Technology Reports (Special Articles) eMBB High-speed, High-capacity 5G NR

Special Articles on 3GPP Release 16 Standardization Activities

5G Advanced Technologies for Mobile Broadband

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In March 2020, NTT DOCOMO began 5G services using NR, as stipulated in the 3GPP Rel-15 specifications. 5G communication services will spread and expand in the future, but there will still be demand for further increases in wireless network speed and capacity. The 3GPP released the Rel-16 specifications in June 2020, enhancing the functionality and performance of the Rel-15 specifications. This article describes technologies increasing speed and capacity in the radio access specifications for Rel-16 NR.

1. Introduction

In March 2020, NTT DOCOMO began 5G communication services using NR as stipulated in the 3rd Generation Partnership Project (3GPP) Release 15 (hereinafter referred to as “Rel-15”) specifications. 5G communication services will spread and expand in the future, but there will be demand for further increases in wireless network speed and capacity. The 3GPP released the Rel-16 specifications in June 2020, enhancing the functionality and performance of the Rel-15 specifications. As outlined in other articles of this special feature [1], the 3GPP Rel-16 specifications feature functionality to improve the quality and performance of enhanced Mobile BroadBand (eMBB), and also functionality to expand usage scenarios and markets. This article describes improvements to quality and performance through advanced Multiple-Input Multiple-Output (MIMO)*1 technology, which increases system capacity and user throughput.

In terms of functions that expand usage scenarios, we also describe Integrated Access Backhaul, a technology that utilizes mobile backhaul*2, New Radio (NR) Unlicensed, a technology for utilizing unlicensed bands*3, and enhancements to Multi-Radio Dual Connectivity (MR-DC)*4 and Carrier Aggregation (CA)*5.

2. MIMO Beam-forming Enhancements

In order to expand the range of application of the MIMO technology specified in Rel-15 and increase the practical user throughput, distributed MIMO*6 has been specified. Enhancements have also been made to specifications for beam management and beam failure recovery created in Rel-15, for more efficient operation of high-frequency beam forming*7.

2.1 Distributed MIMO Technology

In Rel-15, for the Physical Downlink Shared Channel (PDSCH)*8, single user MIMO*9 with up to eight layers*10 was supported using a single Transmission and Reception Point (TRP) at the base station. Rel-16 specifies a distributed MIMO transmission function capable of up to eight layers, coordinating two TRPs at the base station (**Figure 1**). Distributed MIMO transmission increases the number of uncorrelated radio propagation paths, which enables use of higher-rank MIMO transmission.

1) Backhaul Environment Scenarios

To coordinate multiple TRPs for distributed MIMO transmission requires exchange of control information between TRPs. It is assumed that this

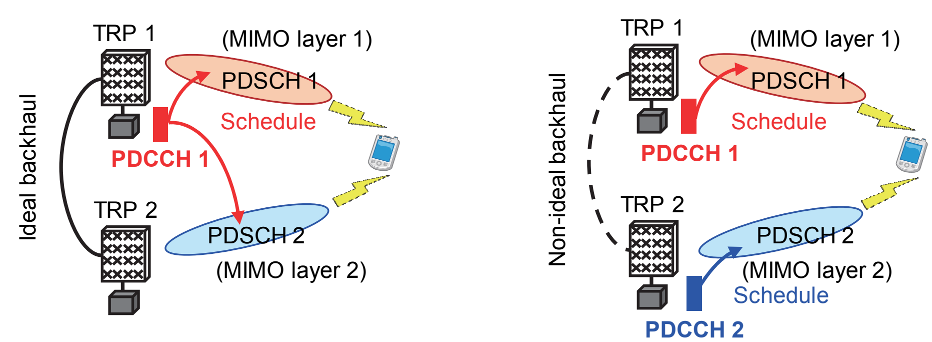

Figure 1　PDSCH distributed MIMO transmission with two cooperating TRPs

*1　MIMO: A signal transmission technology that improves communications quality and spectral efficiency by using multiple transmitter and receiver antennas to transmit signals at the same time and same frequency.

*2　Backhaul: The route connecting base stations to the core network.

*3　Unlicensed band: A frequency band that does not require government licensing, and whose use is not limited to a particular telecommunications operator.

*4　MR-DC: A generic term for DC with connections to LTE and NR base stations or two NR base stations. DC is a technology involving connection to two base stations, a primary and a secondary, and performing simultaneous transmission and reception on multiple carriers supported by these base stations to realize higher transmission speeds.

*5　CA: A technology that achieves higher transmission speeds by transmitting and receiving using multiple carriers supported by a single base station.

*6　Distributed MIMO: A MIMO transmission technology that transmits different MIMO streams from multiple base stations to a single UE.

will be done in both environments where optical fiber or other high quality backhauls can be installed between TRPs and control information can be exchanged with low latency (ideal backhaul environments) and in environments where this is not possible (non-ideal backhaul environments). The actual type of network environment will differ for each country and operator, depending on issues such as whether optical fiber is possible and the density of base station deployment. Communication methods for TRP-coordinated distributed MIMO will differ depending on the environment, so distributed MIMO was specified in Rel-16 for two types of scenario: ideal backhaul, and non-ideal backhaul environments.

2) PDSCH Scheduling

In an ideal backhaul environment, the Physical Downlink Control Channel (PDCCH)*11 transmitted by one of the TRPs is used to bundle together scheduling for PDSCHs transmitted by both TRPs (Fig. 1, left). This method is able to schedule the PDSCHs for each TRP efficiently on a single PDCCH, but it is difficult to apply in environments with non-ideal backhauls.

The PDSCH scheduling function for non-ideal backhaul environments, the PDSCH transmitted by each TRP is used to schedule the PDSCH on that TRP (Fig. 1, right). Note that this method requires twice as many PDCCH transmissions as the ideal relay-line environment method.

3) HARQ-ACK/NACK Transmission

Methods for sending ACKnowledgement (ACK)*12 and Negative ACKnowledgement (NACK)*13 for a Hybrid Automatic Repeat reQuest (HARQ)*14 when performing MIMO transmission with multiple coordinated TRPs are shown in **Figure 2**. Methods for sending HARQ-ACK/NACK for PDSCH received from each TRP by the User Equipment (UE) are specified for both ideal backhaul and non-ideal backhaul environments. When there is an ideal backhaul environment between TRPs, the UE concatenates the HARQ-ACK/NACK bits*15 for the PDSCH received from each TRP and sends them on a single Physical Uplink Control Channel (PUCCH)*16 (Fig. 2,

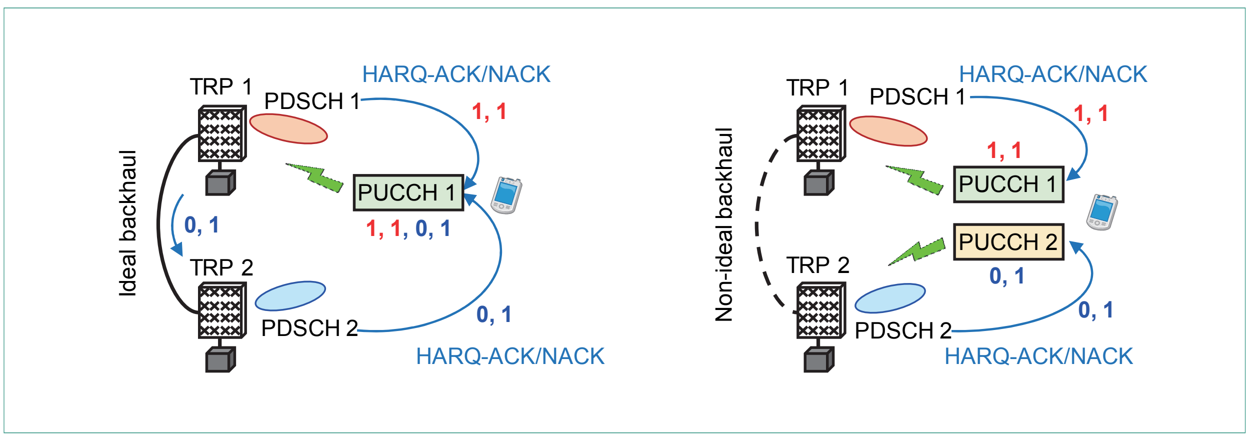

Figure 2 HARQ ACK/NACK transmission to two TRPs

*7 **Beam forming:** A technology that gives directionality to a transmitted signal, increasing or decreasing the signal power in a particular direction. Analog beam forming works by controlling the phase in multiple antenna elements (RF devices) to create directionality, while digital beam forming controls phase in the baseband module.

*8 **PDSCH:** A physical channel for transmitting user data and control information from the higher layer signaling.

*9 **Single user MIMO:** Technology that uses MIMO transmission at identical temporal frequencies for a single user.

*10 **Layer:** A spatial stream in MIMO.

*11 **PDCCH:** Control channel for the physical layer in the downlink.

*12 **ACK:** A receive acknowledgment signal whereby a receiving node can tell the sending node whether or not the data was successfully received (decoded).

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

left). The TRP receiving the HARQ-ACK/NACK bits forwards them to the other TRPs using the backhaul between the TRPs. This method is able to transmit the HARQ-ACK/NACK for multiple TRPs efficiently in ideal backhaul environments. However, using this method in environments with a non-ideal backhaul results in HARQ latency*17 in the amount of the latency on the backhaul between the TRPs.

Accordingly, a method was also specified in which the UE transmits the HARQ-ACK/NACK for the PDSCH received from each TRP to the respective TRP on its PUCCH (Fig. 2, right). With this method, the HARQ latency mentioned above does not occur, even in environments with non-ideal backhauls, but PUCCH transmissions to each TRP are time-multiplexed, so twice the number of PUCCH transmissions as with the ideal backhaul environment method are necessary.

2.2 Beam Management, Beam Failure Recovery Enhancements

The objective of beam management as specified in Rel-15 was to quickly establish and maintain an analog beam pair at the base station and the UE, mainly for high frequencies. Beam management consists of beam measurement at the UE, beam reporting from the UE, and beam indication from the base station.

With beam failure recovery as specified in Rel-15, if beam failure occurs for the Primary Cell (PCell)*18 or Primary SCell (PSCell)*19 due to blocking of the propagation path of a beam being used for communication, the beam that failed is recovered quickly by sending a beam failure recovery request to the base station using a beam that has not failed. The following functional enhancements were made in Rel-16.

1) Beam Reporting Based on Per-beam Reception Quality

In Rel-15, beam information for the N beams with the highest Reference Signal Received Power (RSRP)*20 as measured by the UE are reported to the base station. Here, N is set to 1, 2, or 4 by the base station. Rel-16 adds a function to report beam information for the M beams with the highest Signal to Interference plus Noise power Ratio (SINR)*21 measured by the UE to the base station. Here, M is set to 1, 2, or 4 by the base station. This will enable beam management taking interference between cells or TRPs into consideration, which can be expected to increase communication quality.

2) Low-latency, Low-overhead*22 Beam Indication

In Rel-15, there were cases when the higher layer signaling*23 Radio Resource Control (RRC)*24 message required reconfiguration to indicate the uplink transmission beams. To avoid frequent RRC reconfiguration and enable low latency beam indication, Layer 1 or 2*25 signaling can be used for beam indication. To that end, Rel-16 specifications were enhanced to allow uplink beam indication to be done in Layer 2. In particular, the number of PUCCH beams that can be managed with Layer 2 was expanded from 8 to 64, and beam management using the Aperiodic Sounding Reference Signal (Aperiodic-SRS)*26 can be done in Layer 2. A function that omits explicit beam indications for the uplink, which is called default uplink beams, was

*14 HARQ: A technology that corrects data transmission errors by notifying the transmitter whether the data was received (decoded) correctly and retransmitting the data when errors are detected.

*15 HARQ-ACK/NACK bit: A bit used in HARQ to indicate ACK or NACK, with 1 or 0 respectively.

*16 PUCCH: Physical channel used for sending and receiving control signals in the uplink.

*17 HARQ latency: The amount of time between data transmission and reception of the ACK notification from the receiver, completing the data transmission.

*18 PCell: The component carrier that maintains the connection, among the multiple carriers used in CA.

*19 PSCell: For DC or MR-DC, the component carrier (See *27) that maintains the connection, among the component carriers supported by the secondary base station.

*20 RSRP: Received power of a signal measured at a receiver. RSRP is used as an indicator of receiver sensitivity in a terminal.

*21 SINR: Ratio of desired received signal power to that of other received signals (interfering signals from other cells or sectors and thermal noise).

also specified. With default uplink beams, the uplink beam is linked to the downlink beam indication, so the overhead of uplink beam indication in Layer 2 can be eliminated.

In Rel-15, a Layer 2 beam indication was given for each uplink/downlink channel of each BandWidth Part (BWP) in each Component Carrier (CC)*27. Rel-16 specifies a function enabling single Layer 2 signaling for beam indication across multiple BWP and CC, for a given channel and reference signal, which reduces the overhead of Layer 2 beam indication. Please refer to the special article from 2019 regarding BWP [2].

3) Secondary Cell Beam Failure Recovery

Secondary Cell (SCell)*28 beam failure recovery has been specified (**Figure 3**). If a UE measures reception quality below a prescribed value for a SCell, it sends a beam failure recovery request for the SCell to the PCell or PSCell. The UE also measures beams from SCells and reports the one with the strongest reception power to the PCell. Thus, the SCell beam failure and the new beam information can be reported to the PCell, enabling the SCell beam failure to be recovered quickly.

3. IAB

Integrated Access and Backhaul (IAB) were specified to support further expansion of NR networks so that high-speed, high-capacity services can be provided quickly over wider areas, by also using NR for backhaul links to achieve more flexible, less expensive network design and deployment. This will enable deployment of IAB nodes with functionality equivalent to a base station Distributed Unit (DU)*29, without using a wired backhaul, and is anticipated for expanding and enhancing NR networks indoors and with outdoor small cells*30.

3.1 IAB Architecture

The basic structure of the IAB architecture is shown in **Figure 4**. An IAB node is composed of an IAB Mobile Termination (IAB-MT) component that has functions equivalent to a UE for connecting to the network, and an IAB-DU component with functions equivalent to the DU in a base station.

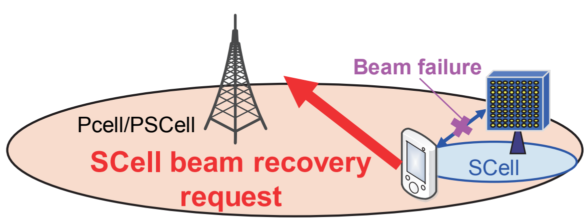

Figure 3 SCell beam failure recovery

*22 **Overhead:** Radio resources used for purposes other than transmission of user data, such as transmitting control information.

*23 **Higher layer signalling:** In this article, higher layer signaling refers to messages that are transmitted and received in order to control terminals in the Medium Access Control (MAC) layer or higher layers. Examples include Radio Resource Control (RRC) messages (See *24) and MAC control elements.

*24 **RRC:** A Layer 3 protocol that controls radio resources in a radio network.

*25 **Layer 1 or 2:** Layer 1 (Physical layer) or Layer 2 (Data link layer) as defined in the Open Systems Interconnection (OSI) reference model.

*26 **Aperiodic-SRS:** A channel sounding reference signal sent aperiodically by the UE when triggered by the PDCCH.

*27 **CC:** A term used to refer to the carriers bundled together when using CA.

*28 **SCell:** A generic term for a component carrier other than the PCell and PSCell, among the multiple carriers used in CA. Also referred to as a secondary cell.

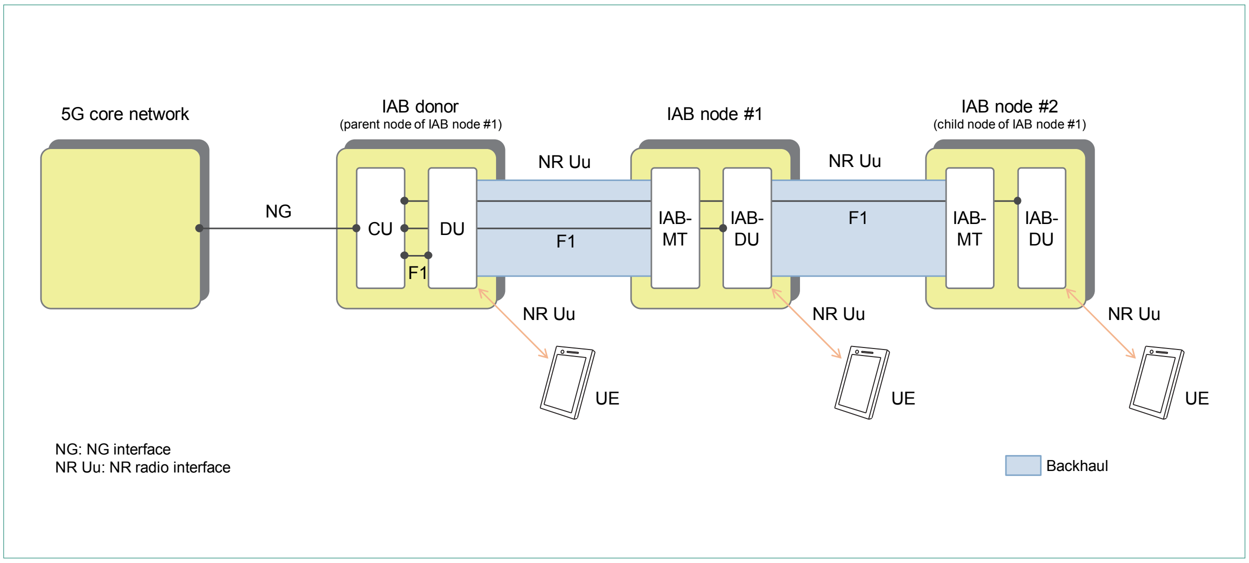

Figure 4　Basic IAB architecture

The IAB-MT is the function that connects with the IAB donor or parent-node DU through an NR radio access channel (NR Uu) as the backhaul link. The IAB-DU is the function that allows UE or child nodes to connect as their access link and, like the DU in a base station, it also has the function to connect to a Central Unit (CU) through an F1 interface.

The Backhaul Adaptation Protocol (BAP)*31 has also been specified to perform data routing when multiple IAB nodes are connected in series or parallel [3].

3.2 IAB Node Operation Procedures

An IAB node activates IAB-DU operation with the following four steps [4].

(1) IAB-MT network connection

The IAB-MT connects to the network, behaving as a UE and according to the same process.

(2) Establish backhaul Radio Link Control (RLC)*32 layer

A backhaul RLC layer is established between the IAB node and the CU to forward control signals to the IAB node.

(3) Routing configuration

The IAB donor configures or updates values including the IAB node BAP address and BAP routing ID for routing IP traffic between the IAB node and the IAB donor. The IAB donor also issues an IP address to the IAB node and associates it with the BAP address.

(4) IAB-DU setup

The IAB node uses the configured IP address, establishes an F1 link with the IAB donor, and begins operating the IAB-DU.

*29 DU: A component of a base station, the node that processes radio signals and transmits and receives radio waves.

*30 Small cell: A generic term for cells transmitting with low power and covering areas relatively small compared to macrocells.

*31 BAP: A protocol for routing data for IAB nodes.

*32 RLC: A Layer 2 sublayer of the radio interface and a protocol that performs services such as retransmission control.

3.3 Physical Layer Functions

For cases when IAB-MT and IAB-DU are implemented with their own dedicated antennas or RF circuits, such as when operating backhaul and access links on different frequencies, IAB nodes can be operated using the Rel-15 NR physical layer*33 specifications. However, for cases when both links in the IAB node share the same antenna or RF circuit implementation, such as when operating both the backhaul and access links on the same frequency, and IAB-MT and IAB-DU must use half-duplex operation*34, enhancements to physical layer functions were required. Specifications for these functions were created as follows. Signalling to synchronize transmission timing between IAB nodes was also specified.

1) Enhanced SSB Transmission Configuration (STC)*35 and SSB-based Measurement Timing Configuration (SMTC)*36

In Rel-16, when half-duplex operation for IAB-MT and IAB-DU is needed, time-sharing operation between IAB-MT and IAB-DU is expected. After the IAB-DU begins operation, to measure the radio quality on the backhaul link using a Synchronization Signals/Physical Broadcast CHannel Block (SSB)*37 and to detect an IAB node with higher radio quality, it can configure up to four transmission configurations (STCs) for the IAB node, different from that for UE, as shown in **Figure 5**. It can also add up to four SMTC settings to measure the SSB at the same time.

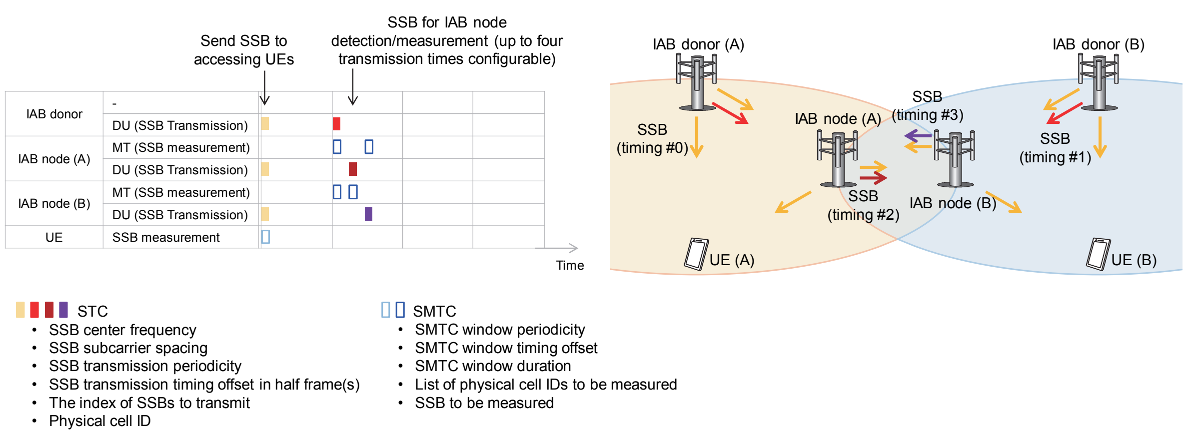

Figure 5 IAB node STC and SMTC configuration example

*33 **Physical layer:** First layer of the OSI reference model; for example, "physical-layer specification" expresses the wireless interface specification concerning bit propagation.

*34 **Half-duplex operation:** A method of alternating signal sending and receiving using the same carrier frequency and frequency band.

*35 **STC:** Configuration of transmission cycle, timing, and other aspects of IAB-DU SSB (See *37) notifications sent to IAB nodes by the network.

*36 **SMTC:** Configuration of transmission cycle, timing and other aspects of SSB (See *37) that the network sends to UE and UE use for measurements.

*37 **SSB:** Synchronization signal for detecting cell frequencies and timing required for communication and broadcast channel notifying of main radio parameters. Sent periodically by base stations.

2) Random Access CHannel (RACH)*38 Enhancements

As with SSB transmission and reception, when half-duplex communication for IAB-MT and IAB-DU is required, IAB-MT RACH transmit occasions must be configured at different times than IAB-DU RACH receive occasions. As shown in **Figure 6**, the timing for IAB-MT RACH transmission can be configured to be offset*39 from the UE transmission in units of frames*40, slots*41, or subframes*42.

3) IAB Node Radio Resource Management

Efficient radio resource management for IAB-MT and IAB-DU has been introduced. An overview of this is shown in **Figure 7**. The CU first configures each time resource semi-statically as Hard, Soft, or Not Available (NA). Here, IAB nodes allocate resources such that IAB-DU can use resources configured as Hard and IAB-MT can use resources configured as NA. The resources configured as Soft can be switched for IAB-DU and IAB-MT dynamically, and the parent node uses the Downlink Control Information (DCI)*43 format 2_5 to dynamically indicate whether a resource can be allocated to the IAB-DU or IAB-MT.

4) IAB-MT Transmit Timing Synchronization

As shown in **Figure 8**, to synchronize IAB-DU transmission with the parent node DU, an IAB node determines IAB-DU transmission timing by correcting by the propagation delay ($T_{\mathrm{propagation}}$) from the IAB-MT reception. Here, propagation delay is derived using:

$$\left(N_{\mathrm{TA}} + N_{\mathrm{TA,\ offset}}\right) \cdot T_{\mathrm{c}}/2 + T_{\mathrm{delta}}$$

N_{TA} and $N_{\mathrm{TA,\ offset}}$ are values to determine UE transmission timing, and T_{c} is the basic NR timing unit. T_{delta} is half the time required for the parent node to switch between transmission and

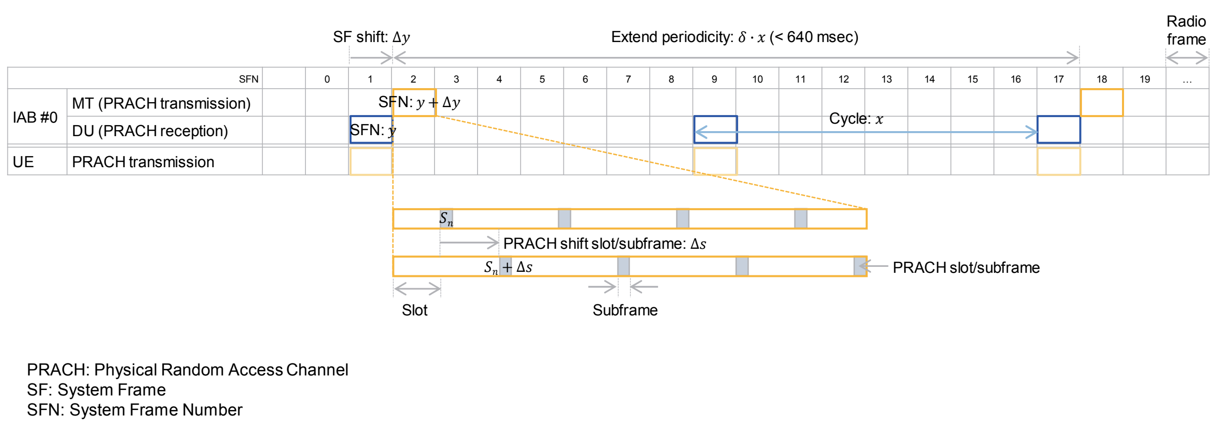

Figure 6 IAB-MT RACH transmission timing configuration example

*38 **RACH:** A physical channel used by mobile terminals as an initial transmitted signal in the random-access procedure.

*39 **Offset:** An amount of change given, to change from a reference position or time to another position or time.

*40 **Frame:** The smallest unit used for signal processing (encoding, decoding). A single radio frame is composed of multiple slots (or subframes) along the time axis, and each slot is composed of multiple symbols along the time axis.

*41 **Slot:** A unit for scheduling data consisting of multiple OFDM symbols.

*42 **Subframe:** A unit of radio resources in the time domain, consisting of multiple slots.

*43 **DCI:** Control information transmitted on the downlink that includes scheduling information needed by each user to demodulate data and information on data modulation and channel coding rate.

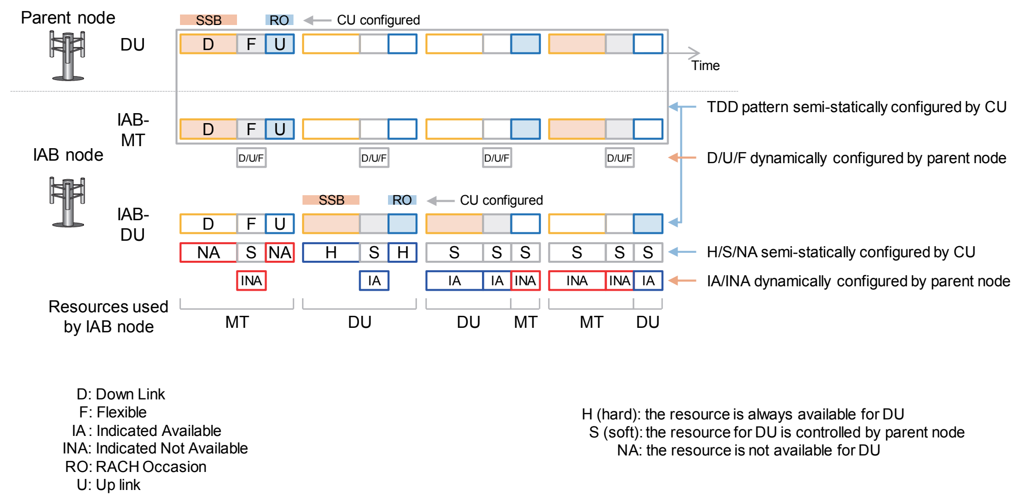

Figure 7　Overview of IAB node resource management example

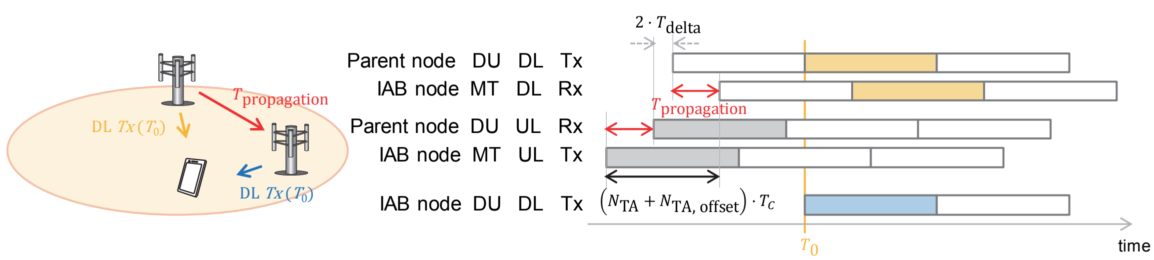

Figure 8　Overview of IAB-MT transmission timing synchronization

reception, and the IAB node indicates this value using a Medium Access Control Control Element (MACCE)*44.

4. NR-U

Utilization of unlicensed bands is attracting attention for handling the rapidly increasing traffic

*44　MACCE: A particular configuration control signal transmitted on the MAC sublayer.

on mobile communication networks, and one of the functions specified in LTE Rel-13 by the 3GPP, which was called Licensed-Assisted Access (LAA)*45, increases communication speed by bundling unlicensed bands with licensed bands. 3GPP has studied use of unlicensed bands further with 5G NR, specifying NR Unlicensed (NR-U) as a feature of NR Rel-16.

4.1 NR-U Deployment Scenarios

NR-U supports a total of five deployment scenarios using CA to transmit and receive simultaneously on multiple CC, including one similar to LTE-LAA with a PCell using licensed-band NR and SCells using NR-U. Others implement more flexible deployment using unlicensed bands, such as using LTE-NR DC with multiple base stations with a PCell using licensed band LTE and a PSCell using NR-U, and NR-U standalone*46 deployment using only unlicensed bands (**Figure 9**).

4.2 Targeted Frequency Bands and Regulation for NR-U

NR Rel-15 anticipated use of high frequency bands up to 52.6 GHz, and specifications were created for Frequency Range 1 (FR1), from 450 to 6,000 MHz, and FR2, from 24,240 to 52,600 MHz. However, the unlicensed bands anticipated for NR-U are in the 5 GHz and 6 GHz bands, so specifications for FR1 had to consider regional regulatory requirements for the unlicensed bands used, and also coexistence with Wi-Fi®*47, LTE-LAA, and NR-U, which

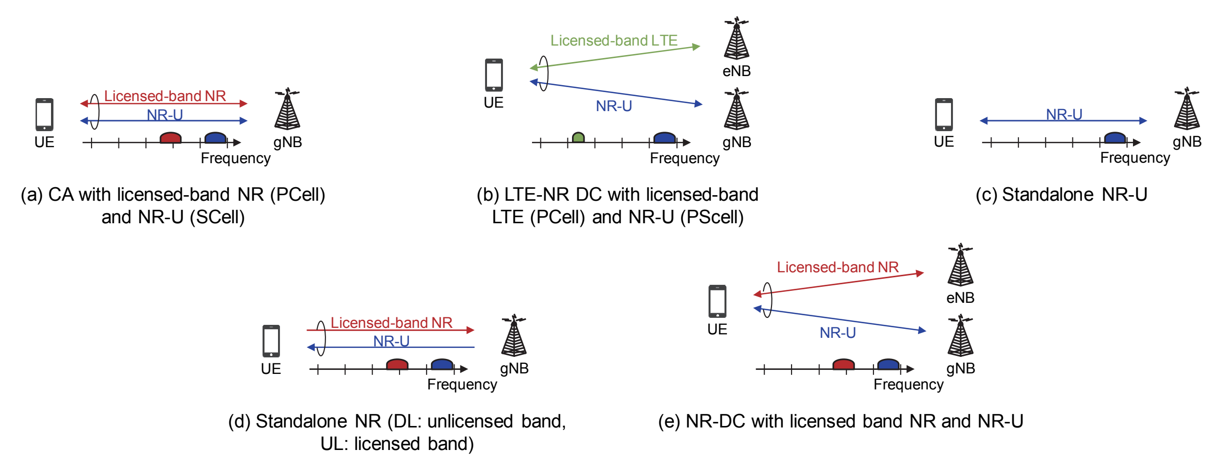

Figure 9　NR-U deployment scenarios

*45 LAA: A generic name for radio access technologies in which terminals obtain configuration information from a PCell using a licensed band, and then use an unlicensed band for radio communication.

*46 Standalone: A deployment scenario using only NR, in contrast with non-standalone operation which uses LTE-NR DC to coordinate existing LTE/LTE-Advanced and NR.

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

use the same bands.

Regional regulatory requirements include regulations such as the Listen Before Talk (LBT) mechanism used in Japan and Europe, which requires radio systems using the 5 GHz band to use carrier sensing*48 to check that other nearby systems are not using the channel before starting to transmit, and only allows them to transmit for a prescribed Maximum Channel Occupancy Time (MCOT). In Europe, the Nominal Channel Bandwidth (NCB) is always 5 MHz or greater, including guard band*49, and the Occupied Channel Bandwidth (OCB), which is the bandwidth containing 99% of the transmitted signal power, must be contained within 80 to 100% of the NCB.

4.3 NR-U Physical Layer Functions

As with LTE-LAA, Load Based Equipment (LBE) behavior is specified for the NR-U channel access method, performing LBT [5] based on random backoff*50 and variable-length Contention Window Size (CWS)*51, considering that it must coexist with other systems. To use frequencies more efficiently and simplify LBT when the absence of other systems is guaranteed by regulations regarding the same frequencies, Frame Based Equipment (FBE) behavior is also specified, which performs LBT based on a prescribed Fixed Frame Period (FFP) and fixed carrier sensing duration.

Also, since Wi-Fi and LTE-LAA are based on a 20 MHz bandwidth, and a single NR CC supports bandwidths greater than 20 MHz, enhancements were also made to wide-band operation, considering issues of coexistence with these other technologies, as well as initial access, uplink and downlink physical signals and channels, and HARQ operation, considering issues such as LBT and OCB regulation as described above (**Table 1**).

5. MR-DC/CA Technology Enhancements

Basic MR-DC/CA functionality was specified in Rel-15, but there were still issues, such as the time required to set up MR-DC/CA or to recover from radio link failures, and the narrow uplink coverage. Rel-16 made technical enhancements to set up and recover MR-DC/CA more-rapidly and to expand uplink coverage.

5.1 Highly-efficient, Low-latency MR-DC Set-up and Recovery

The following two functions were added in Rel-16 for more efficient, lower-latency MR-DC set up and recovery.

(a) Fast MR-DC recovery from a RRC_INACTIVE*52 state

In Rel-15, the RRC_INACTIVE UE state was introduced in addition to the RRC_IDLE*53 and RRC_CONNECTED*54 states, but when transitioning from RRC_CONNECTED to RRC_INACTIVE, the MR-DC configuration was not stored. Because of this, when returning to RRC_CONNECTED from RR_INACTIVE, MR-DC set-up was necessary, increasing the time required for MR-DC recovery.

In Rel-16, a new MR-DC was enhanced, adding a recovery method in which the UE

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

*49 Guard band: A frequency band set between the bands allocated to different wireless systems to prevent interference between the RF signals of those systems.

*50 Random backoff: A technology to avoid collision of multiple simultaneous transmissions that uses periods of random length in which it must check that the carrier frequency is not in use before transmitting.

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

*52 RRC_INACTIVE: A UE 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.

*53 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.

Table 1 Main functional enhancements to NR-U

Function category	Function enhancement details	Reason for function enhancement
Wide-band operation	Whether PDSCH/PUSCH can be received/transmitted based on LBT success or failure on multiple LBT bands (20 MHz)	Coexistence with Wi-Fi and LTE-LAA
Initial access	Multiple SSB transmission candidate positions	Early transmission when LBT succeeds
	Long sequence PRACH preamble	Satisfy OCB requirements
Downlink signal/channel	3 - 13 symbol PDSCH	Early transmission when LBT succeeds
	Search space switching inside and outside COT	Reduce power consumption in COT
Uplink signal/channel	Interlaced PUCCH/PUSCH	Satisfy OCB requirements
	Autonomous retransmission of configured grant PUSCH	Reduce LBT failure probability
	Simultaneous scheduling of multiple PUSCHs	Reduce LBT failure probability Early transmission when LBT succeeds
HARQ operation	Cross-COT HARQ-ACK transmission	Satisfy MCOT requirements
	HARQ-ACK retransmission	Retransmission of important information when LBT fails

PUSCH: Physical Uplink Shared CHannel

will store the MR-DC configuration when transitioning to RRC_INACTIVE. If it transitions back to RRC_CONNECTED, it can use the prior MR-DC configuration to restore MR-DC more quickly, without having to wait for the configuration from the base station as described above. Specifically, after a UE with a MR-DC connection transitions from RR_CONNECTED to RR_INACTIVE, if it receives an RRC Resume message*55 from the base station with instructions to restore the Master Cell Group SCell (MCG SCell)*56 and Secondary Cell Group (SCG)*57 configurations, it can restore the saved Packet Data Convergence Protocol (PDCP)*58, Service Data Adaptation Protocol (SDAP)*59, MCG SCell, and SCG settings. This enhancement enables UE to rapidly restore a MR-DC connection when transitioning from RRC_INACTIVE to RRC_CONNECTED.

(b) Fast MR-DC set-up

Rel-15 specified the following procedure for setting up MR-DC.

(1) Connect with Master Node (MN)*60 (Transition to RRC_CONNECTED state)
(2) Measure quality in neighboring cells and report the results to the MN.
(3) Receive commands to add Secondary Nodes (SN)*61 through the MN and connect with them.

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*54 RRC_CONNECTED: A UE RRC state in which the UE is connected to the base station.

*55 RRC Resume message: An RRC message for returning a UE from RRC_INACTIVE to RRC_CONNECTED.

*56 MCG SCell: A secondary cell in a cell group under the MN (See *60).

*57 SCG: A cell group under the SN (See *61).

*58 PDCP: A sublayer of Layer 2. A protocol that performs ciphering, integrity check, reordering, header compression, etc.

*59 SDAP: A sublayer of Layer 2. A protocol that performs mapping between QoS flows and radio bearers.

*60 MN: In DC, a base station that establishes an RRC connection with the UE. In LTE-NR DC, this would be an LTE base station (eNB).

*61 SN: On a UE performing DC, the base station providing radio resources to the UE in addition to the MN radio resources. With LTE-NR DC, the SN is an NR base station (gNB).

In this procedure, the UE measures quality in neighboring cells only after transitioning to RRC_CONNECTED, so more time after entering RRC_CONNECTED is needed to set up MR-DC.

In Rel-16 technical enhancements to MR-DC include a function in which UE also perform quality measurements in the RRC_IDLE and RRC_INACTIVE states. Then, when transitioning to RRC_CONNECTED, they can quickly report quality values for neighboring cells to the base station. This has resulted in significant reductions in MR-DC set-up latency, compared to the Rel-15 setup procedure described above. More specifically, the base station uses broadcast information*62 and the RRC Release message*63 to notify the UE of prior quality measurement settings, enabling cell quality measurements to be done also in the RRC_IDLE and RRC_INACTIVE states.

5.2 Fast NR SCell Activation during CA

In Rel-15, the basic specifications for MR-DC and NR standalone were made, and the Rel-15 specifications for MR-DC and CA were further enhanced in Rel-16. One enhancement about the necessity to reduce delay to activate a SCell was discussed.

Conventionally, after adding a SCell, when the SCell was not used for a certain period of time, the SCell would transition into a deactivated state, and UE would reduce power consumption by not monitoring the PDCCH and other measures. To communicate using the SCell again, the UE had to measure the Channel State Information (CSI)*64, and perform Automatic Gain Control (AGC)*65 and beam management to transition back to an activated state. Thus, tens of milliseconds were required before it could transition to an activated state. On the other hand, the bandwidth for an NR SCell is wider than for LTE, and can provide high throughput immediately after it is available, so any delay transitioning the NR SCell to be activated and usable will affect throughput, and there was concern that effect could be relatively large compared with LTE.

For these reasons, specifications were added in Rel-16 defining a new dormant state in addition to the activated and deactivated states, in which PDCCH monitoring is suspended, but unlike the deactivated state, CSI measurements and other preparation required for transition back to an activated state are maintained. This enables the connection to return to the activated state (a non-dormant state) quickly. A feature of the NR dormant state is that the dormant state can be set for each BWP in the system bandwidth (dormant BWP). This enables Layer 1 control utilizing functionality of existing BWP. By controlling transitions of dormant BWP in Layer 1, the delay can be reduced compared to delay by controlling in Layer 2, and keeping BWP in the dormant state for longer time helps to reduce UE power consumption.

5.3 Fast MCG Link Recovery

With Rel-15 MR-DC, if a PCell experienced Radio Link Failure (RLF), even if the SCG quality

*62 Broadcast information: Various types of information broadcast simultaneously to each cell, such as the location code required for judging whether location registration is needed for a mobile terminal, information on surrounding cells and radio wave quality required for services in those cells, and information for restricting and controlling outgoing calls.

*63 RRC Release message: An RRC message to transition a UE from the RRC_CONNECTED state to the RRC_IDLE state.

*64 CSI: Information describing the state of the radio channel traversed by the received signal.

*65 AGC: Control which maintains the output at a fixed level independent of the level of the received input signal.

was normal, the UE would have to reestablish the RRC. Rel-16 specifies a technical enhancement to MR-DC, with a mechanism that avoids having to reconnect when there is a RLF on the MCG if quality on the SCG is good, by reconfiguring the MCG using the SCG. Specifically, the UE is able to report the MCG link failure information (including report of neighboring cell quality measurements) to the SN using a split Signaling Radio Bearer 1 (split SRB 1)*66 or SRB3*67, as shown in **Figure 10**. The SN, having received the report of MCG link failure, forwards the relevant information to the MN, and the MN returns a radio resource*68 reconfiguration (RRC) message including a new MCG configuration to the SN. The SN forwards the RRC reconfiguration message to the UE and the UE is able to restore the MR-DC state more quickly than reestablish the RRC.

5.4 NR-DC Power Sharing

Uplink power sharing for NR-DC*69 was specified in Rel-15, basically to set the maximum transmission power semi-statically for each Cell Group (CG)*70. For NR-DC uplink power sharing, Rel-16 specified the following two items to increase the uplink coverage during NR-DC and to achieve higher throughput.

(a) Mode 2 configuration

In addition to the configuration defined in Rel-15 (Mode 1), a Mode 2 configuration was specified, which uses maximum transmission power for each CG when MCG and SCG transmission slots overlap, and when they do not, only consider the NR-DC maximum

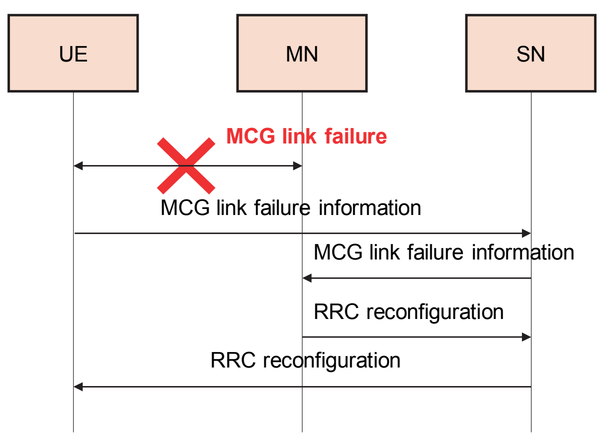

Figure 10 Fast MCG link recovery

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*66 Split SRB1: A bearer for duplicating RRC messages generated by MN for UE performing MR-DC, and transmitting them via SN.

*67 SRB3: A bearer for the SN to send RRC messages directly to a UE performing MR-DC.

*68 Radio resource: General term for radiocommunication resources (radio transmission power, allocated frequency, etc.).

*69 NR-DC: A technology that achieves high-speed transmission by connecting the MN and SN to two NR base stations, and transmitting and receiving on multiple carriers supported by these base stations simultaneously.

*70 CG: Refers to a cell group under a base station. MCG if it is under the MN and SCG if under the SN.

transmission power value*71, and do not consider the maximum transmission power for each CG.

(b) Dynamic power sharing function

Rel-16 NR-DC also supports a dynamic power sharing function. Specifically, when the MCG and SCG transmission slots overlap and the total transmission power for MCG and SCG exceeds the maximum NR-DC transmission power, the UE dynamically reduces the power of the SCG transmission slot, adjusting so the maximum NR-DC power is not exceeded. If the MCG and SCG transmission slots do not overlap, it only considers the maximum NR-DC transmission power value.

A method is also specified for NR-DC dynamic power sharing, in which the UE anticipates MCG transmission when dynamically adjusting SCG transmission power. Specifically, at a prescribed offset time (T_{offset}) before transmission, it predicts whether transmission will overlap with the MCG transmission scheduled on the PDCCH. If it will overlap, it dynamically adjusts SCG transmission power based on $min\,(\hat{P}_{\mathrm{SCG}},\ \hat{P}_{\mathrm{Total}}^{\mathrm{NR-DC}} - \hat{P}_{\mathrm{MCG}}^{\mathrm{actual}})$, the lesser of the maximum SCG transmission power and the result of subtracting the actual MCG transmission power from the NR-DC maximum transmission power. Here, $\hat{P}_{\mathrm{SCG}}$ is the maximum SCG transmission power linear value, $\hat{P}_{\mathrm{Total}}^{\mathrm{NR-DC}}$ is the maximum NR-DC transmission power linear value, and $\hat{P}_{\mathrm{MCG}}^{\mathrm{actual}}$ is the actual MCG transmission power linear value. When there is no overlap, or when there is no MCG transmission, the SCG transmission is limited to the maximum NR-DC transmission power.

5.5 Asynchronous CA Support

The Rel-15 CA specifications were created with the assumption that SCells and frame boundaries are synchronized with PCells and PSCells at the slot level. On the other hand, considering issues such as clock performance, and particularly when FR1 and FR2 cells are combined in the same CG, it is extremely difficult to synchronize all PCells and PSCells with SCells.

For this reason, Rel-16 also specifies CA with SCells and frame boundaries that are asynchronous with PCells and PSCells at the slot level. In particular, the UE is able to adjust SCell frame boundaries according to the difference in timing between PCell or PSCell and SCell configured from the network, in slot units.

In Rel-15, when the FR2 band was used in asynchronous CA with MR-DC, it was not possible to compute the FR2 measurement gap*72 timing based on a FR1 PCell or PSCell, so it was not clear which Serving Cell*73 the computation was associated with.

In Rel-16, it is possible for the UE to set a Serving Cell index configured from the network for the timing reference when computing the FR2 measurement gap, and the FR2 measurement gap timing can be associated with the Serving Cell.

6. Conclusion

This article has described the main functionality

*71 NR-DC Maximum transmission power value: The maximum transmission power value when performing NR-DC, for quasi-static power sharing, computed as $P_{\mathrm{Total}}^{\mathrm{NR-DC}} = \mathrm{MIN}\ \{P_{\mathrm{EMAX},\ \mathrm{NR-DC}},\ P_{\mathrm{PowerClass}}\} + 0.3\mathrm{dB}$. For dynamic power sharing, $P_{\mathrm{Total}}^{\mathrm{NR-DC}} = \mathrm{MIN}\{P_{\mathrm{EMAX},\ \mathrm{NR-DC}},\ P_{\mathrm{PowerClass}}\}$. $P_{\mathrm{EMAX},\ \mathrm{NR-DC}}$ is set to the *p*-UE-FR1 value (maximum power output by the UE on FR1 (frequency range of 450-6,000 MHz)) by the network. $P_{\mathrm{PowerClass}}$ is the maximum UE power output without considering allowable deviation.

*72 Measurement gap: A segment established for measuring frequencies besides those being used for communication.

*73 Serving Cell: Refers to the PCell and SCells when a UE is configured for CA, and just the PCell when not configured for CA.

specified to increase speed and capacity in the Rel-16 NR specifications. These and other Rel-16 NR functions will be used to increase the speed and capacity of 5G NR communications. NTT DOCOMO will continue to promote standardization activities at the 3GPP to further develop and expand deployment of 5G technologies.

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