTE for data transmission and reception. However, from the viewpoint of the network, since the SN continues to be used as a bearer termination node (as shown in Fig. 2 (b)), it does not generate control signals for switching paths to the CN.

In this way, since the flow of U-plane data can adopt a flexible configuration in non-standalone operation from the viewpoint of the network, nomenclature rules have been prepared to deal with this situation. Specifically, the U-plane bearer type is represented by combining two elements as follows.

- Distinguishing between MN-terminated and SN-terminated bearers according to the type of bearer termination node (MN or SN).
- Distinguishing between master cell group (MCG) bearers, SCG bearers, and split bearers according to which node's radio signals are used to transmit and receive data (MN radio only, SN radio only, or both).

As examples, Fig. 2 (c) shows an MN terminated split bearer, and Fig. 2 (d) shows an SN terminated MCG bearer.

3. Main Features of the Higher Layer in NR

This section describes the NR C-plane*21 and U-plane protocol stacks specified in 3GPP standards, and the functions of these protocol stacks.

3.1 C-plane

Figure 3 shows the NR C-plane protocol stack. The C-plane protocol stack is similar to that of LTE, and the protocols below the Packet Data Convergence Protocol (PDCP)*22 use the same protocols as the U-plane. The NR Radio Resource Control (RRC)*23 protocol introduces a number of improvements based on the LTE RRC protocol. **Table 1**

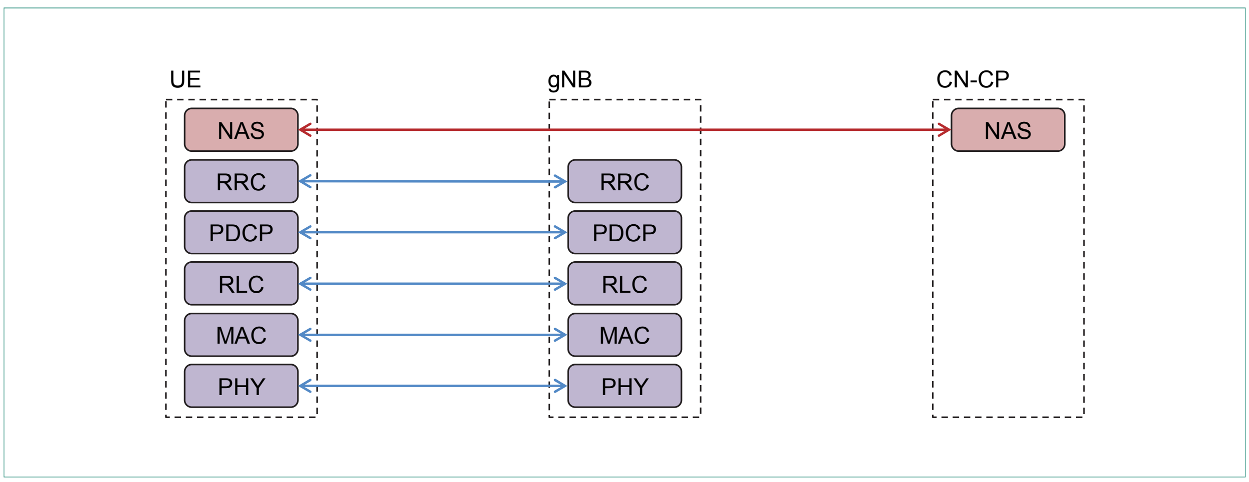


Figure 3　NR C-plane protocol stack

*18 **Cell**: The smallest area unit for sending and receiving radio signals between mobile communication network and mobile terminals.

*19 **Procedure**: A signal processing procedure implemented between base stations, between a base station and a CN, or between a base station and a terminal.

*20 **RLC**: A sublayer of Layer 2 (see *43). A protocol that performs services such as retransmission control.

*21 **C-plane**: A Protocol controls radio resource in RAN.

*22 **PDCP**: A sublayer of Layer 2 (see *43). A protocol that performs ciphering, integrity check, reordering and header compression, etc.

*23 **RRC**: A protocol that controls radio resources in a radio network.

Table 1　List of functions in NR RRC protocol

Function	Sub function	Non-standalone	Standalone	Difference from LTE RRC
System information	Broadcast of minimum system information	✓	✓	—
	Broadcast of other information		✓	Introduction of on-demand/area provision
Connection control	Bearer/cell settings	✓	✓	Introduction of split SRB/direct SRB
	Connection establishment with CN		✓	Introduction of RRC_INACTIVE state
	Paging		✓	Introduction of RAN paging
	Access control		✓	Introduction of unified access control
Mobility	Handover		✓	—
	Cell selection/reselection		✓	—
Measurement	DL quality measurement/reporting	✓	✓	Introduction of beam measurements
	Cell identifier measurement/reporting	✓	✓	—

shows the functional classification in NR RRC, the availability of each function for non-standalone/standalone operation, and the differences from the LTE RRC functions. In the following, the NR RRC functions will be described in terms of how they differ from the LTE RRC functions. For the details of split SRB[*24]/direct SRB[*25] and RRC_INACTIVE[*26] state, see the 2017 special article [2].

1) On-demand/area Provision of System Information[*27]

The RAN broadcasts system information that is needed when the UE is camped on a serving cell (e.g., frequency information of the serving cell and access control information) and other common control information (e.g., cell reselection information, frequency information of the neighboring cell, and public warning information). The UE acquires the system information from the RAN and stores this information during a certain time period.

In LTE, the eNB broadcasts all the information at regular intervals, but the UE may not necessarily acquire and store all of this information. For example, a stationary UE does not need information about neighboring cells, and a UE that does not support inter-Radio Access Technology (RAT) cell reselection[*28] does not need the corresponding frequency information. Based on this background, the gNB needs to broadcast only the Minimum System Information (MSI) and is available for on-demand provision of Other System Information (OSI). Specifically, the gNB can use MSI to indicate whether each OSI is currently being broadcast or providing in an on-demand way. Thus, a UE that needs OSI provided on-demand transmits a system information

*24 Split SRB: A bearer for duplicating RRC messages generated by MN for terminals in DC, and transmitting them via SN.

*25 Direct SRB: A bearer whereby the SN can send RRC messages directly to terminals in DC.

*26 RRC_INACTIVE: A terminal state in RRC where the terminal does not have cell level identification within the base station, and where the context of the terminal is held in the base station and the core network.

*27 System information: Information that includes the location code, which is required to decide whether location registration is needed for a mobile terminal, serving and neighboring cell information, access control information, and so on. Base stations broadcast this in each serving cell.

*28 Inter-RAT cell reselection: Reselection process of cells belonging to different RATs.

request to the gNB and can then obtain the corresponding OSI from the gNB by dedicated signaling*29. Since broadcasting continuously consumes radio resources, the use of on-demand to provide the OSI with low frequency can reduce the usage of radio resources for system information.

Furthermore, although system information in LTE is broadcast on a cell-by-cell basis and has to be acquired by UE every time the serving cell changes, NR RRC allows different cells to share the same OSI. This means the gNB can use MSI to indicate an area using the same OSI. Thus, when the UE moves the serving cell within the area, it is possible to skip the system information acquisition process when the UE has already stored valid OSI acquired from another cell. This is expected to reduce the power consumption of UE.

2) RAN Paging*30

In LTE, the CN records the UE position information over an area consisting of one or more cells, called a Tracking Area (TA)*31. When downlink data occurs for a specific UE in the RRC_IDLE*32 state, the CN transmits paging messages simultaneously via all the eNBs in the TA (**Figure 4** (a)).

In NR, it is assumed that more UEs can be accommodated than in LTE and that the newly defined RRC_INACTIVE state can be applied. When the same method as LTE is applied to UEs in the RRC_INACTIVE state, there is likely to be an increase in the signaling overhead between the CN and RAN and in the consumption of radio resources for sending multiple paging messages. To resolve this issue, it is specified that for UEs in the RRC_INACTIVE state, the RAN should record the UE

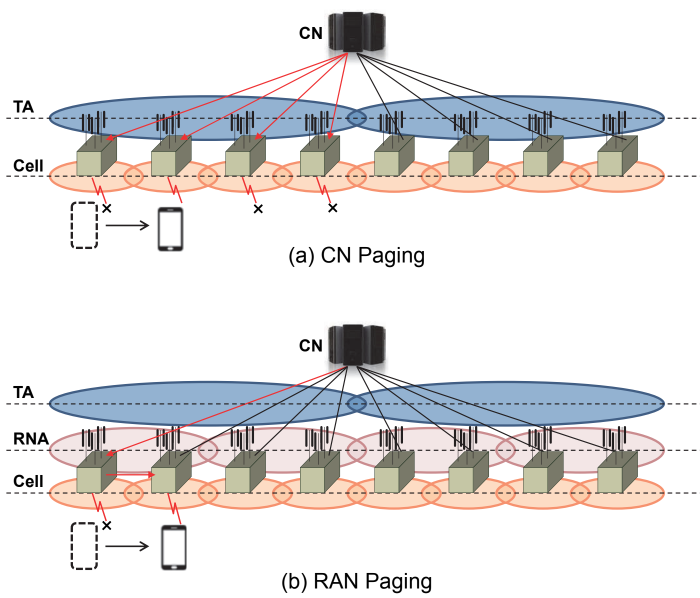


Figure 4　CN paging and RAN paging

*29 **Signaling:** Control signals used for communication between terminals and base stations.

*30 **Paging:** A procedure and signal for calling a UE while camped in a cell in standby mode at the time of an incoming call.

*31 **TA:** A cell unit expressing the position of a mobile terminal managed on a network, and composed of one or more cells.

*32 **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.

position information instead of the CN. Specifically, NR RRC defines a new area that is a subdivision of a TA, called a RAN Notification Area (RNA). A gNB that has received downlink data for a UE in the RRC_INACTIVE state from the CN transmits paging messages simultaneously via all the gNBs in the RNA, which is expected to reduce the signaling overhead between the CN and RAN and the usage of radio resources (Fig. 4 (b)).

3) Unified Access Control

In LTE, the eNB performs access control for restricting connection request signals from UEs and ensuring the connectivity of emergency calls and other important calls while maintaining network equipment by burst traffic. We expect to adopt a similar method in NR. However, since the access control in LTE has been extended along with the functional expansion of the standard specifications, it now includes a mixture of access control specifications, including Access Class Barring (ACB)*33, Service Specific Access Control (SSAC)*34, Extended Access Barring (EAB)*35, and Access Control for general Data Connectivity (ACDC)*36 [5]. This has made the specification much more complicated.

To address this issue, NR defines a Unified Access Control (UAC) specification that unifies the access control specification of LTE. In UAC, each access attempt in UE is mapped to a single access category and one or more access identities, and the RAN is able to control each combination separately.

Table 2 shows the access categories and access identities specified by NR.

- An access category is a service type identifier. Different numbers are assigned to each type of access attempt in the UE, and a region

Table 2 Access categories and identities

Access Category	Type of access attempt
0	Mobile originating signaling resulting from paging
1	Delay tolerant access
2	Emergency call
3	Mobile originating signaling resulting from other than paging
4	Voice call
5	Video call
6	SMS
7	Mobile originating data that do not belong to any other access category
8 ～ 31	Undefined
32 ～ 63	Operator specific definitions

Access Identity	Call type
0	Other than the following
1	MPS call
2	MCS call
3 ～ 10	Undefined
11	AC11
12	AC12
13	AC13
14	AC14
15	AC15

*33 ACB: A method for restricting burst-like connection-request signals during natural disasters or major events (e.g., New Year celebrations, fireworks festivals). The terminal itself evaluates whether or not restriction is required using network-notified access control parameters for each Access Class (AC) that individual terminals belong to, and refrains from sending connection-request signals if its access is indeed being restricted.

*34 SSAC: A method for restricting connection request signals for non-emergency voice calls and video calls.

*35 EAB: A method for restricting connection request signals in a Machine Type Communication terminal.

*36 ACDC: A method for restricting connection request signals from individual applications in a terminal.

that can be independently defined by the operator is also specified.

- An access identity is a call type identifier. Different numbers are assigned to Multimedia Priority Service (MPS) calls*37, Mission Critical Service (MCS) calls*38, and high priority calls (access classes 11–15). Other types of call are uniformly assigned the number zero.

For more details of UAC, the RAN can use MSI to notify the access control parameter, including the combination of an access category and one or more access identities to be restricted. The UE then judges whether or not restriction is required on the basis of the access category and access identity every time an access attempt is requested. If restriction is required, the UE refrains from sending the corresponding message during a specified time period calculated by the access control parameter in MSI. In LTE, UEs in the RRC_IDLE state are mainly subject to access control, but in NR, UEs in all RRC states can be restricted to enable more finely tuned access control.

4) Beam Measurement

The RAN instructs a UE to measure the downlink quality of the cell where the UE is located and of its neighboring cells. On the basis of the quality information reported by the UE, the RAN can perform handover*39 to another cell with better quality or adjust the cell settings to improve the quality and/or throughput.

In LTE, downlink quality measurement and reporting is performed in cell units. In NR, we assume a beamforming*40 environment with massive Multiple Input Multiple Output (MIMO)*41 for high speed and large capacity [6]. In NR, we can also instruct and report in beam units as well as in cell units. This makes it possible to implement handover to appropriate cells and/or beams even in beamforming environments.

3.2 U-plane

The U-plane protocol stack of NR is shown in **Figure 5**. It is based on LTE, and a Service Data Adaptation Protocol (SDAP)*42 layer is provided

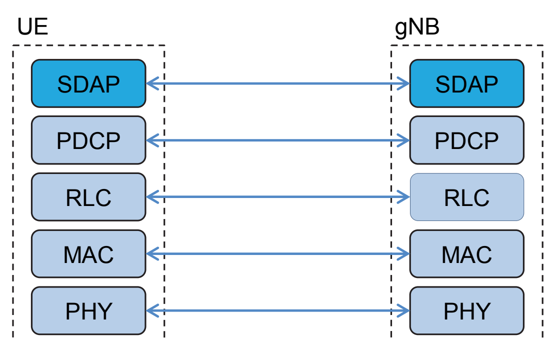


Figure 5 NR U-plane protocol stack

*37 **MPS**: A service that allows specific traffic to be provided to terminals even when the network is congested.

*38 **MCS**: Critical services whose failure or interruption could have serious adverse effects on life and society.

*39 **Handover**: The technique of switching from one cell to another without interrupting communication when a terminal moves between base stations.

*40 **Beamforming**: A technique for increasing or decreasing the gain of antennas in a specific direction by controlling the amplitude and phase of multiple antennas to form a directional pattern with the antennas.

as a new layer 2 protocol on the PDCP layer for 5GC. **Table 3** shows a functional classification of the functions in the other U-plane layer 2*43 protocol, detailing whether or not each function is compatible with standalone or non-standalone operation, and the differences between these functions and the functions in LTE.

This section describes how the SDAP layer is controlled, which is one way in which the U-plane functions differ from LTE. Details of beam control in the Medium Access Control (MAC)*44 layer can be found in a separate item in this special article [6], and details of RLC layer not supporting packet reordering function and PDCP layer packet duplicated transmission control for highly reliable communication such as Ultra-Reliable and Low Latency Communication (URLLC)*45 can be found in an item published in the 2017 special article [2].

Table 3 NR U-plane Layer 2 protocol function list

Layer	Function	Non-standalone	Standalone	Difference from LTE
MAC	Mapping between logical channels and transport channels	✓	✓	—
	Multiplexing/de-multiplexing data of same and different logical channels	✓	✓	New support for data multiplexing/demultiplexing in the same logical channel
	Scheduling	✓	✓	—
	Error correction by HARQ	✓	✓	—
	Priority control between logical channels	✓	✓	—
	Beam management control	✓	✓	New support
RLC	Packet segmentation and reassembly	✓	✓	Packet reordering is not supported
	Duplicate detection	✓	✓	—
	Protocol error detection	✓	✓	—
	Lossless transmission by ARQ	✓	✓	—
PDCP	Header compression	✓	✓	—
	Packet reordering and duplicate detection	✓	✓	—
	Security (ciphering and integrity protection)	✓	(✓)	Integrity protection for U-plane is supported in SA
	Timer-based packet discard	✓	✓	—
	Duplicate packet transmission	✓	✓	New support
SDAP	Mapping between QoS flow and radio bearer		✓	New support

*41 Massive MIMO: MIMO systems that transmit radio signals overlapping in space by using multiple antenna elements for transmission and reception. Massive MIMO systems aim to achieve high-speed data communications with greater numbers of simultaneous streaming transmissions while securing service areas. They achieve that aim by using antenna elements consisting of super multi-element arrays to create sharply formed radio beams to compensate for the radio propagation losses that accompany high-frequency band usage.

*42 SDAP: A sublayer of Layer 2 (see *43). A protocol that performs mapping between QoS flows and radio bearers.

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

*44 MAC: A sublayer of Layer 2 (see *43). A protocol that performs functions such as radio resource allocation, mapping data to TBs, and HARQ retransmission control.

During the initial investigation of 5GC, particularly due to requests from European operators, there were discussions of the concept of "access agnostic" specifications with inclusive support for not only Next Generation (NG)-RAN*46 but also non-3GPP access schemes such as Wireless Local Area Network (WLAN) access and fixed access.

In the Quality of Service (QoS) control*47 of a conventional EPC, per-call QoS-related Tunneling End-point IDentifiers (TEIDs)*48 are dispensed with, and QoS control is performed based on TEID (**Figure 6** (a)). However, considering the affinity with non-3GPP

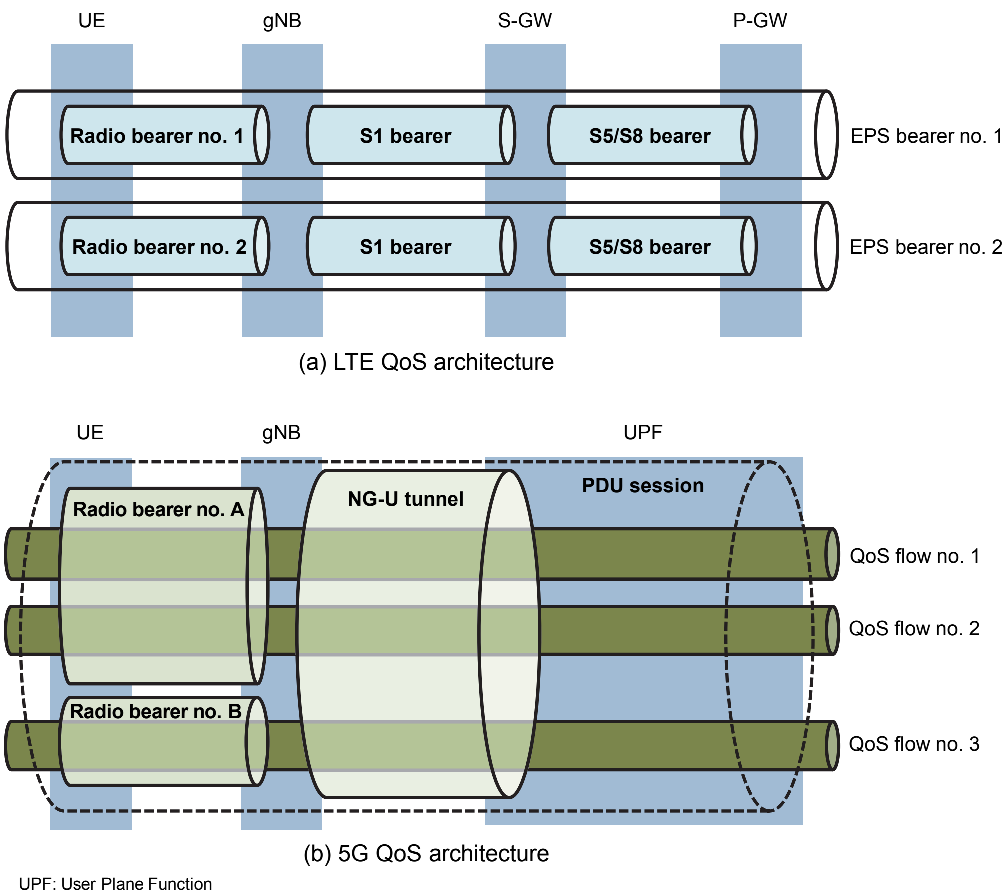


Figure 6　LTE QoS architecture (top) and 5G QoS architecture (bottom)

*45　URLLC: Generic terminology for communication requiring low delay and high reliability.

*46　NG-RAN: A RAN connecting to the 5G core network using NR or Evolved Universal Terrestrial Radio Access as radio access technology.

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

*48　TEID: A connection path identifier used in GRPS Tunneling Protocol.

access networks that do not perform QoS control based on the per-call TEID, it became necessary to introduce a new QoS framework for 5GC. Specifically, a QoS flow*49 method was adopted whereby a dedicated pointer to multiple QoS characteristics is included in each IP packet so that packets with multiple QoS characteristics can be handled without using TEID on individual calls. In the QoS flow method, multiple QoS flows passing through a Protocol Data Unit (PDU)*50 session tunnel set up between the CN and base station are mapped to individual radio bearers*51 established between the base station and the terminal equipment (Fig. 6 (b)).

This mapping between QoS flows and radio bearers is carried out at the SDAP layer newly introduced in NR. Although this mapping can also be set up in the C-plane, the setting and modification of mappings in the C-plane requires the use of RRC signals, resulting in setting delays and overheads*52.

Therefore, reflective QoS control is introduced to implement the setting and modification of mapping in a more dynamic fashion. Specifically, when a change is needed in the mapping between a QoS flow and a radio bearer, the CN assigns a new QoS flow identifier to each packet and sends it to the base station. When the base station detects a new QoS flow identifier, it includes its information in an SDAP header corresponding to a packet and transmits to the terminal. When the terminal receives this packet, it detects the identifier assigned to the corresponding SDAP, updates the mapping information managed by this terminal, and performs transmission of the uplink packet with the corresponding radio bearer. In this way, the base station makes settings and modifications to the mapping of transmitted packets and reports this information to the terminal, thus enabling the implementation of QoS modifications suited to the IP flow more dynamically than when relying on control signals.

4. Network Interface

In LTE networks, X2 and S1 are defined as interfaces between RAN nodes and between RAN and CN. In 5G, X2 and S1 extensions for non-standalone operation and new interface for standalone operation have been discussed. Fig. 1 shows the interface used between nodes.

1) Interface between RAN Nodes (X2/Xn)

Different interfaces are used between RAN nodes for non-standalone and standalone operation. The X2 interface used between eNBs in LTE is reused for interfaces between RAN nodes in non-standalone operation (between eNB and en–gNB in Fig. 1 (a)), and the Xn interface is newly specified between RAN nodes in standalone operation (between ng–eNB and ng–eNB/gNB and gNB/ng–eNB and gNB, as shown in Fig. 1 (b)). The X2 extension functions and the Xn functions are shown in red in **Table 4**.

The extensions of X2 include functions adopting EN-DC and flow control for split bearers for non-standalone operation. The flow control function, which was defined for LTE-DC split bearers in Release 12, is used for appropriately split downlink data when using the radio resources of multiple RAN nodes. Although functions and interfaces just for basic flow control were specified for LTE-DC, the information exchanged between RAN nodes

*49 **QoS flow:** A unit of flow used in QoS control.
*50 **PDU:** A unit of data processed by a protocol layer/sublayer.
*51 **Bearer:** The path to transfer user data packets.
*52 **Overhead:** Control information needed for transmitting/receiving user data, plus radio resources used for other than transmitting user data such as reference signals for measuring received quality.

Table 4 Main functions of X2/Xn interface

	Function	X2	Xn	Overview
C-plane functions	Interface management	✓	✓	Interface setup, reset, configuration update, error indication
	UE context management	✓	✓	Function for UE context management
	Mobility management	✓	✓	Management for e.g. UE inter-node mobility (handover)
	DC within same RAT	✓	*1	Function to operate DC in same RAT
	Load management	✓*2		Function to indicate resource load status to other nodes
	Energy saving	✓	✓	Function for energy saving by turning cells on/off
	Message transfer	✓		Function for forwarding messages to other eNBs
	UE context retrieval	✓		Function for retrieving UE context from other nodes
	EN-DC	✓	*1	Function for operating DC between LTE and NR
	Secondary RAT data usage report	✓		Function for reporting data volume of a RAT when using several RATs (such as EN-DC)
	Inactive management		✓	Function for managing inactive UEs
U-plane functions	User data transfer	✓	*1	Transferring user data during DC
	Flow control	✓	*1	Additional functions: polling, discarding duplicate data, status indication for retransmission data, etc.

*1 To be introduced in December 2018
*2 Notifications in non-standalone operation are under discussion

is further enhanced to optimize the flow control for non-standalone operation. Although Xn is based on the X2 function, the UE context management function is chiefly enhanced for adopting the above-mentioned new QoS flow framework and network slices*53 [3].

2) Interface between RAN Node and CN (S1/NG)

Like the interfaces between the RAN nodes, the interfaces between RAN nodes and CNs also differ between non-standalone and standalone operation. In non-standalone operation, the S1 interface used between eNBs and EPC is reused for interfaces between RAN node (eNB/en-gNB in Fig. 1 (a)) and EPC. On the other hand, the NG interface is newly specified between RAN nodes (ng–eNB/gNB in Fig. 1 (b)) and 5GCs in standalone operation. The S1 extension functions and the NG functions are shown in red in **Table 5**.

The extensions of S1 include a function that reports data volume for a specific RAT in non-standalone operation. In the standardization discussions, there were demands from operators for charging based on the data volume of each RAT (i.e., LTE and NR) in non-standalone operation. Thus, this function was introduced for calculating the amount of data volume via NR. In non-standalone

*53 Network slice: One format for achieving next-generation networks in the 5G era. Architecture that optimally divides the core network in units of services corresponding to use cases, business models, etc.

Table 5 Main functions of S1/NG interface

	Function	S1	NG	Overview
C-plane functions	Interface management	✓	✓	Interface setup, reset/configuration update, error indication
	Bearer/session management	✓	✓	Function for managing UE bearers and sessions
	UE context management	✓	✓	Function for UE context management
	Mobility management	✓	✓	Management for e.g. UE inter-node mobility (handover)
	Paging	✓	✓	Function for paging UEs
	Roaming/access restrictions	✓		Function for notifying RAN node roaming and access restrictions
	NAS signalling transport	✓	✓	Function for exchanging NAS signals between core network and UEs
	Radio quality notification	✓		Function for notifying core node radio quality measured by UEs
	Location reporting	✓	✓	Function for notifying core node current location of UEs
	Warning message information transfer	✓	✓	Function for transferring UE warning message (earthquake, tsunami, etc.)
	Function for secondary RAT data usage reporting	✓	*1	Function for reporting data volume for a RAT when using different RATs simultaneously (such as EN-DC)
	Function for core node selection		✓	Function for selecting core network node according to load status
U-plane functions	Function for user data transfer	✓	✓	Transfer of user data between core network and UEs

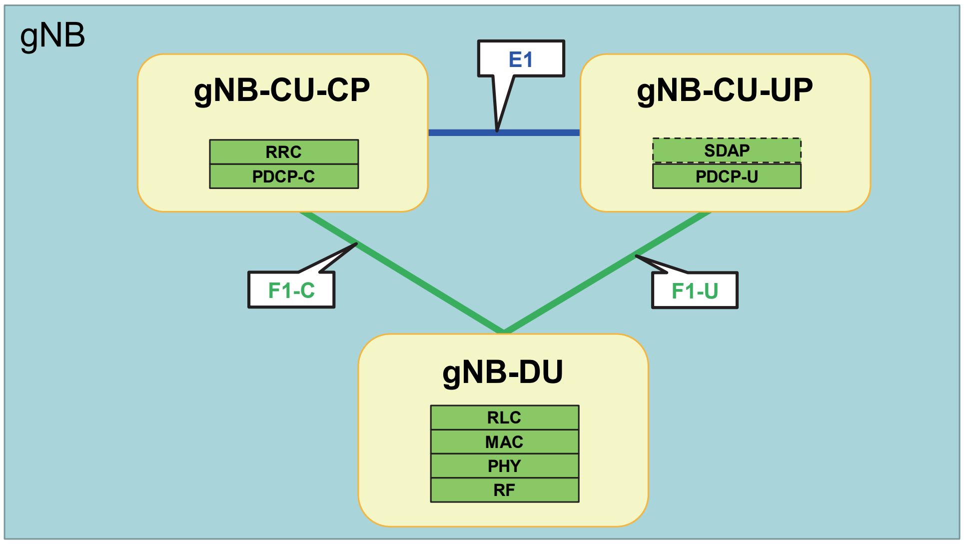
*1 To be specified in December 2018

operation, since the S1-C interface is only established between the MN and CN, the data volume through MN terminated bearers is counted by the MN itself and reported directly to the CN via S1, while the data volume from SN terminated bearers is counted by SN and reported to MN via X2, and then reported by MN to CN via S1. Similar with Xn for X2, although NG is based on the S1 function, the bearer/session management functions and UE context management functions have been chiefly enhanced for adopting a new QoS framework and network slices.

3) Functional Split and Open Interfaces (F1, E1) within RAN Nodes

In 3GPP standardization, the functional split within a RAN node, which places part of the functions in separate logical nodes, and an open interface between logical nodes has been discussed. **Figure 7** shows the functional split of gNB and the interfaces between the logical nodes.

In 3GPP, to address the issue of explosive increases of the bandwidth required for the transport



*SDAP layer is used only for standalone operation.

Figure 7　Functional split of gNB and interfaces that are used

between the Central Unit (CU) and Distributed Unit (DU) by the introduction of massive MIMO and extending the frequency bandwidth using Centralized RAN (C-RAN)*54 deployment, the new functional split between CU (gNB-CU) and DU (gNB-DU) within gNB and the corresponding open interface between these nodes were discussed [2]. Specifically, a functional split was adopted where the PDCP layer and above are located in the gNB-CU, and the RLC layer and below are located in the gNB-DU. The standard interface between them is specified as F1. The functions of the F1 interface are shown in **Table 6**.

In addition to the functional split between gNB-CU and gNB-DU, the functional split of C-plane termination and U-plane termination in gNB-CU was discussed [4]. For example, when the C-plane terminating parts are placed near gNB-DU and the U-plane terminating parts are placed near CN, the RRC signal used by the C-plane can be controlled without long delays and the U-plane functions can be placed in the cloud. Conversely, when the C-plane termination is placed near CN and the U-plane termination is placed near gNB-DU, it is possible to reduce the delays of U-plane signals for edge computing applications, and the C-plane functions can be migrated to the cloud. In the past, this sort of functional split has only been achieved within the same

*54　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 vendor. However, with 3GPP standardization, an open interface between the C-plane termination parts and U-plane termination parts of gNB-CU has been specified so that this sort of functional separation can be achieved even between different vendors. A node that terminates the C-plane of gNB-CU is called gNB-CU-CP, and a node that terminates the U-plane of the gNB-CU is called gNB-CU-UP. The standard interface between these nodes is specified as E1. The functions of E1 are shown in **Table 7**.

5. Conclusion

This article has described the main specifications of the 5G higher layer specified by 3GPP. The 3GPP is continuing its efforts with the aim, by December 2018, of finalizing the standard specifications for a terminal that simultaneously communicates with multiple RAN nodes with 5GC. For Release 16, further enhancements for functional expansion and the study/specification for new functions are planned. Specifically, 3GPP will discuss further enhancement of the higher layers for URLLC, as well as a function for minimizing interruption time during handover and a function for collecting data from gNB for the self-optimization of the network. NTT DOCOMO will continue to contribute to standardization actively by submitting technical proposals in each 3GPP RAN working group (WG).

Table 6　Main functions of F1 interface

	Function	Overview
C-plane functions	Interface management	Interface setup, reset/configuration update, error indication
	System information management	Function for broadcasting system information
	UE context management	Function for UE context management
	RRC message transfer	Function for exchanging RRC signaling between gNB-CU and UE
	Paging	Function for operating paging for UEs
	Warning message information transfer	Function for transferring UE warning message (earthquake, tsunami, etc.)
U-plane functions	User data transfer	Transfer of user data between gNB-CU and gNB-DU
	Flow control	Flow control for gNB-DU

Table 7　Main functions of E1 interface

Function	Overview
Interface management	Interface setup, reset/configuration update, error indication
Bearer management	Function for managing bearers for UEs

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