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Business Creation in the 5G Era

General Manager of 5G & IoT Business Department
Hisakazu Tsuboya

The year 2020 saw the launch of fifth-generation mobile communications system (5G) services by many carriers in the global market. Today, with already about 80 5G networks in operation in more than 30 countries, the unprecedented speed of 5G deployment reflects the expectations generated by 5G. In the standardization stage, 5G came to be called an "enabling technology" that, instead of being limited to the mass market, could be extended to the business sector as in B2B2X (Business to Business to X). In addition to features such as low latency and large-capacity transmission in the radio section as frequently publicized in the media, 5G is being strongly identified as a design concept clearly different from past mobile networks. For example, 5G enables greater virtualization of the network and allows for edge computing*1. Through contributions made during the standardization process, 5G has rightfully come to reflect the intentions of not just carriers and communications equipment vendors but also of new players such as cloud operators. From a position in charge of business in the 5G era, I must work to provide competitive businesses quickly with a clear understanding of this background—it's not simply a matter of understanding 5G deployment from a technical standpoint. This viewpoint will become all the more important from here on with ongoing 5G enhancements and the coming of the sixth-generation mobile communications system (6G).

The three elements of business success, which have also been true in past migrations of the mobile network to a new generation, are "technical evolution of the communications platform," "complementary technologies that can leverage the full potential of that evolution and tie-ups with partners having those technologies," and "provision of services that naturally satisfy companies and individual customers as beneficiaries so that newly created services coincide with market preferences." At NTT DOCOMO, we have been on the front line contributing to a range of activities from basic studies to practical development toward 5G. In particular, we quickly set up the DOCOMO 5G Open Partner Program to promote service development in collaboration with many partner companies. The 22 solutions announced simultaneously with the commercial launch of 5G on March 25, 2020 combine elemental technologies such as high-definition image processing, AI analysis, and eXtended Reality (XR) that can leverage the full potential of 5G. These solutions strongly reflect the 5G business features at launch time. As a business team, we have been proposing these solutions to different industries and engaging closely with various business sectors. In addition, we have been offering potential customers the chance to experience for themselves the new value offered by these solutions while continuing to develop customer-pleasing products.

At the same time, the ICT business environment is now extending into more advanced fields. The expanded business of cloud operators that I mentioned earlier combines the evolution and pace of the communications platform up to now, and it is believed that business in the 5G era will shift to a more diverse competitive environment reflected by keywords such as "cyber-physical fusion" and "Digital Transformation (DX)*2." In the face of these changes, NTT DOCOMO as a corporate enterprise will collaborate with partners to promote IoT businesses that have grown under 3G/LTE and a DX based on structured data generated by those processes. Additionally, going forward, we will promote high-definition image/video transmission technologies expected to grow considerably under 5G and an integrated DX that adds unstructured data generated by those technologies.

Finally, the fact that the commercial launch of 5G occurred at the same time as the COVID-19 pandemic will probably be discussed in various forms for years to come. The spread of this novel coronavirus presented social problems beyond our expectations resulting in new modes of living described by words such as "remote" and "dispersed." In past migrations to the next-generation mobile network, there has always been somewhat of a time lag in the appearance of related technologies and creation of new businesses. This time, however, there is a strong feeling that new services will be created at amazingly high speeds in sharp contrast to past trends. I too am more proactive than ever and look forward to the challenge of making timely and relevant business proposals.

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*1 Edge computing: Technology that distributes edge servers near users to shorten transmission distance and reduce latency.

*2 DX: The changes that digital technology causes or influences in all aspects of human life.

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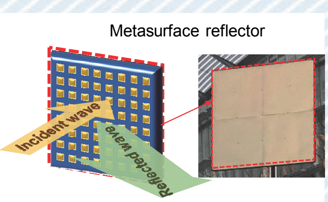

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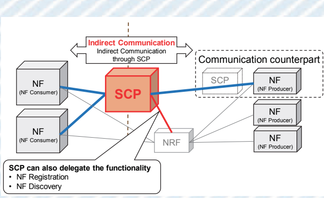

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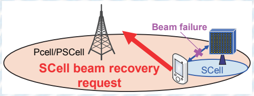

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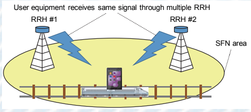

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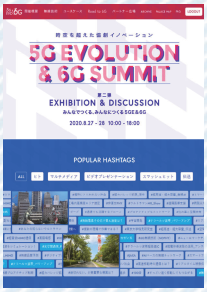

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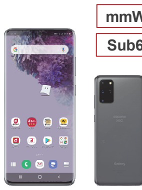
	High-spec model	High-spec model	High-spec model	High-spec model	High-spec model	High-spec model	High-spec model
Image	Sub6 	Sub6 	Sub6 	Sub6 	mmW Sub6 	mmW Sub6 	mmW Sub6 
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Special Articles on 5G (2)—NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

Mobile Terminals for 5G Communications

Communication Device Development Department Yusaku Inoue Yuta Oguma
Satoshi Tarouda
Product Department Tetsuya Inagaki Young-Cheol Yu
Naoya Sato

The introduction of 5G will enable more comfortable communications on mobile terminals thanks to its high speed, large capacity and low latency. Meanwhile, due to the expected future increases in traffic volume and the need for further improvement in throughput, NTT DOCOMO has been studying EN-DC, which combines the new 5G frequency bands with the existing 4G frequency bands. In this article, to handle the new 5G frequencies, we describe an overview of the newly developed mobile terminals, RF configurations, standardized test methods, heat countermeasures, and NTT DOCOMO's future mobile terminal development initiatives.

1. Introduction

In April 2019, the Ministry of Internal Affairs and Communications announced the allocation of new frequencies for the 5th generation mobile communications system (5G), and newly allocated frequencies in the 3.7 GHz band (3.6 to 3.7 GHz), the 4.5 GHz band (4.5 to 4.6 GHz) and the 28 GHz band

(27.4 to 27.8 GHz) to NTT DOCOMO. NTT DOCOMO launched communications services capable of up to 3.4 Gbps downlink in March 2020 and up to 4.1 Gbps downlink in September of the same year, using Evolved Universal Terrestrial Radio Access Network New Radio Dual Connectivity (EN-DC)*1, which combines the new 5G frequency bands with the existing 4G frequency bands.

In this article, with the introduction of the new 5G frequency bands, we describe NTT DOCOMO's technological development efforts to contribute to 3GPP formulation of standard specifications, the Radio Frequency (RF)*2 configuration that realizes the EN-DC combination of the new 5G and existing 4G frequency bands, and describe the standard test method for the new 28 GHz band introduced in 5G. In addition, we describe heat countermeasures to enable users to use mobile terminals safely and securely, since increases in mobile terminal power consumption is accompanied by increased heat generation.

2. Features of 5G Devices

There are a wide variety of 5G mobile devices. These include data communication devices and communication modules such as smartphones, mobile Wi-Fi routers, and Customer Premises Equipment (CPE) like indoor routers. These 5G-enabled devices have evolved from LTE, and offer real-time, more realistic user experiences through high speed, large capacity, low latency, and multi-terminal connections.

With the aim of popularizing new experiences, NTT DOCOMO is providing a total of seven 5G-enabled devices during the introduction phase of 5G services - four Sub6*3 + LTE-enabled smartphones, two millimeter Wave (mmW)*4 + Sub6 + LTE-enabled smartphones, and one Wi-Fi router (**Figure 1**). All new high-spec smartphone models in spring-summer 2020 are 5G-enabled, with throughput of up to 3.4 Gbps downlink and 182 Mbps uplink with Sub6-enabled models, and up to 4.1 Gbps downlink

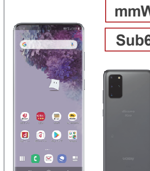
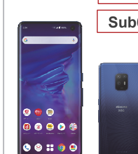
	AQUOS R5G	Galaxy S20 5G	LG V60 ThinQ 5G	Xperia 1II	Galaxy S20+5G	arrows5G	Wi-Fi STATION (SH)
	High-spec model	High-spec model	High-spec model	High-spec model	High-spec model	High-spec model	High-spec model
Image	Sub6 	Sub6 	Sub6 	Sub6 	mmW Sub6 	mmW Sub6 	mmW Sub6 
Release Date	March 25, 2020	March 25, 2020	May 11, 2020	June 18, 2020	June 18, 2020	July 30, 2020	June 1, 2020

Figure 1 New 5G-enabled devices in spring-summer 2020

*1 EN-DC: An architecture for 5G NSA operations, using 5G as another radio resource in addition to the RRC connection over 4G radio.

*2 RF: The radio frequency circuit.

*3 Sub6: A division of the frequency band. A radio signal with a frequency between 3.6 GHz and 6 GHz.

*4 mmW: A division of the frequency band. A radio signal with a frequency between 30 GHz and 300 GHz.

and 480 Mbps uplink with mmW-enabled models. In addition, device specifications, which show the remarkable evolution of underlying technologies, include display: Organic Light Emitting Diode (OLED) mainstream, ultra-thin bezel; battery: larger capacity; camera: multi-lens, Artificial Intelligence (AI) utilization; Central Processing Unit (CPU)/Graphics Processing Unit (GPU): high-performance and low-power processing; memory: more than 10 GB Random Access Memory (RAM), etc.

"Evolution from LTE" and "connectivity as a hub" are two features implemented and embodied in these 5G devices.

First, with "evolution from LTE," devices have processing power, display size, battery capacity, etc. that enable use cases including improved real-time viewing of eSports, multi-angle viewing of sports games, recording/sharing 8K videos, and more.

With "connectivity as a hub," particular efforts have been made to enhance external interface functions to connect with various peripheral devices. Specifically, support for DisplayPort*5 over USB Type-C*6, connectivity with Wi-Fi 6 (IEEE 802.11ax*7) tethering, and improved end-to-end communications speeds allow users to experience 5G on connected peripheral devices.

3. Terminal Radio Unit Configuration for 5G Communications

3.1 Handling Frequencies

In 3GPP standard specifications, frequency bands are generally classified into the following two frequency ranges.

- FR1 (Frequency Range 1): 450 to 6,000 MHz
- FR2 (Frequency Range 2): 24,250 to 52,600 MHz

FR1 consists of two frequency bands - a frequency band the same as an existing 4G frequency band and the new 5G frequency bands. The new frequency bands allocated for 5G in Japan are the 3.7 GHz band (n77, n78), the 4.5 GHz band (n79), and the 28 GHz band (n257). n77, n78, n79 and n257 represent the Time Division Duplex (TDD) frequency bands defined for New Radio (NR). Among them, the frequencies allocated to NTT DOCOMO are 3.6 to 3.7 GHz, 4.5 to 4.6 GHz, and 27.4 to 27.8 GHz, as shown in **Figure 2**. The domestic law for the use of an existing 4G frequency band for 5G came into force on August 27, 2020. Use of it is expected in Japan in the future.

5G methods include Stand Alone (SA)*8 and Non-Stand Alone (NSA)*9 [1], while mobile terminals in spring-summer 2020 are NSA-enabled. In NSA, EN-DC technology combining 4G and 5G frequency bands is used. As shown in **Table 1**, we developed mobile terminals equipped with an EN-DC combination of the existing 4G frequency bands and the 3.7 GHz, 4.5 GHz and 28 GHz bands. Using the 3.7 GHz band and 4.5 GHz band achieves up to 3.4 Gbps downlink and up to 182 Mbps uplink. Using the 28 GHz band achieves up to 4.1 Gbps downlink and up to 278 Mbps uplink. Uplink throughput of up to 480 Mbps is planned for the future.

3.2 Terminal Radio Unit Configuration Implementation Method

Since both the 3.7 GHz and 4.5 GHz bands were scheduled to be allocated in Japan, the coexistence

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*5 DisplayPort: A video output interface standard established by the Video Electronics Standards Association.

*6 USB Type-C: A connector standardized by the USB Implementers Forum.

*7 IEEE 802.11ax: A wireless standard defined by IEEE that utilizes the 2.4 GHz and 5 GHz bands, and supports a transfer rate of 9.6 Gbps.

*8 SA: Stand-alone format. A form of mobile communication network on which terminals connect using a single wireless technology.

*9 NSA: Non stand-alone format. A form of mobile communication network on which terminals connect via multiple radio technologies.

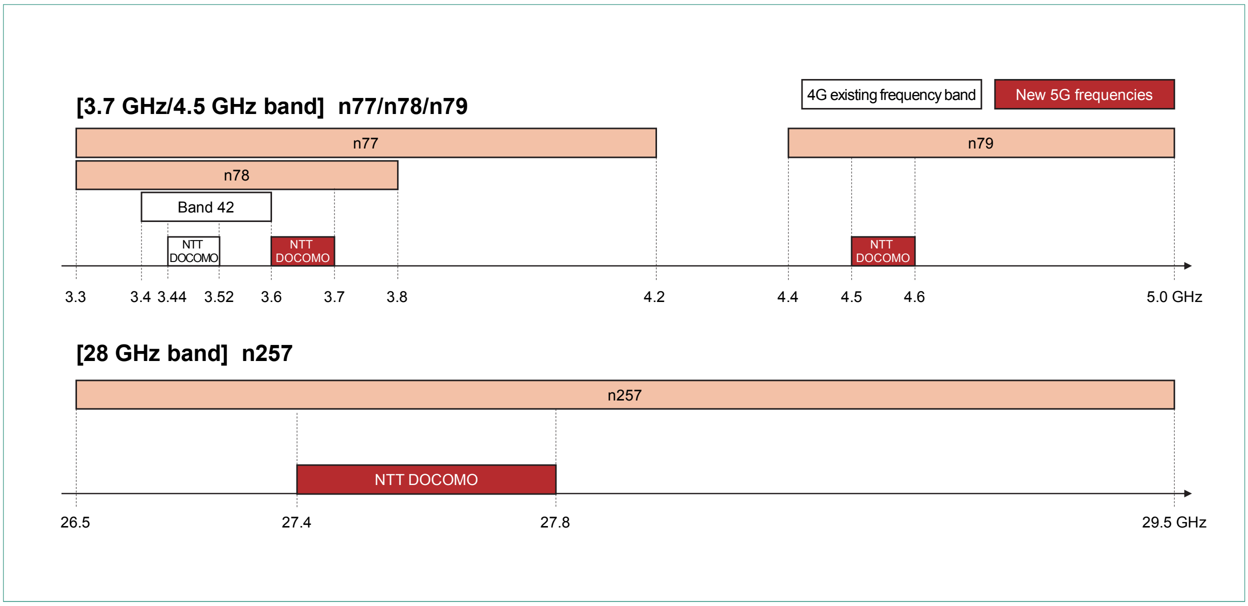

Figure 2 New 5G frequencies allocated to NTT DOCOMO

Table 1 EN-DC band combination example

EN-DC band combination	Frequency band
Band 1 + n78	2 GHz (20 MHz) + 3.7 GHz (100 MHz)
Band 1 + n79	2 GHz (20 MHz) + 4.5 GHz (100 MHz)
Band 1 + n257	2 GHz (20 MHz) + 28 GHz (400 MHz)
…	…
Band 1 + Band 3 + Band 42 + n78	2 GHz (20 MHz) + 1.7 GHz (20 MHz) + 3.5 GHz (20 MHz x 3) + 3.7 GHz (100 MHz)*1
Band 1 + Band 3 + Band 42 + n79	2 GHz (20 MHz) + 1.7 GHz (20 MHz) + 3.5 GHz (20 MHz x 3) + 4.5 GHz (100 MHz)*1
…	…
Band 1 + Band 3 + Band 42 + n257	2 GHz (20 MHz) + 1.7 GHz (20 MHz) + 3.5 GHz (20 MHz x 3) + 28 GHz (100 MHz)*2

*1 EN-DC band combination when 3.4 Gbps achieved
*2 EN-DC band combination when 4.1 Gbps achieved

of the 3.7 GHz and 4.5 GHz bands was discussed at a 3GPP Standardization Meeting. When conventional regulations for protections between frequency bands were applied to the 3.7 GHz and 4.5 GHz bands, there were concerns about reducing uplink coverage by reducing the transmission power of mobile terminals for mutual protection, or high costs related to installing expensive filters, from the perspectives of the proximity of the frequency bands, and the fact that the bands are high frequencies. For this reason, NTT DOCOMO studied the interference between the 3.7 GHz and 4.5 GHz bands with other telecommunications carriers in Japan, and examined appropriate protection regulations that would not require a decrease in transmitted power or expensive filtering, as long as there were no interference impacts. At the 3GPP Standardization Meeting, NTT DOCOMO agreed to propose the above protection regulations under a joint name of domestic telecommunications carriers to secure uplink coverage and achieve low-cost devices. As a result, it was possible to satisfy standard specifications with low-loss, low-cost LC filters*10.

A typical RF configuration for EN-DC is shown in **Figure 3**. To realize EN-DC, the two frequency bands must be separated to enable simultaneous communication. There are two methods to achieve this. One is to place a filter (demultiplexer*11) directly below the antenna to separate the multiple frequency ranges at low loss (Low band*12, Mid band*13, Ultra-high band*14 (4.5 GHz band) separation). The other is to separate the antennas at each frequency used for simultaneous communication (Ultra-high band (3.7 GHz band) separation). The technical issue when using a demultiplexer is how to suppress signal power loss due to the pass loss of the device, while the issue with separating antennas is maintaining a compact size because more area is required for antennas. Since the 3.7 GHz and 4.5 GHz bands must be equipped with four receiving antennas in standard specifications, we devised and implemented the RF configuration in light of the aforementioned issues.

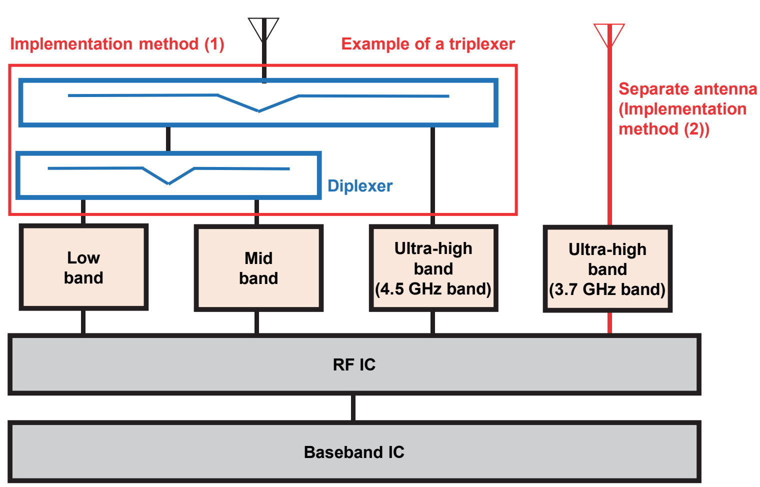

Figure 3 RF configuration example

*10 **LC filter:** A type of filter with relatively low attenuation characteristics for interference signals, but that can be implemented with low loss and low cost.

*11 **Demultiplexer:** A low-loss filter for separating multiple frequency bands. Called a "diplexer" when separating two frequency bands and a "triplexer" when separating three frequency bands. A diplexer consists of a low-pass filter (a filter that allows low frequencies to pass, but attenuates high frequencies) and a high pass filter (a filter that allows high frequencies to pass, but attenuates low frequencies).

*12 **Low band:** Band 28 (700 MHz) and Band 19 (800 MHz) among the frequencies used by NTT DOCOMO.

*13 **Mid band:** Band 21 (1.5 GHz), Band 3 (1.7 GHz) and Band 1 (2 GHz) among the frequencies used by NTT DOCOMO.

*14 **Ultra-high band:** Band 42 (3.5 GHz), Band n77/n78 (3.7 GHz) and Band n79 (4.5 GHz) among the frequencies used by NTT DOCOMO.

4. Evaluation of FR2 RF Performance of 5G Terminals

In this section, we describe the RF performance evaluation method in mobile terminals for the mmW frequency band defined by NR (FR2 frequency band in 3GPP).

4.1 Evaluation Method of FR2 RF Performance

With the integration of the transceiver and antenna in FR2, since it is not possible to measure with a connector, Over The Air (OTA)*15 provisions were introduced as RF specifications. The OTA provisions define Equivalent Isotropic Radiated Power (EIRP)*16 in the beam direction including antenna characteristics, Total Radiated Power (TRP) that specifies the total power emitted from the device, and Equivalent Isotropic Sensitivity (EIS)*17 [1]. The 3GPP standard specifications in Release 15 define three measurement systems to achieve EIRP, TRP, and EIS measurements: Direct Far Field (DFF)*18, Indirect Far Field (IFF)*19, and Near Field To Far-field (NFTF)*20. Currently, IFF measurement methods achievable with comparatively small test systems are becoming popular. The following describes the Compact Antenna Test Range (CATR), an IFF measurement technique, and a measurement system for FR2 RF performance evaluation.

Figure 4 shows a schematic of CATR. With measurement of antenna radiation characteristics such as EIRP, TRP and EIS, the distance between the Device Under Test (DUT) and the measurement antenna must be the distance to satisfy far field*21 conditions, so that the radio waves received by the DUT or the measurement antenna become

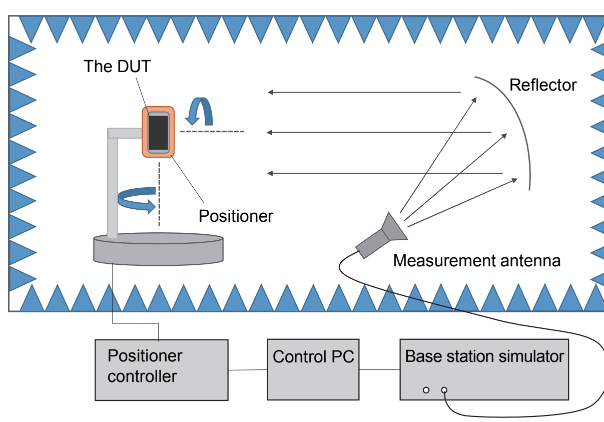

Figure 4 CART schematic

*15 OTA: A method for measuring radio characteristics transmitted or received from a base station or terminal, by positioning it opposite a measurement antenna. Equipment configurations without antenna connectors have been defined and specified in this test method for NR base stations and terminals.

*16 EIRP: The transmission power at a specified reference point in radio radiation space.

*17 EIS: The received power at a specified reference point in radio reception space.

*18 DFF: The basic measurement system in OTA measurement. The DUT and the measuring antenna are opposed each other. The distance between the DUT and the measurement antenna must fulfill far-field conditions.

*19 IFF: A pseudo far-field measurement system. A spherical wave is converted into a planar wave through a reflector on the propagation path between the DUT and the measurement antenna.

planner waves[*22]. The distance to satisfy the far field condition depends on the size of the DUT and the wavelength. Assuming the size of a typical smartphone or tablet terminal, for example, a distance of about 17 m or more would be required for the 28 GHz band, meaning a large measurement system would be required. However, converting from spherical wave to planar wave by a reflector in CATR eliminates the limitation by the far field conditions so that the measurement system can be miniaturized. This also improves transmission and reception dynamic range[*23] because the path length between the DUT and the measurement antenna is shortened, which reduces path loss.

1) EIRP Measurement Procedure

As shown in Fig. 4, the DUT is installed on the positioner and connected to the base station simulator.

After connection, the radio waves emitted from the DUT are received at the measurement antenna and the received power is measured. The EIRP is calculated by adding corrections such as propagation loss[*24] and cable loss to the measured received power. The positioner is a mechanism for rotating in the horizontal and the vertical directions on a central axis to freely control the relative direction between the DUT and the measurement antenna. This mechanism makes it possible to measure EIRP in any direction on a spherical surface centered on the DUT. Note that the spacing between measurement points on the sphere is defined as a measurement grid. In addition, unlike the TRP measurement procedure described later, the test is carried out without fixing the transmission beam direction of the mobile terminal.

2) TRP Measurement Procedure

The concept of measurement points is similar to 1). TRP is calculated based on the EIRP measured using the measurement grid. However, with TRP measurement, the mobile terminal transmission beam is fixed in the maximum transmission beam direction, and the measurement is performed with the transmission beam direction unchanged for each measurement point.

3) EIS Measurement Procedure

The basic measurement procedure is similar to 1) and measures the reception sensitivity including antenna gain[*25] at each measurement point on the spherical surface centered on the DUT. The specific reception sensitivity definition refers to received power that can achieve 95% of the maximum value as throughput on reception of signals from the measurement antenna.

4.2 5G Terminal Transmission and Reception Performance in FR2

EIRP and EIS measurements were performed on FR2-enabled 5G mobile terminals. Using the aforementioned CATR as the measurement system, peak values and spherical coverage (EIRP/EIS values satisfied by 50% of the area) were calculated from the EIRP and EIS values at each measurement point. The test was also performed with the FR2 band measured as n257, with measurements performed with both the elevation angle and the azimuth angle at 15° as the interval between measurement points.

The measured/calculated EIRP/EIS peak values and spherical coverage (@50%-tile Cumulative

*20 NFTF: In this measurement system, the DUT and the measurement antenna are opposed to each other, as in the case of DFF. However, the distance between the DUT and the measurement antenna is shorter than the distance in far-field conditions, and the obtained measurement results are converted to far-field measured values.

*21 Far field: The region where the electromagnetic field radiated from an antenna is determined only by its direction function and does not depend on the distance to the point of observation.

*22 Planar wave: An electromagnetic wave where the amplitude and phase of the electromagnetic field are constant within a plane perpendicular to the propagation direction.

*23 Dynamic range: The range of input signal that can be processed without distortion.

Distribution Function (CDF)*26) and their respective 3GPP specification values are shown in **Figure 5**. It can be confirmed that the EIRP and EIS peak values meet the 3GPP standard specifications.

5. Heat Countermeasures for 5G Terminals

5.1 User Safety

NTT DOCOMO attaches great importance to the development of mobile terminals in terms of the safety and convenience of users. Especially for the Japanese market, mobile terminals are developed with the minimum condition that they will not cause burns under any load, and are developed with the aim of not impairing merchantability while minimizing the heat that users feel during use.

5.2 NTT DOCOMO Temperature Rise Standards

As temperature rise standards that mobile terminals must satisfy, we first set a standard (1) for low temperature burns so that terminals can be used safely. We referred to ISO 13732-1 [2] for standard temperatures referred to by Mobile Computing Promotion Consortium (MCPC) [3].

Furthermore, based on user feedback about all mobile terminals sold to date, we set standards (2) and (3) so that users can use terminals comfortably (so that mobile terminals do not get hot).

(1) Temperature rise standards to prevent low temperature burns

The maximum temperature rise of parts in contact with the user is set so that low temperature bums cannot occur when the user touches the terminal surface under its highest load.

(2) Temperature rise standards for communications/calling

The maximum temperature rise when a single function related to communications and calling is running is set.

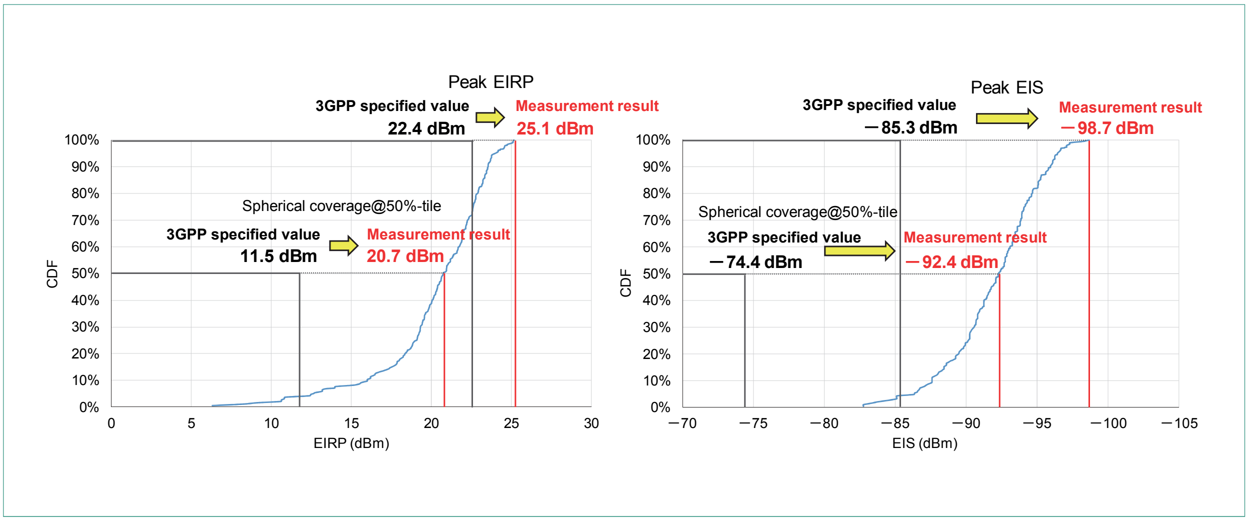

Figure 5 CDF measured value of EIRP and EIS

*24 Propagation loss: The amount of attenuation in the power of a signal emitted from a transmitting station until it arrives at a reception point.

*25 Antenna gain: A measure of the sharpness of antenna directivity usually expressed as the ratio of radiated power to that of an isotropic antenna.

*26 CDF: A function that represents the probability that a random variable will take on a value less than or equal to a certain value.

(3) Temperature rise standards for combined operations

The maximum temperature rise and rise rate under conditions of modeled usage scenarios that may be encountered by general users are set.

These standards have been mandatory for LTE-enabled mobile terminals, and have been set as a standard with 5G-enabled mobile terminal development to be followed when communicating.

5.3 5G Terminal Heat Generation

Power consumption tends to increase with 5G-enabled mobile terminals due to the many factors shown below.

- Increased number of parts to support mmW and wide frequencies
- Increased power consumption of the parts themselves due to improved communications speeds and CPU processing speeds
- Increased CPU load for applications specialized for services that greatly benefit from 5G communications, such as Augmented Reality (AR), Virtual Reality (VR) and high-quality video watching.

Increases in power consumption are accompanied by an increase in heat generation. To address this, expanding the surface area of the mobile terminal to dissipate and diffuse heat is an easy solution. However, it is not possible to endlessly enlarge 5G-enabled mobile terminals if excellent design is to be maintained.

5.4 Heat Countermeasures for 5G Terminals

To minimize heat generation while keeping the size compact, mobile terminals employ components with lower power consumption as well as advanced heat dissipation measures. In this section, we describe general and typical measures.

1) Addition of Heat Dissipating Elements (Hardware)

Heat sources in mobile terminals include CPUs, RF components for communications and power amplifiers[*27]. The structure is designed so that heat generated from these components is efficiently diffused to the surface of the mobile terminal (front, rear, frame) to dissipate it, and pastes and sheets are used as Thermal Interface Materials (TIM)[*28]. Compared to LTE-enabled mobile terminals, 5G-enabled mobile terminals utilize more heat dissipating elements.

2) Adoption of Vapor Chamber (Hardware)

Some models employ vapor chambers[*29] to more effectively diffuse heat from the aforementioned heat generation sources. The vapor chamber is a thin metal heat pipe[*30], a simple yet highly functional heat diffuser that absorbs heat from a heat source and emits it away. Heat pipes were also used in conventional LTE-enabled mobile terminals, but vapor chambers have become more widely used in 5G-enabled mobile terminals.

3) Application of Functional Limitations as Heat Control (Software)

Although these measures have been implemented, if the temperature exceeds the specified value during use, the performance of operating functions is limited to temporarily suppress the temperature rise.

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*27 Power amplifier: A component that amplifies the signal output from a communication IC, and supplies it to the antenna.

*28 TIM: A highly thermally conductive substance used to efficiently dissipate the heat generated from components.

*29 Vapor chamber: A thermal diffuser that uses a heat pipe in the form of a plate to increase the amount of heat transferred.

*30 Heat pipe: A thermal diffuser for transferring heat from a heat source to another location. Heat pipes are often constructed like metal tubes with high thermal conductivity. The interior is under reduced pressure and contains a small amount of liquid, such as pure water. As one end is overheated, the liquid evaporates and moves to the other end and returns to a liquid state, thereby transferring heat.

By implementing these measures, 5G-enabled mobile terminals satisfy the aforementioned standards. In other words, even when various functions involving 5G communications are used, users can safely use mobile terminals.

6. The Broadening of Devices in the 5G Era

Leading up to the 5G era, various services and solutions have emerged that utilize features of 5G networks such as high speed, high capacity and low latency, as well as latest technologies including XR*31, AI, and big data.

However, current smartphones have not been able to use the full potential of these technologies due to constraints such as display size and performance of cameras, sensors, etc.

Therefore, in addition to the evolution of smartphones themselves, NTT DOCOMO proposes the "My Network Concept" to create cutting-edge services and solutions with partners, by strengthening the linkages between smartphones and peripheral devices.

To provide value by linking smartphones and peripheral devices, it is important to expand peripheral devices and develop environments where various peripheral devices can be easily used to realize experiences that cannot be provided by smartphones alone. We describe "Magic Leap 1*32" below as an example of realizing these requirements.

1) Overview of Magic Leap 1

Magic Leap 1 from Magic Leap is a light-weight, wide-angle wearable headset that utilizes spatial computing*33 to provide an interactive world that combines the real with the digital. Even without a monitor, seamless digital content can be projected and manipulated in real space.

When using game content in a residential living room, it is possible to blend the world of gaming with real rooms and furniture, giving the user an unprecedented immersive and interactive experience where characters pop out of walls or walk around on tables (**Figures 6** and **7**).

Figure 6 Interactive experience image (1)

*31 XR: A generic term for AR, VR, and Mixed Reality (MR), etc.

*32 Magic Leap 1: "MAGIC LEAP", "MAGIC LEAP 1", "LIGHTWEAR", "LIGHTPACK", the Magic Leap logo, and all other trademarks are trademarks of Magic Leap, Inc.

*33 Spatial computing: Technology that recognizes real-world objects and spaces, and fuses them with digital information. This technology allows us to overcome limitations of 2D displays and enables us to interact with the digital world in the same way as the real world, by combining the worlds together.

Magic Leap 1 includes high-performance displays and nine sensors, and is composed of Lightwear (the glass part) to achieve advanced space recognition and display capabilities, a pocket-sized Lightpack (the processor part) to achieve laptop-like performance with low power consumption, and Control (the controller part) that supports Six Degrees of Freedom (6DoF)*34 **(Figure 8)**.

2) The Future Outlook

Amongst advanced users, it is common to use more than dozens of peripheral devices. On the other hand, there are many barriers to creating a world where all users can easily, safely and conveniently use peripheral devices.

Figure 7　Interactive experience image (2)

Figure 8　Magic Leap 1

*34　6DoF: Indicates the degree of freedom to move in three-dimensional space. Users can move their position forward/backward, left/right, up/down along 3 perpendicular axes, and rotate in relation to each axis. This allows users to identify their position in space, and content can be displayed in accordance with the user's movement.

For example, linking devices together requires many steps and is cumbersome. In addition, there is insufficient data to understand users in order to recommend devices or methods of use based on their hobbies, preferences, and literacy, and to help make the overall experience enjoyable.

To remove these barriers, NTT DOCOMO would like to contribute to the development of the entire industry by connecting device manufacturers with service providers, and to form a new ecosystem*35.

7. Conclusion

In this article, we described an overview of the 5G service-enabled terminals provided since March 2020, and details of efforts to realize 5G-enabled mobile terminals, such as radio component configuration and evaluation of it, and heat countermeasures.

Going forward, we will expand 5G-enabled models, enhance seamless linkage with peripheral devices, and provide advanced wireless technology so that a wider range of users can experience 5G-era terminals.

REFERENCES

[1] S. Nagata, et al.: "Technical Overview of the 3GPP Release 15 Standard," NTT DOCOMO Technical Journal, Vol. 20, No. 3, pp. 37-48, Jan. 2019.

[2] ISO13732-1: "2006 Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces -," Oct. 2006.

[3] MCPC TR-023: "Mobile Device Safety Design Guidelines Version 1.00," Mobile Computing Promotion Consortium Technical Committee, Apr. 2016 (In Japanese).

*35 Ecosystem: A symbiotic mechanism in which various businesses partner up, utilize each other's technologies and assets, and engage with society to create a series of processes from research and development through to sales, advertising and consumption.

Technology Reports (Special Articles) Consumer Services Corporate Solutions Network Customization

Special Articles on 5G (2)—NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

Services and Solutions in 5G Communications

Smart-life Planning Department Takefumi Akashi

5G & IoT Business Department Hidenori Tasaki Sungmyeong Koh

Solution Service Department Masato Yamada Kenji Takashio

Seigo Harano Syunji Soyano

Fumitoshi Yamada

In March 2020, NTT DOCOMO launched 5G services. At the time, utilizing 5G features such as high speed and large capacity, NTT DOCOMO provided seven consumer services such as "Shintaikan Live CONNECT," which enables multi-angle (multi-viewpoint) and VR live viewing, and 22 corporate solutions.

In this article, we describe 5G consumer services, corporate solutions, and the Network Customization service that supports them.

1. Introduction

When NTT DOCOMO launched its 5th Generation mobile communication system (5G) commercial services in March 2020, it leveraged 5G features such as high speed and large capacity to provide consumers with seven services, including "Shintaikan Live CONNECT," which enables multi-angle (multi-viewpoint) and Virtual Reality (VR) live viewing. In addition, for business-to-business areas, as part of efforts to create new use scenarios with a wide range of partners, NTT DOCOMO has been providing the DOCOMO 5G Open Partner Program™ since February 2018, and to date demonstrated over 300 5G usage models through co-creation with partners. In addition, at the start of services, NTT DOCOMO began providing 22 solutions, focusing on potential solutions to social issues such as industrial sophistication, urban development, and work style reform.

In this article, we describe consumer services, three solutions of the 22 corporate solutions, and the Network Customization service that supports them.

2. 5G Services

2.1 5G Consumer Services

Consumer services are designed to provide unique experiences to users through NTT DOCOMO's proactive efforts to create brand new, never-before-seen user experiences by combining elements that can be realized with 5G such as 8KVR, multi-angle viewing and XR*1. We believe that the four main areas of 5G in recent times are music and live performance, games, video, and sports, which can easily and directly reflect the characteristics of 5G. In this article, we describe the services provided by NTT DOCOMO in these four areas.

1) Music/live Performance

In the music and live performance area, we offer "Shintaikan Live CONNECT." Shintaikan Live itself has been around since before the advent of 5G, offering new online experiences for live music, such as multi-angle video distribution, AR figures*2, TIG Live*3 and comment functions, but by leveraging 5G technology, "Shintaikan Live CONNECT" has further evolved as a video distribution service. Specifically, it has evolved to become an 8K VR live service that enables real-time viewing of 360-degree VR footage captured by 8K cameras installed in live performance venues. Users can also wear VR goggles and watch via a smartphone to enjoy immersive video that feels like being in the front row of the venue. "Shintaikan Live CONNECT" continues to evolve as a service to enable artists and fans to connect, or fans to connect with each other, and enable new ways to enjoy live performance.

Next, we introduce "Heart-to-Heart Communication - BORDERLESS LIVE 5G" VR live performances by virtual artists in "Live broadcast anime, Intuition × Algorithm ♪,"a virtual idol-themed anime created by a Chinese-Japanese cooperation. Transcending limitations such as national borders, BORDERLESS LIVE 5G lets viewers enjoy live events unique to the virtual.

2) Games

High-speed, high-capacity 5G streaming technology will dramatically change the user gaming experience. What was previously enjoyed by purchasing packaged software or by downloading it online is now available in the cloud, and the big hit titles with their massive data, which were mainly played on gaming consoles in the home, can now be played easily on smartphones.

"d Game Play Tickets" provided by NTT DOCOMO lets users play large capacity, console-like games without having to download an app. With d Game Play Ticket, we plan to offer many titles of cloud-based games in the future. Here, we introduce two highly-attractive consumer game titles already offered. The first one is "DYNASTY WARRIORS 8 (Shin Sangoku Musou 8)" from Koei Tecmo Games. This popular action game set in the world of "Romance of the Three Kingdoms" is also offered in a 4K version that takes advantage of high speed and

*1 XR: A generic term for Augmented Reality (AR), VR, Mixed Reality (MR), etc.

*2 AR figure: A miniature artist that appears in 3D when the user holds a smartphone over to artist goods printed with AR markers.

*3 TIG Live: Enables transition to mail-order sites, etc. when the user touches an object in live video.

large capacity of 5G. The second one is Square Enix's Final Fantasy XV. This is the immensely popular and well-known RPG game.

In addition to the d Game Play Tickets, "Evangelion Battlefields," a smartphone game app based on the popular "Evangelion" anime has been customized for NTT DOCOMO 5G. This game enables multiple players to simultaneously match via 5G. In addition to the games introduced in this article, a variety of game titles will be provided in the future, and we will strive to improve new game experiences that make the most of 5G features.

3) Video

We believe that XR and multi-angle viewing will become the standard for 5G-era video. Here, we introduce three services provided by NTT DOCOMO for this new video viewing style.

The first is "Disney VR." Together with Walt Disney Japan, NTT DOCOMO has been offering "Disney Plus" since June 2020 and it has been well received. Now, we offer "Disney's MYTH: Anna and the Snow Queen/Hidden Myth" as the latest VR content. This is the first VR short story set in the world of Disney Animation Studio's feature film "Anna and Snow Queen 2," and is exclusively offered by NTT DOCOMO in Japan. The provision of a trial version of this VR content has commenced in 102 docomo shops across the country.

The second service is two new types of content available through d Anime Store. The first content on offer is "vertical-horizontal content" that utilizes the automatic rotation function of the smartphone screen to switch video by simply changing the orientation of the smartphone while playing back video. First on offer is music videos of a group called Tokyo Jihen when the screen is sideways, and animations produced by "Kamikaze Douga" viewable when the screen is upright. The second on offer is content that supports multi-angle viewing. The aforementioned "Shintaikan Live CONNECT" multi-angle function lets users freely view 2.5-dimensional stage works based on the highly-popular anime "Kimetsu no Yaiba" by choosing from various positions and angles. This is a new viewing style for the 5G era.

The third service is the "Hikari TV for docomo" multi-streaming function. This 5G smartphone-dedicated function enables up to seven programs to be viewed simultaneously from among the mobile-dedicated channels available on Hikari TV for docomo. Users who want to watch multiple programs simultaneously are happy with this service as it lets them watch their favorite sports matches or keep an eye out for the appearance of their favorite artists that they do not want to miss on music programs while watching other programs.

NTT DOCOMO provides these three services in the video area, and plans to continue to focus on providing new 5G-era video services.

4) Sports

In the sport area, NTT DOCOMO has taken a range of initiatives as a top partner of the Japan Professional Football League (J.League). On Sunday, September 27, 2020, we partnered with Kashima Antlers to provide a new game watching support service leveraging 5G that can be experienced at the stadium, including real-time viewing of video of the game from multiple angles not visible from one's stadium seat, replay viewing at any time, and easy visualization of stats.

From this season, NTT DOCOMO will also become a top partner of the Japanese Table Tennis

League (T.LEAGUE) and use cutting-edge technologies such as multi-angle viewing, 360-degree cameras, XR, AI highlights, and automatic stats generation to provide new viewing experiences to users by collaborating with T.LEAGUE going into the third season. In addition, while promoting joint planning of official services including digital content of player trading cards, the NTT Plala remote production functions*4 will be advanced to maximize the spectator experience such as match video and arena production viewing while achieving operational efficiency. Through these efforts, NTT DOCOMO is striving to expand the potential and value of sport.

The above introduced 5G services NTT DOCOMO provides in four areas. Nevertheless, we will further evolve our initiatives to provide new experiences to users and continue to make every effort to create new value for the era of high speed and large capacity through 5G popularization.

3. 5G-enabled Solutions

3.1 Remote Work Support Solution "AceReal® for docomo"

AceReal for docomo is a remote support and technology transfer solution for on-site workers created through collaboration between SUNCORPORATION and NTT DOCOMO. By transmitting footage of cameras mounted on AceReal to remote locations, skilled workers in remote locations can support on-site workers as if they were at the work site (**Figure 1**).

AceReal for docomo is a service that combines hardware and software. The service enables highly confidential information to be exchanged without any Internet connection through a cloud server constructed on DOCOMO Open Innovation Cloud (**Figure 2**).

At Tokyo Reiki Kogyo Co., Ltd where AceReal was implemented, work time was reduced to one-quarter when skilled workers in their offices

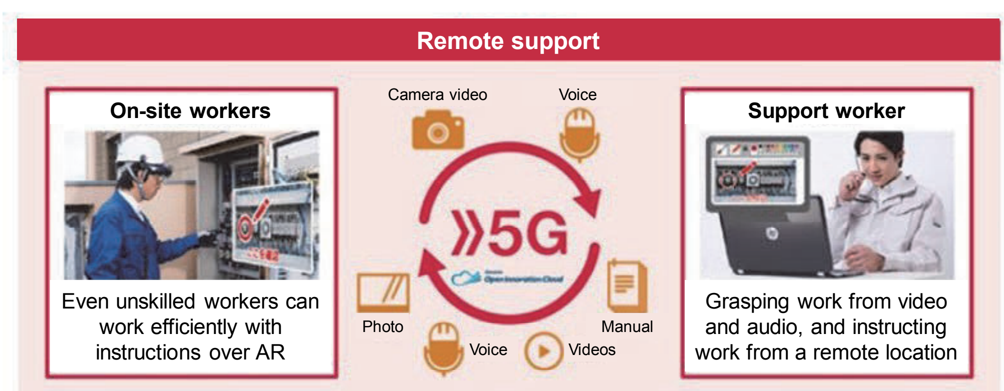

Figure 1 Remote support by AceReal for docomo

*4 Remote production functions: Consolidating production functions such as editing and video archiving in a single location reduces facilities, operations and costs at each venue.

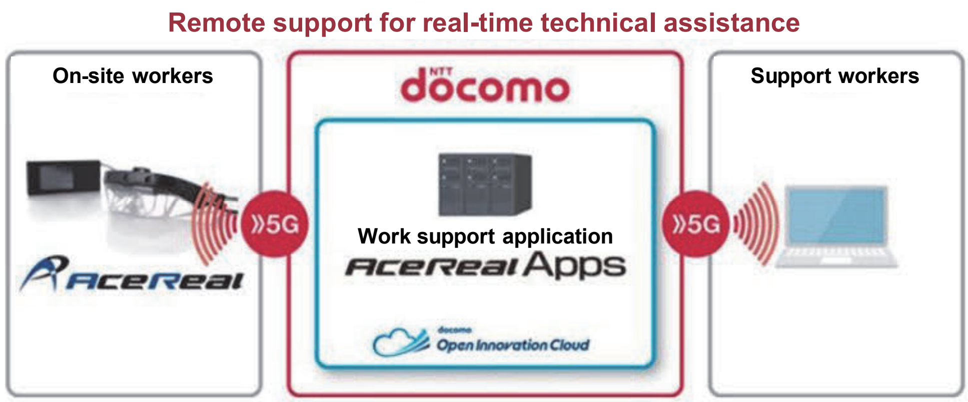

Figure 2 Structure of AceReal for docomo

provided instructions while viewing video from the site in real time and the on-site workers responded to their instructions.

Being not only for inspection and maintenance purposes, usage scenarios are expanding with inquiries from municipalities across the country about remote technology transfer, promotion of smart agriculture and support for medical professionals, etc.

3.2 Facial Authentication Entry and Exit Management Solution "EasyPass powered by SAFR"

This is a facial recognition-enabled entry and exit management solution, built in the DOCOMO Open Innovation Cloud, by combining the SAFR™ high-speed, high-precision AI facial authentication software from RealNetworks, Inc. with the highly open Security Center Synergis™ entry and exit management system from Genetec™ Inc., which enables linkage with cameras from a wide range of manufacturers.

Pointing a camera on a smartphone with a dedicated app at the faces of people entering and exiting enables real-time comparison with preregistered facial photo data to identify whether people have been approved for admission (**Figures 3** and **4**). The solution also enables attendance status management, authentication result recording and confirmation of the history of recorded authentication results, etc.

Features of EasyPass™ powered by SAFR are as follows:

- Smartphones eliminate the need for major construction and shortens the lead time to implementation.
- Facial authentication employs SAFR, the fastest and lightest of the algorithms that achieved a person rejection rate of less than 0.0335% in the WILD Face test in July 2019 conducted by the National Institute of Standards and Technology (NIST) in the United States
- Maintains high authentication accuracy even

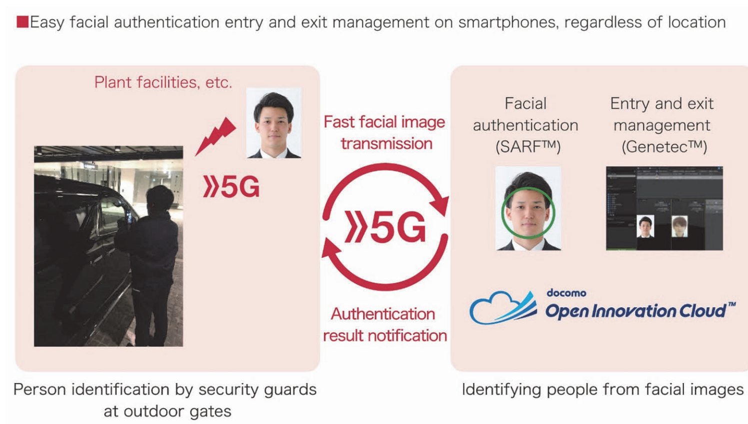

Figure 3 Solution overview

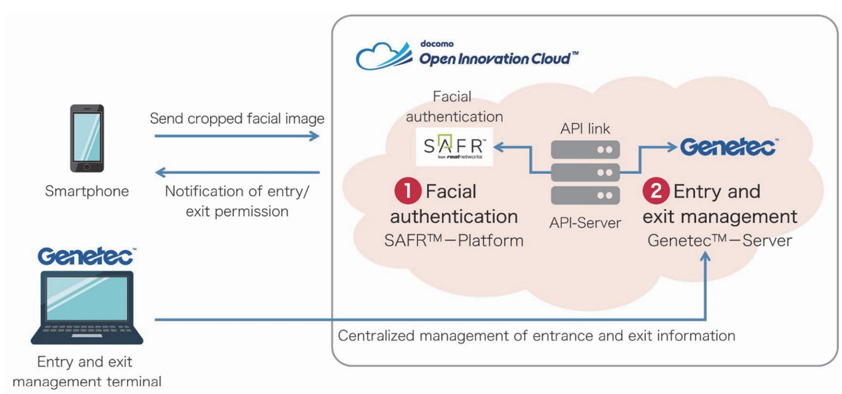

Figure 4 Overall structure

when wearing a mask*1
- High security with the Cloud Direct option available

Although entry/exits control will be presumably utilized at factories and plant entrances mainly in the manufacturing industry and secondary industries such as electricity and gas, this technology also has promise for usage in non-contact type physical security as part of novel coronavirus measures.

3.3 LiveU

LiveU is a 5G video transmission solution. Simply connecting the camera and the LiveU transmitter makes it possible to transmit video of relays, interviews, live, or sports video (**Figure 5**, **Photo 1**).

LiveU has two features.

*1 When adding optional SAFR functions.

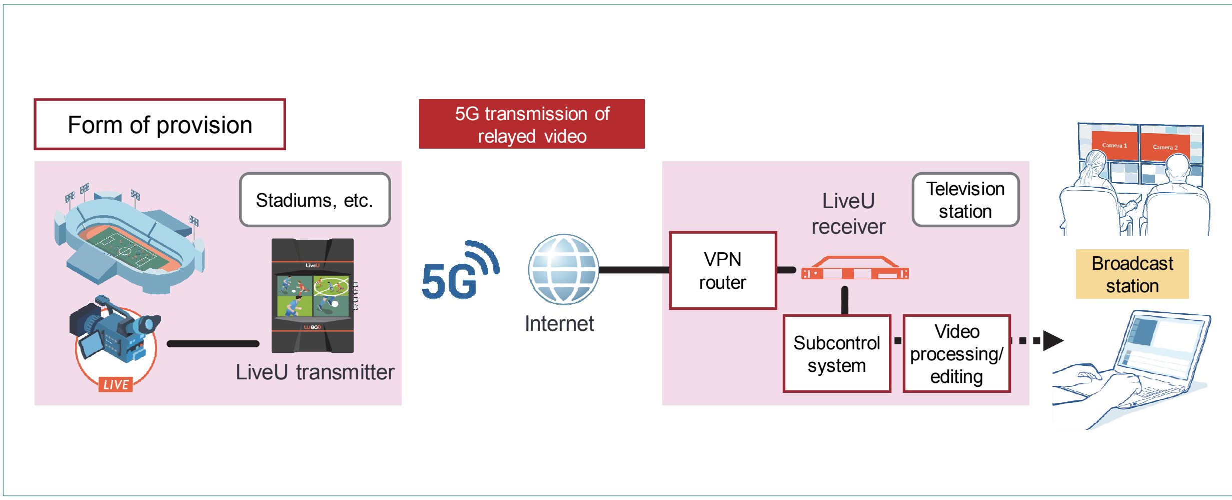

Figure 5 LiveU overview

Photo1 LiveU transmitter

The first is that it takes advantage of the high speed and large capacity of 5G to transmit 4K video. Meanwhile, patents have been acquired for bonding technology, which bundles different communication standards such as 5G, 4G, and Wi-Fi, enabling stable transmission through radio communications (**Figure 6**).

Second, it is possible to operate the LiveU transmitter in the cloud. This feature enables field personnel to focus on capturing camera video and enables relay activities with fewer relay crews (**Figure 7**).

Relay systems can be easily assembled, making them available for industries other than media.

4. docomo 5G Open Partner Program Future Initiatives

Demonstrations and trials of over 300 cases in various fields have been conducted under the docomo 5G Open Partner Program through provision of 5G information and venues for 5G experiences and testing, like docomo 5G Open Lab.

Making use of this acquired know-how and promoting business matching among partners, the aim is to expand the circle of co-creation across Japan

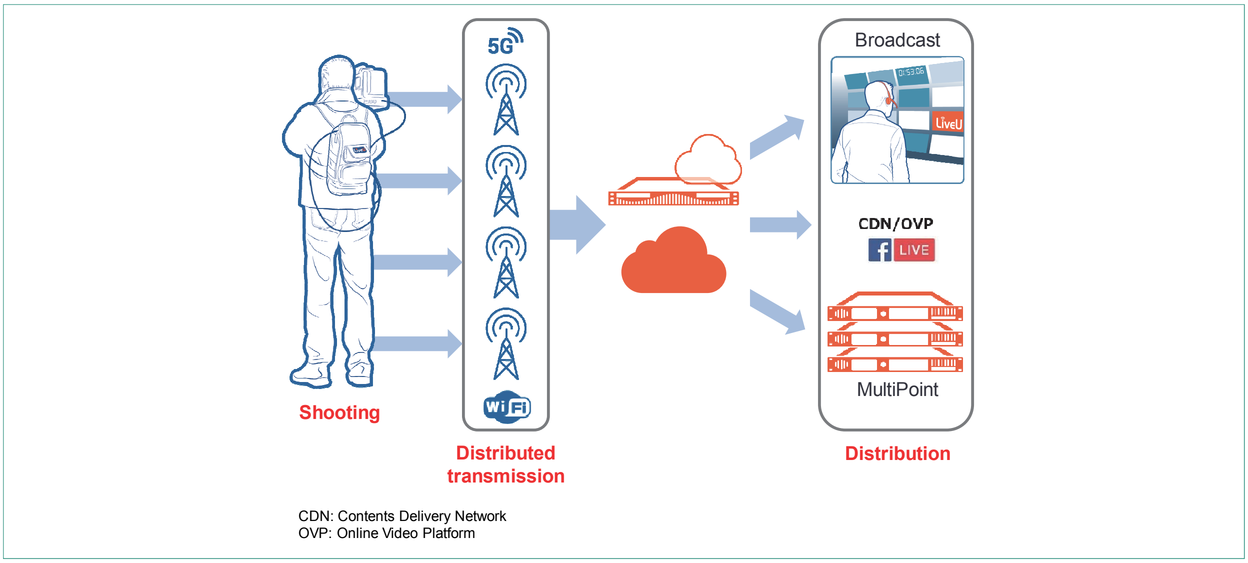

Figure 6　Distributed transmission technology

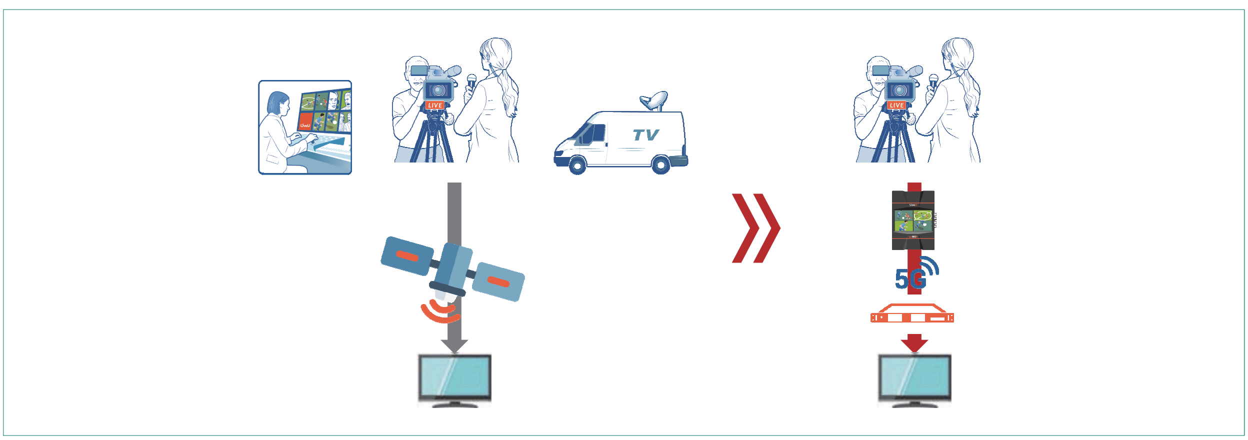

Figure 7　Reduction of photography crews and equipment

by solving social issues with municipalities and companies.

The docomo 5G DX AWARDS 2020 was also held as a business matching initiative. This award promotes the discovery of unique technologies, products and services (hereinafter referred to as "assets") owned by a wide range of companies, not only large, but also small, medium-sized and venture companies, to further accelerate initiatives to create new solutions with 5G.

With the themes of industrial sophistication, work style reform, urban development, education and health care, this award is presented for unique assets owned by companies that are reviewed and commended for the significance of their use as commercialized 5G services. We aim to put assets that won this award into service quickly through the docomo 5G Open Partner Program as collaborative solutions.

5. Network Customization

Since March 25, 2020, NTT DOCOMO has been providing Network Customization, a comprehensive consulting service for networks that supports 5G and other communication networks. Network Customization offers everything from area surveys to construction design and deployment assistance tailored to customer requirements.

The service consists of multiple network solutions and currently offers the following four menus (**Figure 8**):

(1) Wireless technology consultancy: The service accepts inquiries about issues related to overall networks and makes the best suggestions for customers, including general purpose network technologies such as LTE and Wi-Fi as well as DOCOMO 5G.

(2) Local 5G construction support: Based on its accumulated know-how, NTT DOCOMO supports customers who want to build local 5G for applications such as automated production lines aimed at eliminating labor shortages in factories, and provides support for applications to ministries, area surveys and network equipment selection through to installation.

(3) Carry 5G: Provision of portable 5G base stations to create temporary 5G areas in a short period of time for live relay from event venues, etc.

(4) DOCOMO Open Innovation Cloud: Cloud services with Multi-access Edge Computing (MEC)*5 features such as low latency and high security

Each menu is described below.

5.1 Wireless Technology Consultancy

This service accepts inquiries about issues related to overall networks and makes the best suggestions for customers, including general purpose network technologies such as LTE and Wi-Fi as well as DOCOMO 5G (**Figure 9**).

Wireless technology consultancy has two features:

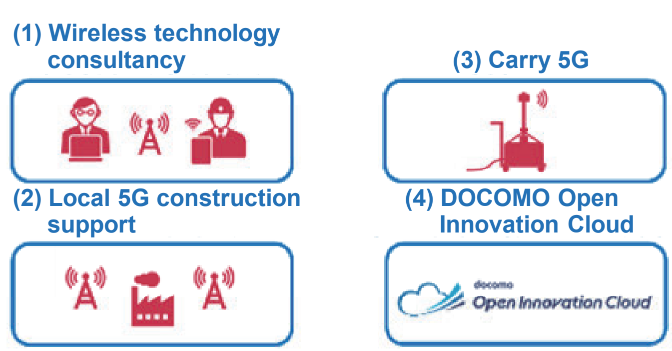

Figure 8 Network Customization 4 menus

*5 MEC: A mechanism of installing servers or storages within a carrier network, at locations near users.

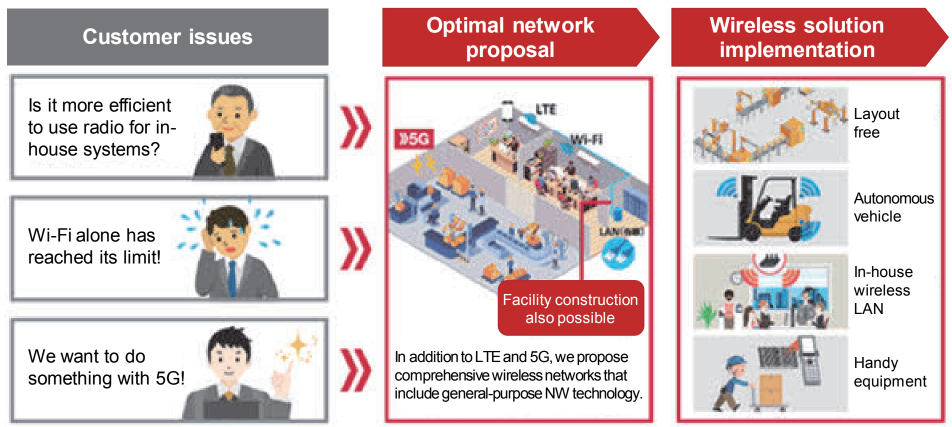

Figure 9 Wireless technology consultancy

(1) Comprehensive consultant proposals including Wi-Fi, etc.

In addition to wireless consultancy with LTE/5G utilizing NTT DOCOMO's long experience and know-how in building wireless facilities, the service also offers proposals of comparative studies with communication environments such as Wi-Fi and Low Power Wide Area (LPWA)*6.

(2) Pre-testing with 5G radio waves

This consultancy verifies the size of the 5G area by emitting 5G test radio waves in the customer environment such as the factory or office slated for installation, and also provides communications testing with customer systems to avoid the anxiety associated with 5G implementation.

5.2 Local 5G Construction Support

Local 5G is a private network isolated from the public network that offers construction of network environments with excellent independence, flexibility and stability. However, highly specialized area design and radio wave applications make it difficult for customers to build these themselves.

This support service leverages NTT DOCOMO's radio system operational know-how as a telecommunications carrier for building local 5G network for customers (**Figure 10**). The service helps customers reduce construction time, build high-quality coverage areas and optimize costs.

Local 5G construction support is broadly divided into the following three types (**Figure 11**).

(1) Consulting/design for optimal antenna placement design, and research and examination of antenna mounting methods

(2) Selection, proposal and provision of network equipment to meet customer requirements

(3) Installation of network equipment and antennas, interference adjustment, and license application

*6 LPWA: Wireless communications technology that can support a wide communications area on the kilometer level with low power consumption.

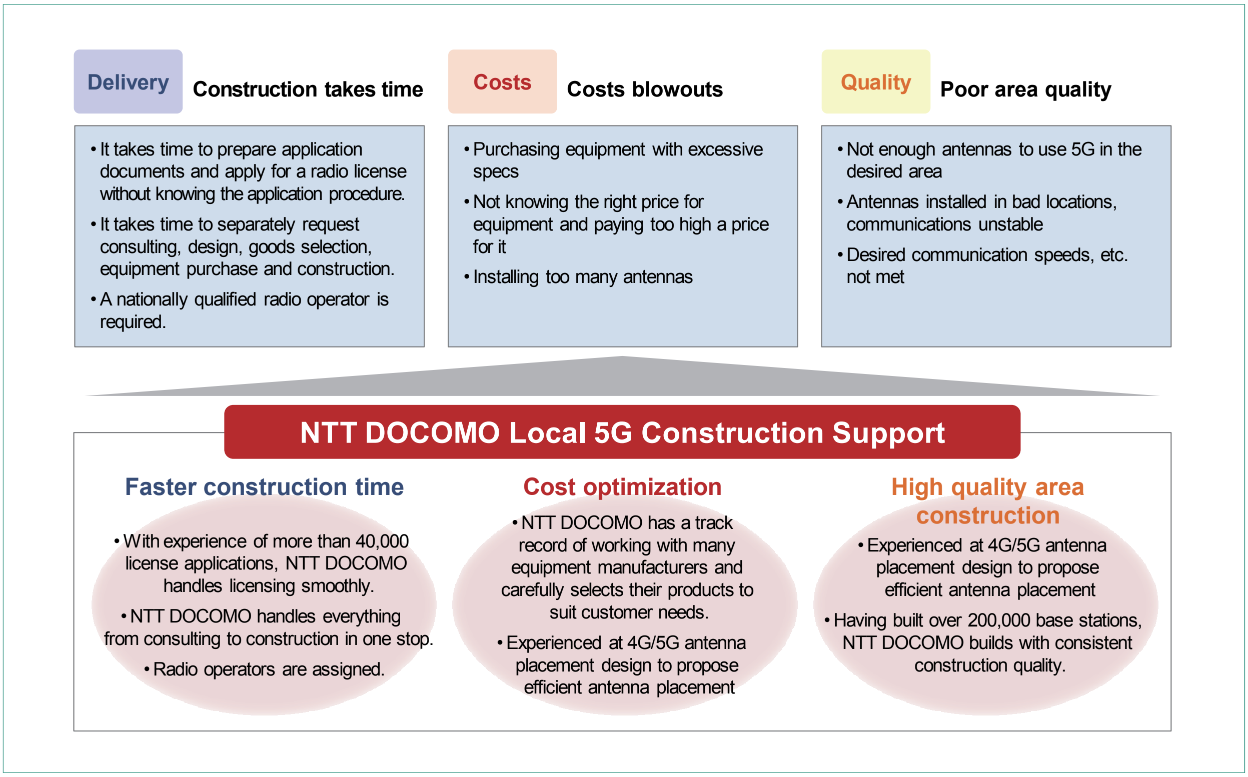

Figure 10　Challenges of local 5G construction by customers and the effectiveness of NTT DOCOMO support for local 5G construction

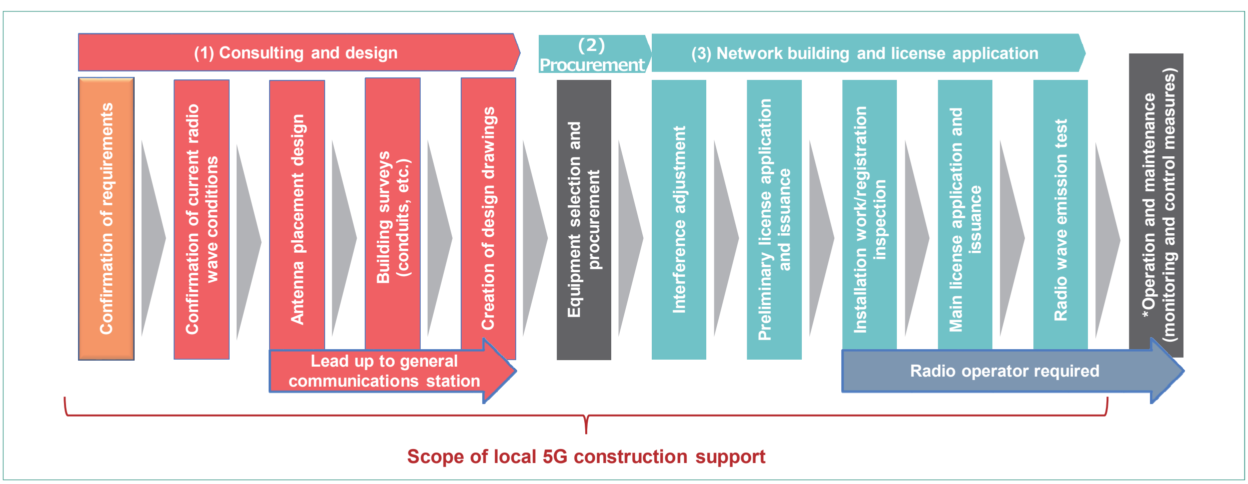

Figure 11　Contents of local 5G construction support

Partial support also available according to customer requests, such as area design support only or license application support only.

With Local 5G, only the 28.2 to 28.3 GHz frequency band has been systemized, and is separate from the bands allocated to NTT DOCOMO, although the 4.6 to 4.9 GHz and 28.3 to 29.1 GHz bands are expected to become available by the end of 2020 (**Figure 12**).

Although there are two types of local 5G configurations - NSA (Non-Stand Alone) and SA (Stand Alone) - only NSA configurations can be provided at this time (**Figure 13**). An overview of each is given below.

- NSA

  A network configuration that combines a 4G (enhanced LTE (eLTE)*7) control signal network called an "anchor" with a 5G network.

- SA

  A network configuration that does not use an anchor and only operates on a 5G network (local 5G equipment).

NTT DOCOMO 5G is currently an NSA configuration using NTT DOCOMO eLTE as the anchor. However, NTT DOCOMO eLTE cannot be provided as an anchor for local 5G at this time. Therefore, the NTT DOCOMO local 5G construction support service provides construction support for both a 5G network and a private LTE network to serve

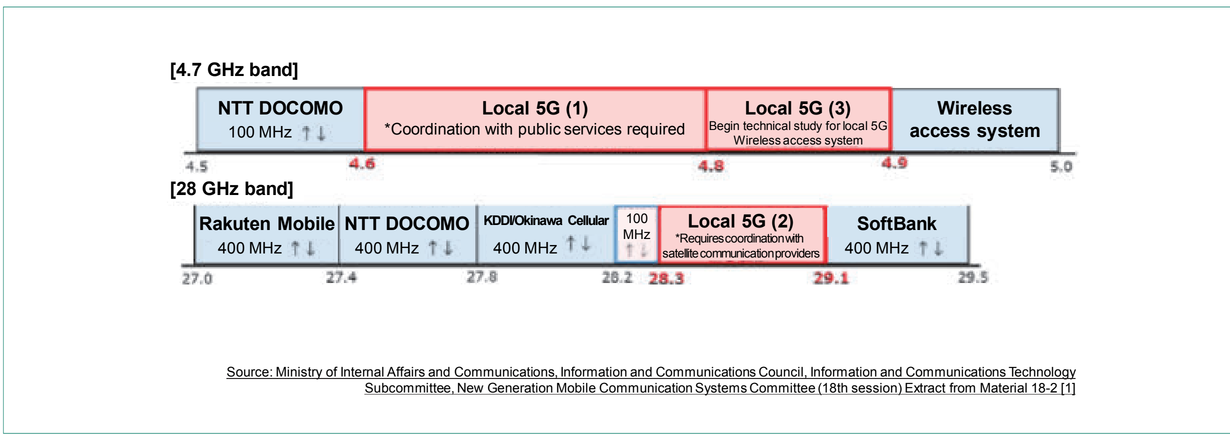

Figure 12 Frequency allocation for local 5G

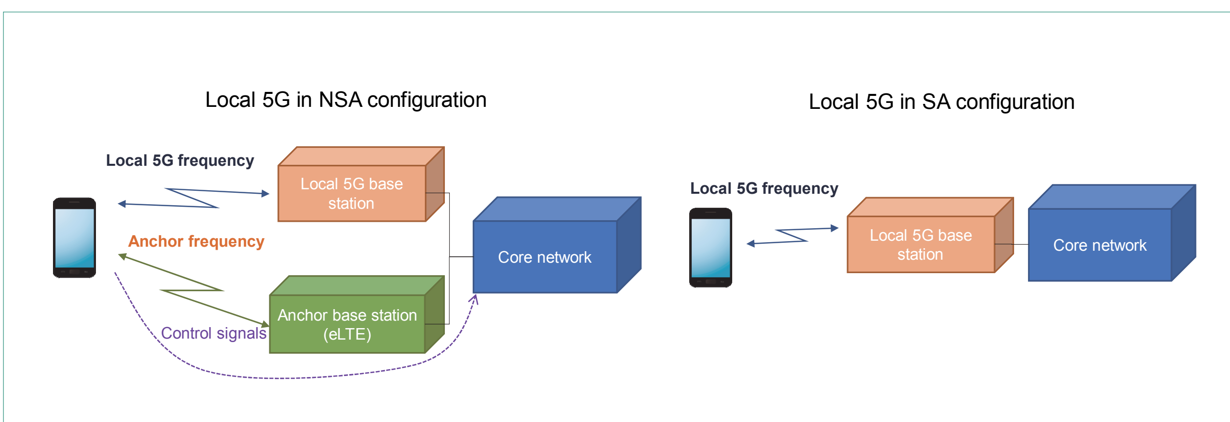

Figure 13 Local 5G configuration in NSA and SA

*7 eLTE: A radio access system extending LTE that conforms to 3GPP Rel. 15 or later.

the anchor. We expect it will be possible to provide SA configurations after 2021.

Because frequency bands and network configurations differ from NTT DOCOMO 5G in this way, NTT DOCOMO 5G terminals cannot be used with local 5G and dedicated terminals must be provided. In addition, since the local 5G facilities are in their early stages, there is a compatibility problem between devices and terminals, and it is not easy to secure terminals for each network configuration. However, in the NTT DOCOMO local 5G construction support service, terminals with a proven connection to equipment can be introduced and provided.

5.3 Carry 5G

Base station facility construction requires large-scale works not only for the installation of radio equipment, but also antenna equipment such as steel towers, power poles and various other accompanying processes, and a certain period of time is required from pre-preparation to facility construction.

Addressing these issues, Carry 5G™ is a service that delivers 5G areas to the customer's desired location more easily without requiring the conventional large-scale construction.

Carry 5G can provide a solution for temporarily use of 5G outside a 5G area, for example, at various event venues such as stadiums, at work sites such as tunnel drilling or building construction, or for new system and solution verification (**Figure 14**).

Proposing various solutions such as video transmission in one package when building 5G areas with Carry 5G maximizes the value of NTT DOCOMO 5G, supports customer in problem solving and new value creation.

1) Carry 5G Features

(1) Response to requests for temporary use of

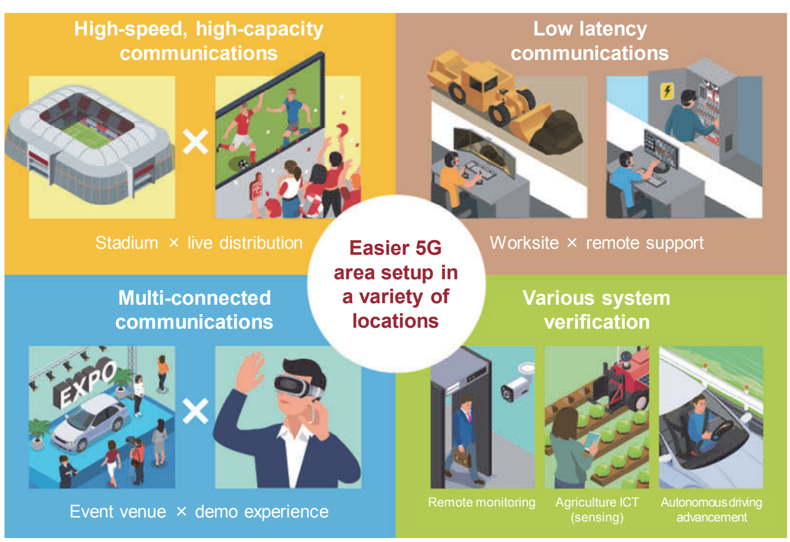

Figure 14　Image of usage scenarios

5G by providing NTT DOCOMO 5G areas

(2) Specialized trolley with 5G communications equipment installed in the requested area

(3) Provides 5G areas cheaper and faster than the conventional

2) System Configuration Image

Some of the processes required for normal base station construction (location securing, antenna installation design and construction) can be omitted by installing a complete set of 5G communication equipment on a trolley, making it possible to provide a 5G area more cheaply and more quickly (**Figure 15**).

3) Operational Patterns

This service has been operated at various events and featured in the media, and has gained high local attention and popularity (**Photo 2**).

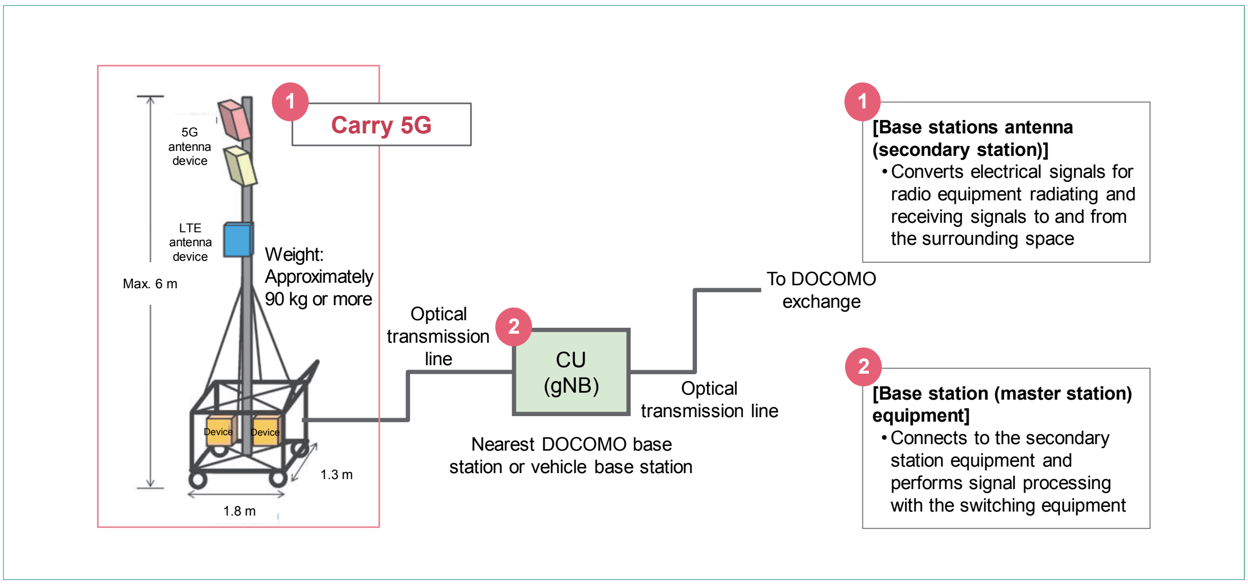

Figure 15　Carry 5G system structure

Photo 2　Operating at various events

5.4 DOCOMO Open Innovation Cloud

1) Overview

Since March 2020, NTT DOCOMO has been providing DOCOMO Open Innovation Cloud, a commercial service that offers cloud computing facilities connected to the DOCOMO network (hereinafter referred to as "cloud infrastructure").

DOCOMO Open Innovation Cloud is a cloud service with the characteristics of MEC, such as low latency and high security, and is enabled by building cloud infrastructure in facilities on the DOCOMO network (**Figure 16**).

As an optional cloud infrastructure service, Cloud Direct offers low-latency*2, high-security 5G communications and has been commercially available since June 2020 in the four data centers of Tokyo, Kanagawa, Osaka, and Oita. The service enables direct connection of terminals to cloud infrastructure to optimize the communication path (**Figure 17**).

2) Features of Cloud Direct

(1) Reducing network transmission latency

The communication path between the 5G communication terminal and cloud infrastructure is optimized to reduce transmission latency.

(2) Closed network access for highly secure communications

Cloud services can be accessed through highly secure communications environments by directly connecting cloud infrastructure and the DOCOMO network to implement closed network communications that are separated from the Internet. Connections from lines other than those registered on the DOCOMO network in advance are rejected to enable secure usage.

(3) Network-on-demand that enables changing the connection destination of the mobile line

As a Cloud Direct management function,

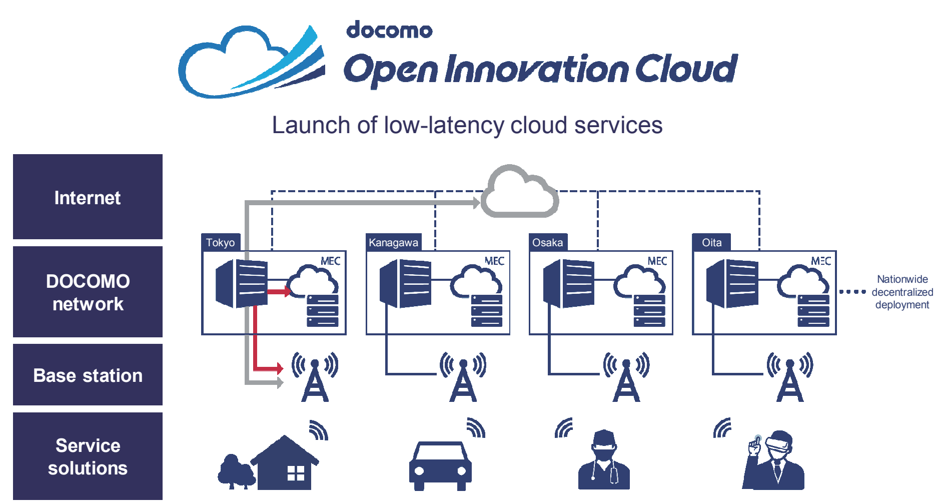

Figure 16 DOCOMO Open Innovation Cloud

*2 Since the latency time varies depending on various conditions of radio and wired sections, there is no guarantee that the transmission latency on the network will always be less than a certain amount.

"network-on-demand" lets users adaptively change the destination cloud base of their mobile line. Having a cloud base close to the location of the connected terminal selected as the connection destination further reduces transmission latency.

3) On-board Solutions

During the 5G pre-service period from September 2019, DOCOMO Open Innovation Cloud provided a trial environment for partners participating in the DOCOMO 5G Open Partner Program, and technical verifications were conducted with 33 companies. It was agreed with partners to install 11 solutions on cloud infrastructure for video transmission and VR/AR. etc., and commercial provision commenced. In addition, cloud infrastructure also includes the DOCOMO image recognition platform*3 developed by NTT DOCOMO. Expanding these solutions and features step-by-step, cloud infrastructure is expected to be widely utilized for 5G-era solutions and services.

6. Conclusion

This article has described consumer services, three corporate solutions in 22 solutions, and the Network Customization service that supports them.

As a consumer service, we will continue to provide additional new experiences and create new value. We will also take business-oriented initiatives to combine DOCOMO Open Innovation Cloud that reduces network transmission latency and provides secure cloud environment and Network Customization that proposes construction of optimal communication environments from 5G-centered communication networks through to local networks with the aim of social implementation of 5G solutions.

Diversification of customer needs has also led to diversification of communications needs. We will continue to add Network Customization menu items step-by-step to respond to the diverse needs of

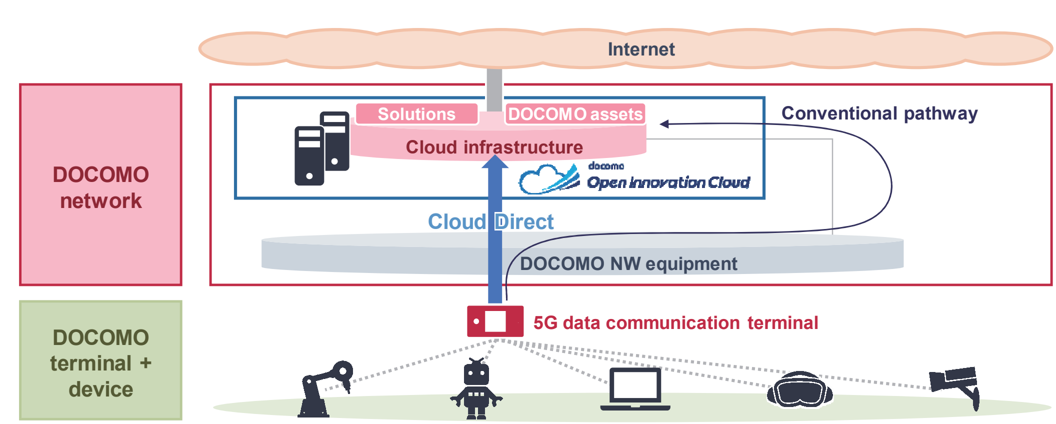

Figure 17 Cloud Direct

*3 Part of this image recognition technology is technology that comprises the "corevo®" AI of the NTT group.

customers and propose construction of optimal communication environments.

REFERENCE

[1] Ministry of Internal Affairs and Communications: Information and Communications Council, Information and Communications Technology Subcommittee, New Generation Mobile Communication Systems Committee (18th session), July 2020 (In Japanese).
https://www.soumu.go.jp/main_sosiki/joho_tsusin/policyreports/joho_tsusin/5th_generation/02kiban14_04000811.html

Technology Reports (Special Articles) 5G Evolution Millimeter Wave Field Experiments

Special Articles on 5G (2)—NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

Field Experiments on Millimeter-wave Radio Technology for 5G Evolution

6G Laboratories Yoshihisa Kishiyama Daisuke Kitayama
Satoshi Suyama Yuki Hokazono

As commercial 5G deployment has already begun around the world, R&D for 5G evolution to further develop 5G in the 2020s is required. In this article, we describe efforts with three field experiments related to further evolution of 5G millimeter-wave radio technology, an important issue in 5G evolution.

1. Introduction

5th generation mobile communications systems (5G) have already gone into commercial operation around the world, and NTT DOCOMO also launched commercial services in March 2020. However, as challenges and further expectations for 5G are identified, research and development to further 5G technological development will be required into the 2020s. NTT DOCOMO began examining requirements for 5G evolution and 6G from around 2017 [1], and released 6G technical concepts (a white paper) in January 2020 [2]. A number of initiatives are also underway regarding field experiments for 5G evolution.

This article describes field experiments using the 28 GHz band, a 5G frequency band, as part of efforts to further develop millimeter-wave*1 radio technology, a crucial issue in 5G evolution. Specifically, we describe a coverage improvement experiment with a metasurface*2 reflector [3] [4], a 5G high-speed travel experiment on the Tokaido Shinkansen [5] [6], and a field experiment of fishing area remote monitoring using an underwater drone [7] [8].

*1 Millimeter-wave: Customarily called "Millimeter waves", these are radio signals in the frequency band from 30 GHz to 300 GHz as well as the 28 GHz band targeted for 5G.

2. Coverage Improvement Experiment with a Metasurface Reflector

With millimeter waves, the challenge is covering areas in the shadows of shield objects such as buildings or trees that put the Base Station (BS) antenna and the Mobile Station (MS) out of radio sight (non-line-of-sight) of each other. To improve coverage in such non-line-of-sight environments and communications quality, metamaterial*3 and metasurface technologies composed by regular positioning of structures smaller than the wavelength have recently been gaining attention [9]. Applying these technologies to a reflector makes it possible to freely design the propagation direction and beamwidth*4 of reflected waves regardless of the installation direction/size of the reflector. Thus, this technology can be installed on a wall surface of a building, etc., to guide reflected waves in a specific direction. We performed field experiments of the technology in a real environment.

2.1 Experiment Overview

In this experiment, a 28 GHz band 5G transmission experimental apparatus fitted with the same BS (made by Ericsson) and MS (made by Intel) beamforming*5 as in literature [10] was used. The effective bandwidth per Component Carrier (CC)*6 was 90 MHz, with 4CC Carrier Aggregation (CA)*7 performed from 27.5 GHz to 27.9 GHz. The time ratio of the Up Link (UL) and Down Link (DL) subframes*8 was 1:1.

Figure 1 shows the concept of the metasurface reflector and the metasurface reflector used in this experiment. Metawave Corporation manufactured the metasurface reflector. The unit cell*9 structure of the metasurface is patterned with patch-type metal on a substrate surface, and the rear surface is covered with metal. The structure of the metal patches and the rear metal determines the resonance frequency, and the phase of the reflected waves varies greatly around this resonance frequency. Accordingly, any reflected wavefront can be designed by distributing the patch size within

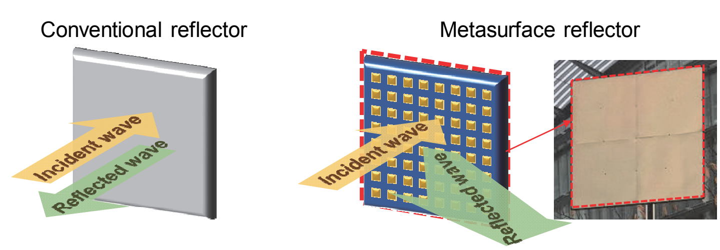

Figure 1 Conceptual diagram of a conventional reflector and the metasurface reflector used in this experiment

*2 **Metasurface:** An artificial surface technology with two-dimensional periodic arrangement of structures that is a type of artificial medium (metamaterial (see *3)), and that achieves an arbitrary dielectric constant and magnetic permeability by periodic arrangement of structures that are smaller than the wavelength.

*3 **Metamaterial:** An artificial material that causes electromagnetic waves to behave in ways that they do not in natural materials.

*4 **Beamwidth:** The antenna radiation angle at which the beam is radiated with gain of −3dB or less from the maximum antenna gain.

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

the substrate to cover the area.

The experimental environment and the angles of incidence/reflection designed for the metasurface reflectors are shown in **Figure 2**. Experiments were performed by installing a BS antenna on the rooftop (at a height of 37.4 m) of the Tokyo International Exchange Center in the Odaiba area of Tokyo. Since the road in front of the building was shielded by the installation building itself and communications quality was poor, we installed a metasurface reflector at a position in line of sight of the BS, and verified that the reflected waves from the metasurface reflector created a 5G coverage area in the road front of the building. The metasurface reflector used in this verification test was designed to have incidence/reflection angles in the vertical direction of approximately 50°/30° and was installed at a height of 3.4 m. To form a reflected wave with sufficient power, the size of the reflective plate was 80 cm x 80 cm. However, assuming that the incident wave is a planar wave*10, only a very narrow beam (half power beamwidth*11: approximately 2° to 3°) is formed in the open area and thus the area covered thins. Therefore, the metasurface reflector was designed so that both the reflected angle and the half power beamwidth of the reflected wave are 18°.

2.2 Experimental Results

Distributions of received power (Beam Reference Signal Received Power (BRSRP)*12) and DL throughput characteristics measured by driving the MS vehicle in front of the International Exchange Center are shown in **Figure 3**. Without the metasurface reflector installed, the BRSRP went below −70 decibels milli (dBm)*13 because the front of the building is non-line-of-sight, resulting in a significant drop in received power compared to the area in radio sight (> −50 dBm). However, with the metasurface reflector installed, it can be seen that BRSRP and throughput characteristics improve due to the 28 GHz band reflected waves

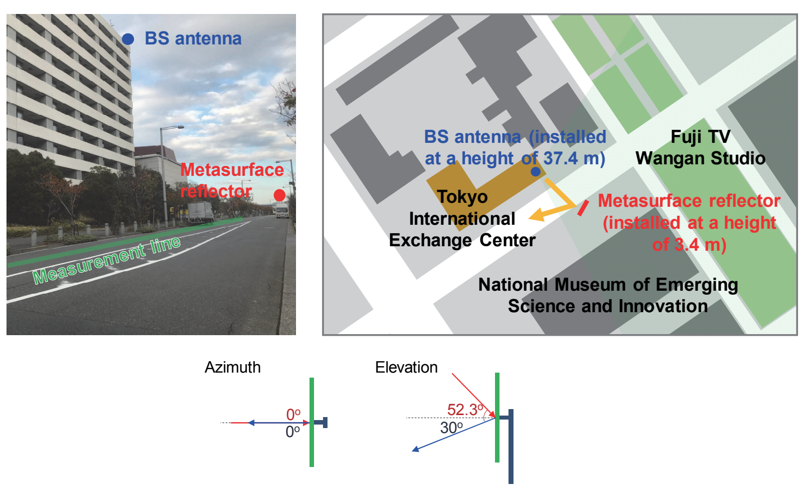

Figure 2 Metasurface reflector experimental environment and angle of incidence/reflection design of the reflector

*6 **CC:** A term used in CA (see *7) to denote one of several frequency blocks.

*7 **CA:** A technology that enables high-speed communications by bundling multiple blocks of frequencies to create a wide-bandwidth.

*8 **Subframe:** A unit of radio resources in the time domain consisting of multiple Orthogonal Frequency Division Multiplexing (OFDM) symbols.

*9 **Cell:** The unit of area division that make up the service area of a mobile communications network.

*10 **Planar wave:** An electromagnetic wave where the amplitude and phase of the electromagnetic field are constant within a plane perpendicular to the propagation direction.

*11 **Half power beamwidth:** The angular range over which the power emitted from an antenna goes from its maximum value to half of that value. Expresses the sharpness of the directivity.

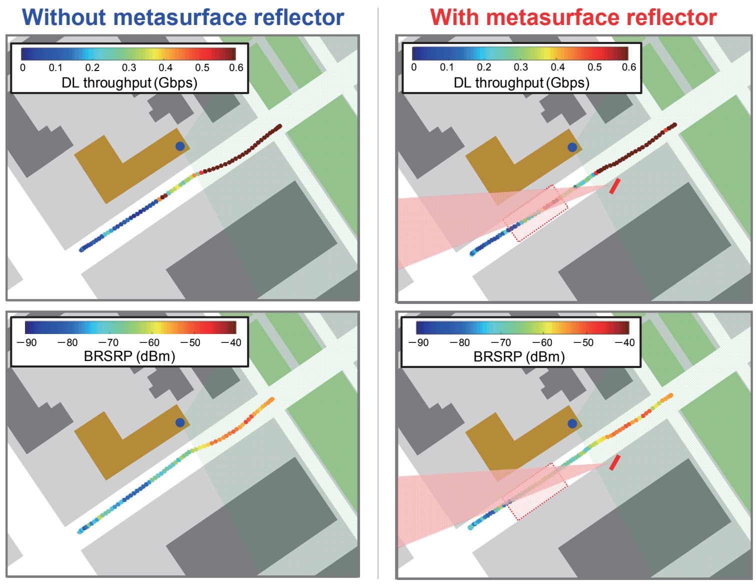

Figure 3 Distributions of received power and DL throughput

reaching the front of the building.

The variation characteristics of BRSRP and DL throughput relative to the travel distance of the MS vehicle are shown in **Figure 4**. The installation of the metasurface reflector improved BRSRP over a driving distance range of 40 m to 75 m corresponding to the front area of the building, confirming an improvement of up to approximately 15 dB. The throughput was also improved in the same range to a maximum of approximately 500 Mbps (no reflector plate: 60 Mbps --> with reflector plate: 560 Mbps).

3. 5G High-mobility Experiment Using the Tokaido Shinkansen

For 5G evolution, NTT DOCOMO is examining how high-speed communications using high-frequency bands such as 28 GHz can be provided stably even in high-speed mobile environments such as high-speed trains. Doppler frequency shifts*14 are higher in high-frequency bands than in low-frequency bands, and in high-speed train environments such as the Shinkansen, since Doppler frequency shifts are further increased with high mobility, there are concerns about deterioration in characteristics. Addressing these issues, in cooperation with Central Japan Railway Company, we conducted transmission experiments from August to September 2019 near Shin-Fuji Station in Shizuoka Prefecture using a 28 GHz-band 5G experimental device with a beam tracking function and the test version of an N700S-model Shinkansen rolling stock traveling at 283 km/h on the Tokaido Shinkansen railway.

*12 BRSRP: RSRP per beam. RSRP is the reception level of a reference signal measured at the mobile terminal.

*13 dBm: Power value [mW] expressed as 10 log (P). The value relative to a 1 mW standard (1 mW = 0 dBm).

*14 Doppler frequency shift: The shift in carrier frequency due to the Doppler effect.

3.1 Experiment Overview

In the experiment, three BSs for 5G experiment were installed on the road along the Tokaido Shinkansen railway, approximately 100 m away from the railway. A detailed diagram of the setup is shown in **Figure 5**. The MS was placed near the window glass by a passenger seat in the test version of the N700S-model Shinkansen rolling stock. Between BS2 and BS3, there are trees and a river at approximately 1,000 to 1,100 m points creating a non-line-

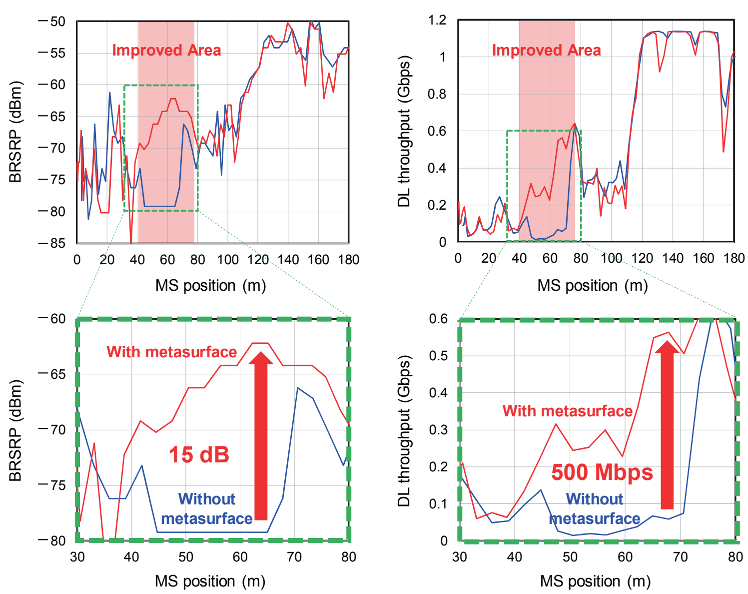

Figure 4　Variable characteristics of received power and DL throughput

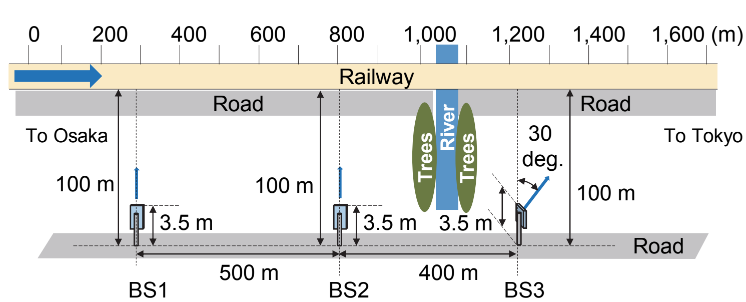

Figure 5　BS positioning

of-sight environment that the MS would traverse. The bandwidth of the 28 GHz-band 5G experimental equipment is 700 MHz and the maximum DL data rate is 3.3 Gbps. Each BS is equipped with two 48-element array antennas*15 and the MS is equipped with two 32-element array antennas, each generating a beam. To maximize received power, combinations of BS and MS beam candidates are selected every 10 ms to achieve beam tracking.

3.2 Experimental Results

Figure 6 shows the DL throughput performances measured during a single run. The throughput was measured at a point approximately 180 m, achieving up to approximately 320 Mbps in front of BS1. A throughput of up to approximately 170 Mbps was observed at BS2, a throughput of up to 980 Mbps was measured in the frontal direction of BS3, and 50 to 200 Mbps was observed up to the 1,700 m point. The Cumulative Distribution Function (CDF)*16 properties of DL throughput by MS moving speed obtained in multiple run experiments are shown in **Figure 7**. The throughput at the MS moving speed of 0 to 20 km/h is the result of driving a car on the road parallel to the Tokaido Shinkansen railway. The throughput deteriorated as the MS moved faster, which is likely due to an increase in Doppler frequency shift. The median value*17 of the throughput at 283 km/h was approximately 130 Mbps and the maximum value was 1.3 Gbps. We confirmed that communication exceeding 1 Gbps can be obtained using the 28 GHz band, if beam tracking can be performed in high-speed train environments.

4. Field Experiment of Remote Monitoring of Fishing Grounds Utilizing an Underwater Drone

One challenge for 5G evolution and 6G is coverage

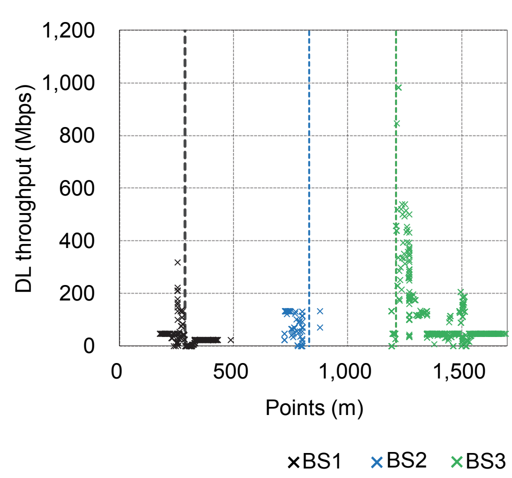

Figure 6 DL throughput performances

*15 **Array antenna:** An antenna consisting of multiple elements.

*16 **CDF:** A function that represents the probability that a random variable will take on a value less than or equal to a certain value.

*17 **Median value:** The value in the middle when countable data is ordered in increasing (or decreasing) size.

expansion in the sky, sea and space [2]. Such initiatives can be expected to further expand the environments in which people and objects can operate and thus create new industries. As an example of the "sea" use case, in collaboration with the University of Tokyo, NTT DOCOMO conducted a field experiment of remote monitoring of fishing grounds utilizing a 5G-enabled underwater drone [11].

4.1 Experiment Overview

Figure 8 shows the experimental structure. An MS was installed on a small vessel moored at sea, and an underwater drone wired to the MS device was put into the sea where an oyster farm is located. Full HD underwater video captured by underwater drone camera was transmitted by radio with UL to a shore-based BS, while at the same time pilot signals were sent to the underwater drone by radio with DL from BS to MS without

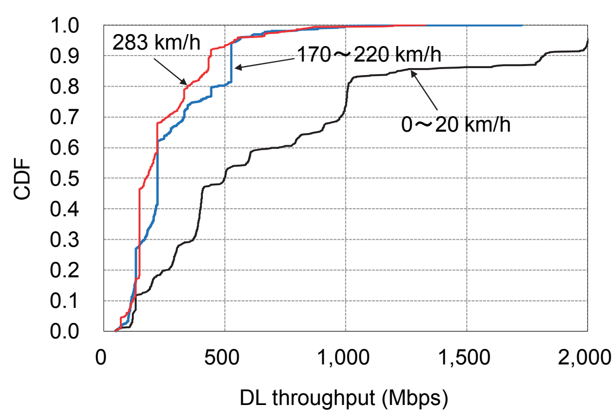

Figure 7　CDF of DL throughput by MS moving speed

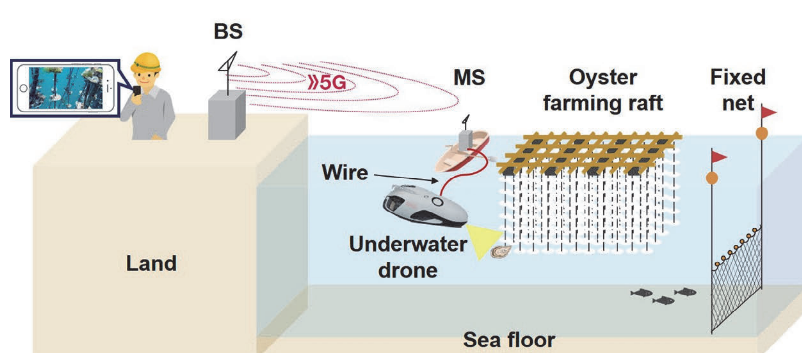

Figure 8　Experimental configuration of remote monitoring of fishing ground

any time lag. The vessel was moored approximately 150 m from the BS at the location of the oyster farm rafts. In this experiment, the same 28 GHz band 5G transmission experimental equipment used in the experiment described in Section 2 was used.

The experiment was conducted at Yanagawa Fisheries, Etajima City, Hiroshima Prefecture. Taken from on land, **Photo 1** shows the BS installed on land and the MS installed on the vessel. At the time of the experiment, the height of the land from the sea surface was approximately 3.0 m, the antenna height of the BS was approximately 1.7 m, and the mechanical tilt*18 was set at 0°. **Photo 2** shows the MS taken onboard the vessel. The approximately 1.0 m antenna height of the MS was adjusted to approximately 2.0 m from sea level. The underwater drone used was a PowerRay [12] from PowerVision Japan Co., Ltd.

4.2 Experimental Results

In this experiment, the target BLock Error Rate (BLER)*19 was set to both 0.1% (a focus on stability) and 10% (a focus on communications speed) to evaluate considering the trade-off between communication speed and stability in 5G industrial usage. The CDF characteristics of the DL throughput are shown in **Figure 9** (a), and the CDF of the DL Modulation and Coding Scheme (MCS)*20 is

Photo 1 5G BS installed on land and 5G MS installed on the vessel

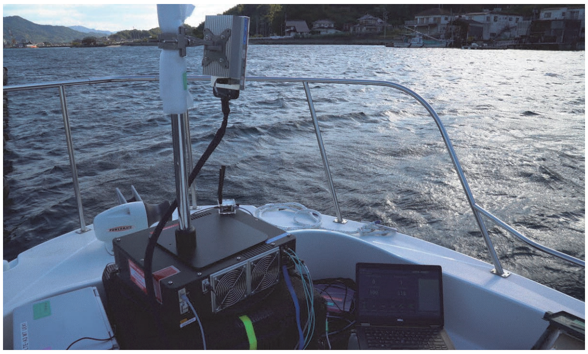

Photo 2 5G MS on deck

*18 Tilt: The inclination of an antenna's main beam direction in the vertical plane.

*19 BLER: The error rate in blocks of transmitted data.

*20 MCS: Combinations of modulation scheme and coding rate decided on beforehand when performing Adaptive Modulation and Coding (AMC).

shown in Fig. 9 (b). From the figure, it can be seen that the variation in DL throughput is smaller when the target BLER is fixed to 0.1%. This is because the MCS is held low to suppress information errors due to the rocking of the vessel. In contrast, with the target BLER at 10%, a relatively high MCS is easy to select and a better throughput is obtained. Since communication speeds in the order of only a few percent of DL throughput characteristics is needed for the small capacity data transmission required to control the underwater drone, it is generally preferable to lower the target BLER to prioritize stability of communications. However, in the case of this experiment, packet loss*21 was not caused by retransmission even with a target BLER of 10%, making low-latency drone control sufficiently possible.

Figure 10 (a) shows the CDF characteristics of

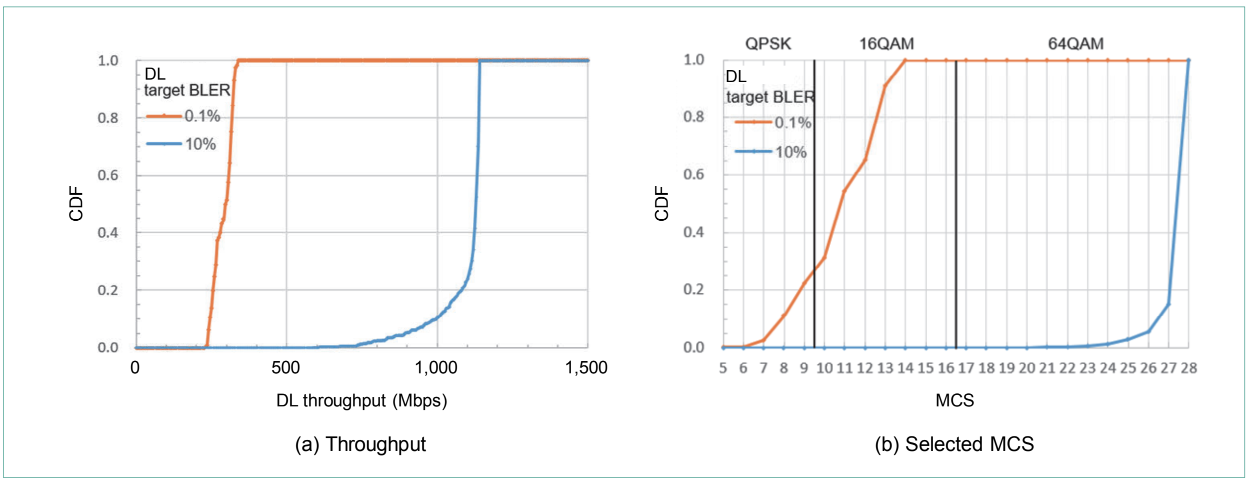

Figure 9 DL CDF characteristics per target BLER

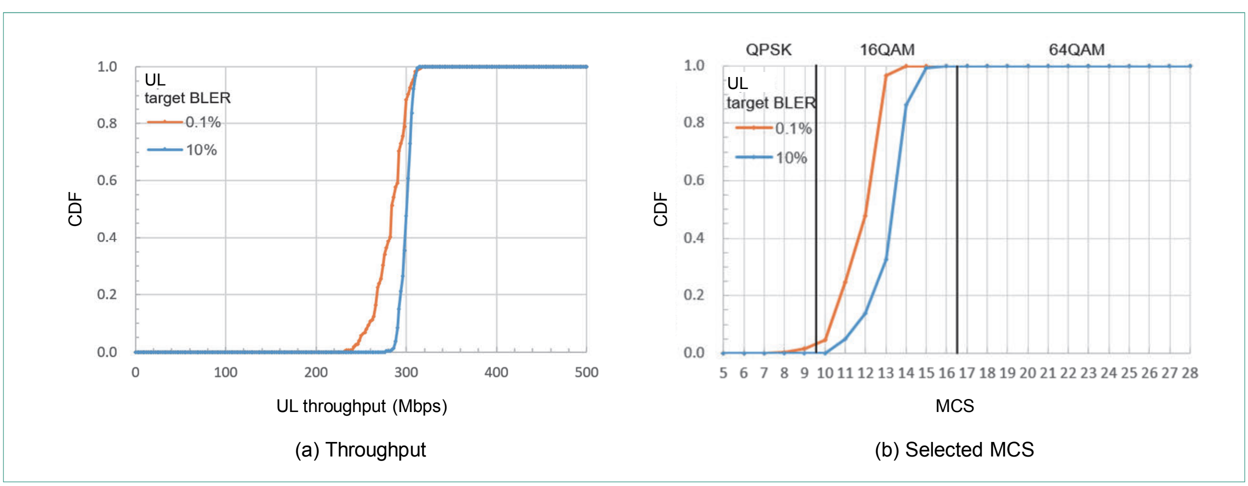

Figure 10 UL CDF characteristics per target BLER

*21 Packet loss: The failure of error-free data packets to be delivered to their destination due to congestion or other issues.

UL throughput when the target BLER is set to 0.1% and 10%, and Fig. 10 (b) shows the CDF of the UL MCS. From the figure, although there was no significant difference in UL throughput variation when the target BLER was set to 0.1% and 10%, slightly higher throughput was obtained when the target BLER was 10%. Compared to DL, the reason there is no difference is likely due to insufficient Signal-to-Noise Ratio (SNR)*22 for selecting a high UL MCS with this experimental configuration and equipment.

Figure 11 shows video of the oyster farm captured by the underwater drone when the target BLER for UL and DL was set to 10%. The user was able to operate the underwater drone without time lag while viewing the underwater scene in high resolution through full HD video.

5. Conclusion

This article has described field experiments using the 28 GHz band, a 5G frequency band, as part of efforts to further develop millimeter wave technology, a crucial issue in 5G evolution. We described a coverage improvement experiment with a metasurface reflector, a 5G high-speed travel experiment on the Tokaido Shinkansen, and a field experiment of fishing ground remote monitoring using an underwater drone. Moving forward with 5G evolution, the expansion of non-terrestrial coverage, and Ultra-Reliable and Low-Latency Communications (URLLC) capabilities for industry will be considered in standardization. NTT DOCOMO plans to continue to work on evolving these radio technologies.

REFERENCES

[1] Y. Kishiyama: "Initial review of Beyond 5G radio access technology," IEICE BS-2-2, Sep. 2017 (In Japanese).
[2] NTT DOCOMO: "White Paper: 5G Evolution and 6G," Jan. 2020.
[3] NTT DOCOMO Press Release: "World's first successful demonstration experiment for enlarging a 5G area in the 28 GHz band with a reflector using metamaterial technology," Dec. 2018 (In Japanese).
[4] D. Kitayama, D. Kurita, K. Miyachi, Y. Kishiyama, S.

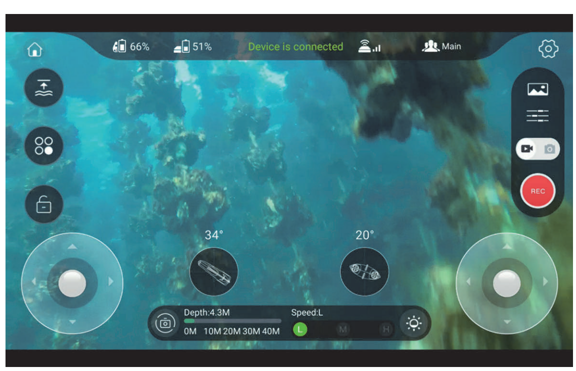

Figure 11 Oyster farm video transmitted in 5G

*22 SNR: The ratio of the desired signal power to the noise power.

Itoh and T. Tachizawa: "5G Radio Access Experiments on Coverage Expansion Using Metasurface Reflector at 28 GHz," 2019 IEEE Asia-Pacific Microwave Conference (APMC), pp.435-437, 2019.

[5] NTT DOCOMO Press Release: "DOCOMO Achieves World's First 5G Communication Between High-speed Bullet Train and Experimental Base Stations," Sep. 2019.

[6] N. Nonaka, K. Muraoka, T. Okuyama, S. Suyama, Y. Okumura, T. Asai and Y. Matsumura: "28 GHz band 5G transmission experiments in high-speed mobile environments using the Shinkansen," Information Technology Bulletin, RCS 2019-264, Dec. 2019 (In Japanese).

[7] NTT DOCOMO Press Release: "Successful demonstration experiments for remote monitoring of fishing grounds utilizing 5G and an underwater drone," Nov. 2019 (In Japanese).

[8] Y. Hokazono, T. Minamida, Y. Aburakawa, D. Ping and A. Nakao: "Underwater drone remote control experiments using the 28 GHz band in 5G," IEICE Technical Report, NS 2019-241, Mar. 2020 (In Japanese).

[9] M. D. Renzo, M. Debbah, D. Phan-Huy, A. Zappone, M. Alouini, C. Yuen, V. Sciancalepore, G. C. Alexandropoulos, J. Hoydis, H. Gacanin, J. Rosny, A. Bounceur, G. Lerosey and M. Fink: "Smart radio environments empowered by reconfigurable AI meta-surfaces: an idea whose time has come," EURASIP Journal on Wireless Commun. and Networking 2019, No.129, May 2019.

[10] D. Kurita, K. Tateishi, D. Kitayama, A. Harada, Y. Kishiyama, H. Murai, S. Itoh, A. Simonsson, and P. Okvist: "Indoor and Field Experiments on 5G Radio Access for 28-GHz Band Using Distributed MIMO and Beamforming," IEICE Trans. Commun., Vol.E102-B, No.8, Aug. 2019.

[11] A. Nakao: "Regional Revitalization through DX – Utilization of Latest Information and Communication Technology," NTT DOCOMO Technical Journal, Vol.28, No.2, pp.4-7, Jul. 2020 (In Japanese).

[12] PowerVision Japan Co., Ltd. "PowerRay," (In Japanese). https://www.powervision.me/jp/product/powerray (available Aug. 2020).

Technology Reports (Special Articles) 5G Evolution Standardization 3GPP Release 16

Special Articles on 3GPP Release 16 Standardization Activities

5G Evolution Directions and Standardization Trends

6G Laboratories Satoshi Nagata Hiroki Harada
Core Network Development Department Kenichiro Aoyagi
Radio Access Network Development Department Hideaki Takahashi

5G services have begun in many countries around the world, and in Japan, 5G commercial services began in March 2020. Furthermore, in the area of research and development, steady progress is being made in studying technologies and drafting standards to drive the evolution (enhancement) of 5G. This article describes the directions of 5G evolution and standardization trends toward 5G evolution in 3GPP Rel-16 specifications.

1. Introduction

Nippon Telegraph and Telephone Public Corporation (forerunner to NTT) began mobile communication services with the world's first cellular system on December 3, 1979. Since then, mobile communications technology has been evolving and expanding to next-generation systems every 10 years. Services too have been evolving together with technical developments, and while mainly limited to voice calls and simple e-mail in the beginning, they now enable anyone to exchange multimedia information such as photographs, music, and video. Recent years, moreover, have seen an explosive growth in the use of smartphones and an even greater diversity of multimedia communication services thanks to high-speed communications technology beyond 100 Mbps under the Long Term Evolution (LTE) system. For its part, NTT DOCOMO launched commercial fifth-generation mobile communications system (5G) services in March 2020 as another milestone in the evolution of its mobile communications technology.

Owing to technical features such as high-speed and large-capacity transmission, low latency, and massive connectivity, 5G is expected to enhance multimedia communication services provided up to 4G and to provide new value as basic technology supporting industry and society together with advanced technologies such as Artificial Intelligence (AI) and Internet of Things (IoT). As shown in **Figure 1**, mobile communications technology has been evolving in 10-year intervals while mobile communication services have been changing greatly in roughly 20-year cycles. We can therefore expect the next big change driven by 5G evolution (5G enhancement) and the next-generation sixth-generation mobile communications system (6G) to support industry and society in the 2030s [1].

In this article, we describe the main directions of 5G evolution with an eye to 2030 and the schedule for drafting standards toward 5G evolution in 3rd Generation Partnership Project (3GPP) Release 16 (hereinafter referred to as "Rel-16") specifications.

2. Main Directions in 5G Evolution

On the road toward 5G evolution, a number of technical issues have been uncovered based on 5G pre-commercial and commercial services launched in various countries around the world. The 5G system is the first generation of a mobile communications system to support high frequency bands in excess of 10 GHz. It features technology that can achieve ultra-high-speed wireless data communications of the several Gbps class using frequency bandwidths of the several 100 MHz class that are dramatically wider than previous technology. At

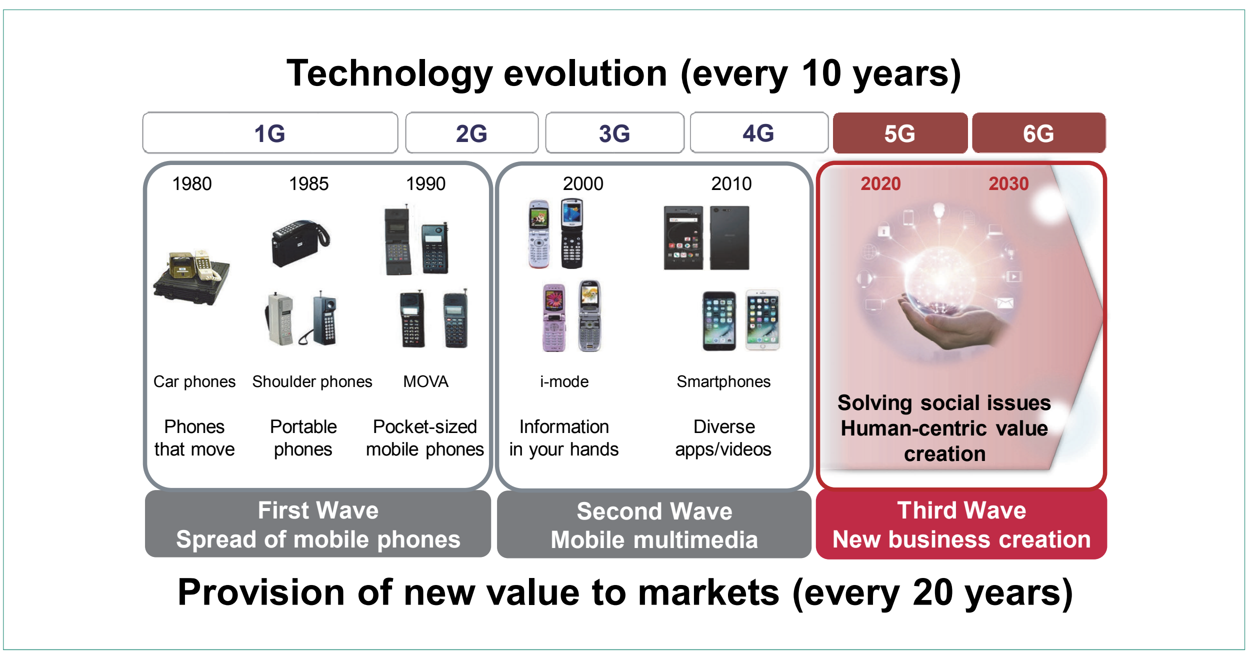

Figure 1　Evolution of technology and services in mobile communications

the same time, there is still much room for further development of high-frequency-band technology such as millimeter waves*1 in mobile communications. In particular, the need for coverage improvement and uplink performance improvement in a Non-Line-Of-Sight (NLOS)*2 environment and for mobility performance improvement are issues that have come to light through 5G-related trials. In addition, many expectations are being placed on 5G as technology that can support industry and society of the future, and industrial use cases in particular often have special requirements or require high radio performance. In Japan, discussions on "local 5G" specific to industrial use cases have been attracting the attention of the industrial world. There is therefore a need for further development of 5G technologies so that a wide range of industrial requirements can be satisfied in a flexible manner. The main directions in 5G evolution for addressing these issues and requirements are "exploiting new frequency bands," "improving system performance and efficiency," and "expanding use cases and services" as summarized below (**Figure 2**).

1) Exploiting New Frequency Bands

3GPP Rel-15 specifications support frequencies up to 52.6 GHz. With the aim of pioneering future usage scenarios using frequency bands in excess of 52.6 GHz, studies are being conducted at 3GPP on extending New Radio (NR)*3 technology toward frequency bands up to 71 GHz as a global target toward International Mobile Telecommunications (IMT)*4 as specified at the World Radiocommunication Conference (WRC)*5-19 [2] of the International Telecommunication Union (ITU) held in 2019.

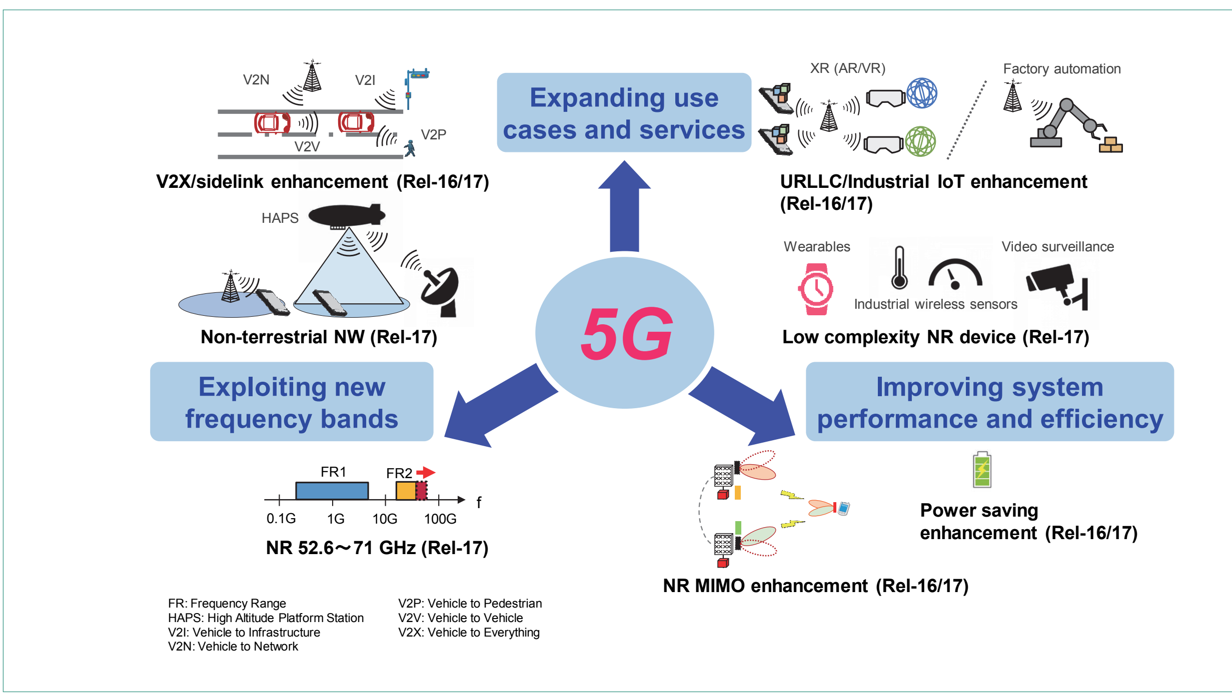

Figure 2 Directions in 5G evolution

*1 Millimeter waves: Radio signals in the frequency band from 30 GHz to 300 GHz as well as the 28 GHz band targeted by 5G that are customarily called "millimeter waves."

*2 NLOS: Describes an environment where there are obstacles between the transmitter and receiver. In this case, communication can only take place over waves that have been reflected, refracted, etc.

*3 NR: A new radio access system specified at 3GPP for 5G not compatible with LTE and LTE-Advanced.

*4 IMT: A generic term for international mobile communications systems standardized at ITU encompassing IMT-2000 (3G), IMT-Advanced (4G/LTE), IMT-2020 (5G), etc.

2) Improving System Performance and Efficiency

In NR under Rel-15, the plan was to improve performance and efficiency relative to LTE. However, optimization that takes into account new operation scenarios such as by making use of millimeter-wave characteristics was not taken up. For this reason, there are ongoing studies at 3GPP on reducing power consumption in terminals that use millimeter waves and on improving the performance of Multiple Input Multiple Output (MIMO)*6 technology and mobility. Some of these functional enhancements have been prescribed in Rel-16 specifications.

3) Expanding Use Cases and Services

In addition to services for existing smartphones and mobile phones, many studies are being conducted at 3GPP on the core network*7 and radio-extension technologies to satisfy requirements for a variety of use cases and services such as industrial automation, IoT, and Vehicle to X (V2X) communications through 5G. These studies are focusing on radio-extension technologies for achieving even higher reliability and lower latency, on network slicing*8, enhanced Quality of Service (QoS) control*9, enhanced security measures, AI applications, etc. for dealing with the evolution of diverse communication services, and on functional extensions to the 5G Core network (5GC) for achieving flexible and timely network construction and operation. Some of these functional enhancements have been prescribed in Rel-16 specifications.

The schedule for drafting standards toward 5G evolution at 3GPP is shown in **Figure 3**. Following the drafting of Rel-15, the initial 5G standard, the

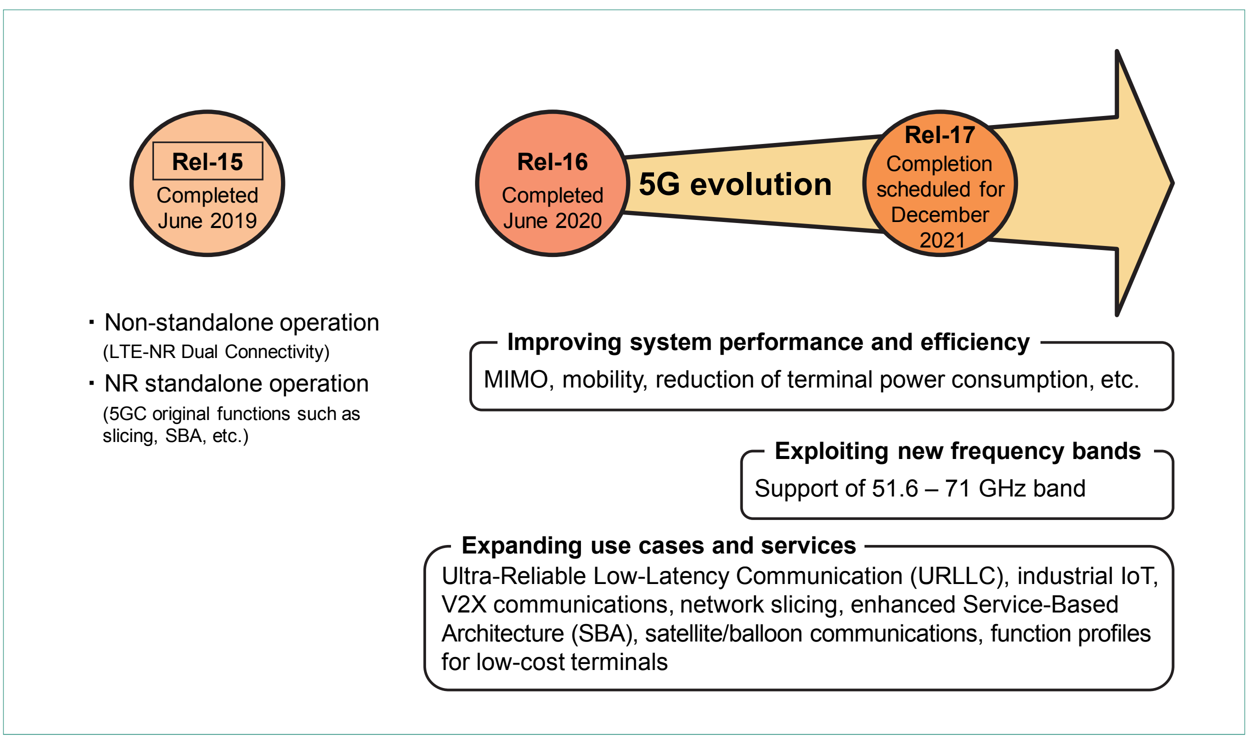

Figure 3　5G evolution at each 3GPP release

*5　WRC: A conference that reviews, and if necessary, revises Radio Regulations, the international treaty governing the use of radio-frequency spectrum, and the orbits of geostationary and non-geostationary satellites. The conference normally meets once every three to four years, and is attended by administrations, ITU registered corporations and related organizations.

*6　MIMO: A signal transmission technology that uses multiple antennas at both the transmitter and receiver to perform spatial multiplexing and improve communication quality and spectral efficiency.

drafting of Rel-16 as an expansion of Rel-15 was completed in June 2020. Discussions toward the drafting of Rel-17 specifications have already begun. At 3GPP, the plan is to draft standards and specifications toward 5G evolution, implement functional extensions across a wide range of fields, and respond to market demands in a time frame that straddles Rel-16 and Rel-17.

3. Conclusion

This article described technologies under study toward 5G evolution and the schedule for drafting associated standards at 3GPP. For details on the 5G core network and 5G radio extension technologies specified in 3GPP Rel-16, we ask the reader to refer to other Special Articles in this issue [3] [4].

REFERENCES

[1] NTT DOCOMO White Paper: "5G Evolution and 6G," Jan. 2020.
[2] Y. Itoh et al.: "2019 ITU Radiocommunication Assembly 2019 (RA-19), World Radiocommunication Conference (WRC-19) Report," NTT DOCOMO Technical Journal, Vol.22, No.1, pp.45–51, Jul. 2020.
[3] S. Nagata et al.: "Advanced 5G Radio Technologies in 3GPP Release 16," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.62–70, Jan. 2021.
[4] K. Aoyagi et al.: "Overview of 5G Core Network Advanced Technologies in 3GPP Release 16," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.49–61, Jan. 2021.

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

*8 Network slicing: 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.

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

Technology Reports (Special Articles) 5G Core Network Network Slicing Network Data Analysis

Special Articles on 3GPP Release 16 Standardization Activities

Overview of 5G Core Network Advanced Technologies in 3GPP Release 16

Core Network Development Department Kenichiro Aoyagi Hiroshi Ishikawa
Atsushi Minokuchi

Deployment of 5G, which is being advanced rapidly by telecommunications operators in Japan and around the world, was initially focused on a non-standalone configuration providing both NR and LTE access. However, development of a 5G Core network (5GC) is also advancing, which will implement a standalone configuration providing only NR as well as other new technologies such as network slicing. Discussion of future extensions to core network functionality is expected to focus on 5GC.

This article gives an overview of 5GC functionality specified in 3GPP Release 16.

1. Introduction

5G Core network (5GC), which is specified in Release 15 (Rel-15) from the 3rd Generation Partnership Project (3GPP), is a core network*1 that will provide New Radio (NR)*2 in a standalone*3 configuration for 5th Generation mobile communication systems (5G), together with new communication technologies such as network slicing*4 [1]. 3GPP Rel-16 introduces new functionality mainly targeting 5GC, and makes other advances such as expanding network slicing and other 5GC platform functions and improving support for various services provided by 4th generation mobile communication systems (LTE). This article gives an overview of the 5GC features specified in Rel-16.

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

2. Overview of 3GPP Rel-16 5GC Technology

2.1 Newly Introduced Functionality

1) Vertical LAN

Vertical LAN refers to a network that applies various new communication functions specified in Rel-16 to realize particular requirements and services for a "vertical domain", which is an industry, enterprise or organization that is developing, producing or providing a particular type of product or service of the same type. These Rel-16 functions realize features such as real-time communication between IoT devices in smart factories and other environments. Further detail can be found in another article in this special feature [2].

2) Network Data Analysis Functions

5GC specifies a Network Data Analytic Function (NWDAF) that handles collection and analysis of various data from the network. Network automation making full use of NWDAF (enablers for Network Automation: eNA) was discussed thoroughly for Rel-16, and functionality was extended to implement various use cases.

As shown in **Figure 1**, NWDAF is equipped with functionality to connect with each Network Function (NF)*5 through Service-Based Interfaces (SBI), to collect data from each NF and from Operation, Administration and Management (OAM)*6, and to analyze the data. The results of NWDAF analysis can be used by the communications operator for various operational tasks, by NFs directly to control communication, and by external applications through the Network Exposure Function (NEF)*7 and Application Programming Interfaces (API)*8.

The analysis items provided by NWDAF as specified in Rel-16 are shown in **Table 1**. Use cases

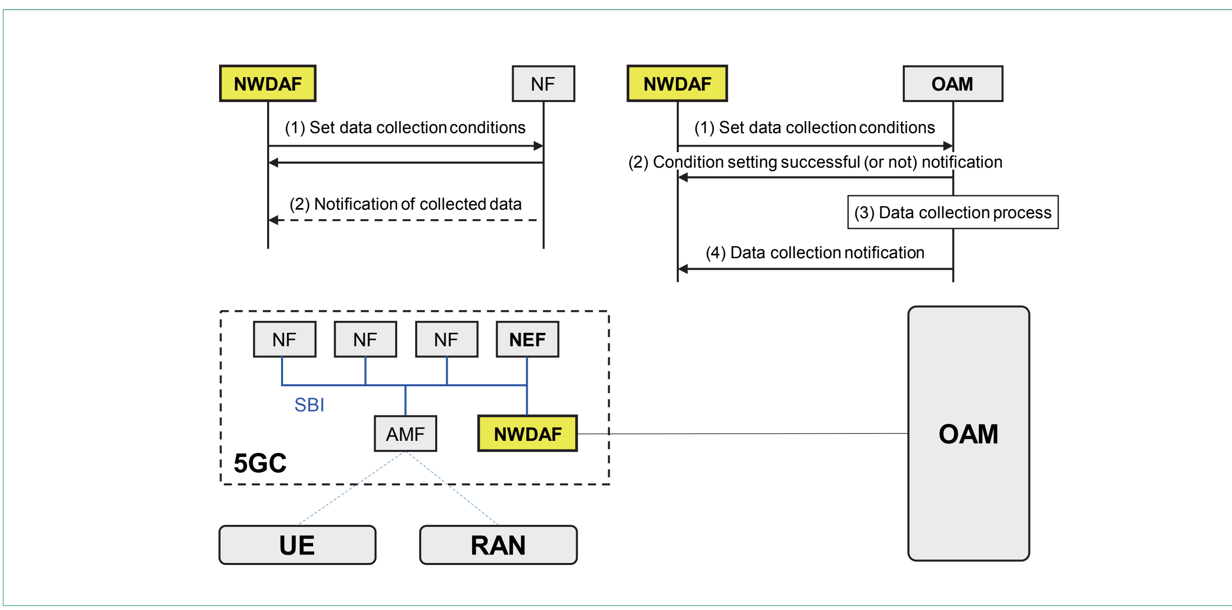

Figure 1 Network configuration using NWDAF

*2 NR: The radio interface between base stations (gNB (See *40)) and terminals (UE) specified in 3GPP Release 15.

*3 Standalone: Standalone systems operate with only NR, in contrast with non-standalone systems that operate NR in cooperation with existing LTE/LTE-Advanced using LTE-NR DC.

*4 Network slicing: A feature introduced in 5GC that provides communication services by partitioning various network communication resources according to use, to satisfy the varying requirements of each slice.

*5 NF: The 5GC architecture has been reorganized to be composed of network function units rather than the conventional network device units, in logical units that identify individual network functions.

*6 OAM: Functions for maintenance and operational management on a network.

Table 1 NWDAF analysis items

Analytics ID	Analysis description
load level information	Analysis of network slice congestion level
Service Experience	Analysis of service experience
NF load information	NF load information
Network Performance	Network performance information
UE Mobility UE Communication Abnormal behaviour	Analysis of device mobility, communication, and identification of abnormal behavior
User Data Congestion	Information on user data congestion
QoS Sustainability	Quality of Service sustainability

include network optimization operations, such as managing cell occupancy using cell occupancy and traffic data, selecting optimal User data Plane (U-Plane)*9 routes, or analyzing to identify devices with particular behaviors and taking further measures as necessary. Application for operation of connected cars is also anticipated, such as using prediction of communication quality in a given area and span of time (Predictive QoS) to achieve low latency, which is important for providing self-driving cars, or for securing sufficient bandwidth to transmit high-quality video or other data.

2.2 Enhancement of 5GC Platform Functions

1) Enhancement of SBA

5GC has adopted a Service Based Architecture (SBA)*10 in which communication between NFs is achieved through APIs. Each NF provides APIs for one or more NF Services, and performs its NF processing. Considering Unified Data Management (UDM)*11 as an example, UDM is a NF Producer providing NF Services, namely that of providing the Subscriber Data Management Service to NF Consumers, such as AMF, which use the NF Service. The UE Context Management Service performs retrieval, registration, deletion and changes to UE state for the Access and Mobility Management Function (AMF)*12. In this way, individual processes are implemented in various services.

SBA was introduced in Rel-15, but the following issues have been identified.

- Only the signaling between NFs were be optimized, and is not optimized for flexible operation within a NF, and not optimized for overall extensibility of NFs.
- Operations of NFs, such as addition, modification, planned removal or reselection due to failure, is not specified for NFs except for AMF, which has its own dedicated specifications.

The Service Framework*13 was reviewed to resolve these issues, and a study to implement such

*7 NEF: A NF that provides APIs for obtaining internal 5GC information or controlling within the 5GC from applications outside of 5GC.

*8 API: Interface specification used for exchange between 5GC equipment.

*9 U-Plane: The communication path used for transmission of user data between a device and the network.

*10 SBA: A type of network architecture used in 5GC, which defines sets of network functions as NFs and introduces unified service-based interfaces (SBIs) between NFs so they can use each others' services.

*11 UDM: An information management facility in 5GC that stores and provides information including subscriber data, UE contexts (area of attach, and session information).

*12 AMF: Facility in 5GC that serves the UE in particular area.

advanced processing was done. As part of reconsidering the Service Framework, NF Discovery*14, NF Registration*15, and Authorization*16 were originally assumed to use only direct communication, but in the review, a Service Communication Proxy (SCP)*17 was introduced, which allows use of indirect communication between the NFs (**Figure 2**, **3**). Specifically, by introducing the SCP, NF Discovery can be performed by SCP as a proxy rather than by the NF Consumer (Delegated Discovery), and also delegating the routing of signaling to SCP, which allows deployment of NF Consumers to be simplified.

To implement advanced processing, the concept of a NF Set was introduced (**Figure 4**). Both NF Services and NFs operate with multiple instances, and by introducing a mechanism that enables a NF Service Instance or NF Instance to cover the

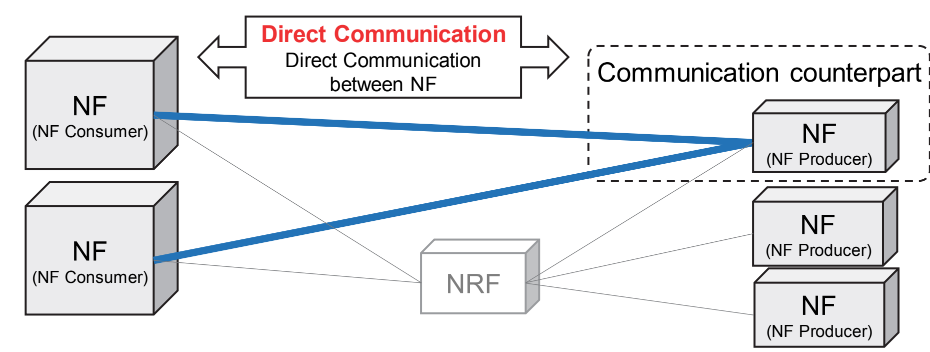

Figure 2　Direct method

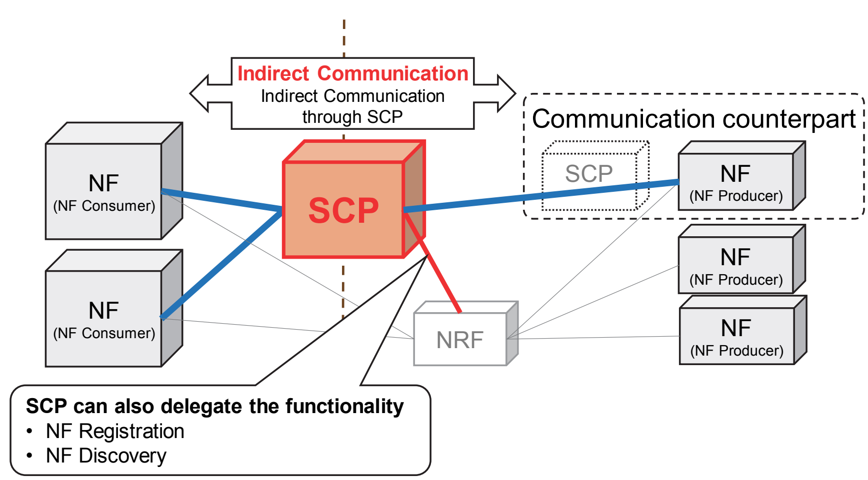

Figure 3　Indirect method (using SCP)

*13　Service Framework: The framework for providing NF functions as services in 5GC.

*14　NF Discovery: The mechanism for discovering NFs and Services provided by NFs. Performed before using a NF Service.

*15　NF Registration: Procedure for registering services provided by a NF.

*16　Authorization: Controls use of a service provided by a NF.

*17　SCP: Equipment that relays signals between NFs rather than having NFs communicate directly. Can perform service discovery in addition to signal routing.

processing of another instance if these instances are in the same "set", processing can continue without affecting earlier processing.

This enables optimization of signal processing, with multiple Instances providing the same NF Service, continuously distributing processing among themselves and improving efficiency.

2) Enhancements to Subscriber Data Management Functions

The architecture implementing user data sharing between 5GC and EPC is shown in **Figure 5**.

In Evolved Packet Core (EPC)*18, subscriber information is held by the Home Subscriber Service (HSS)*19, while in 5GC UDM is defined. Both

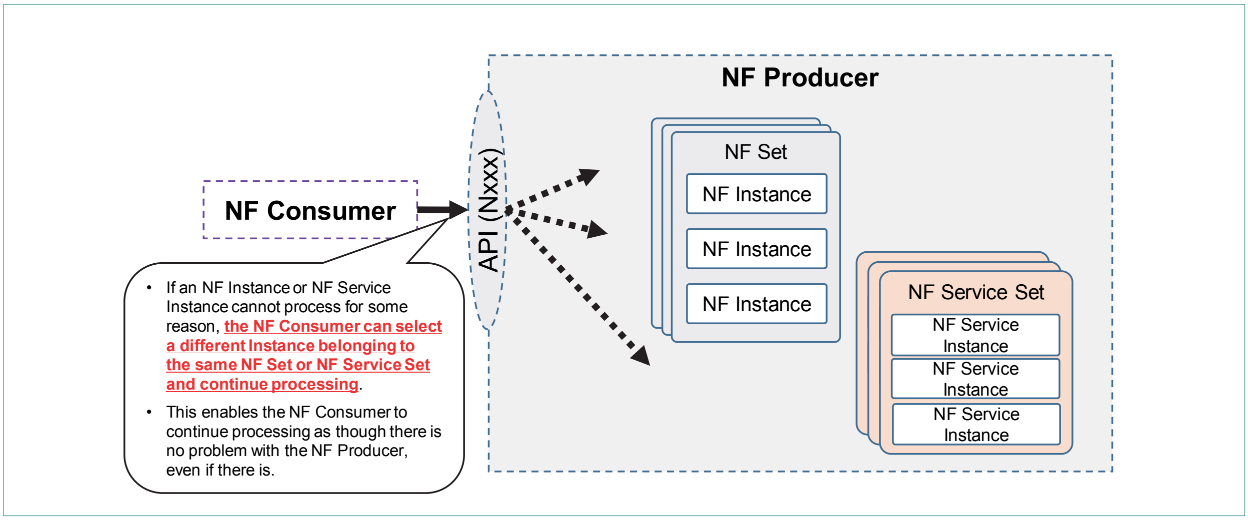

Figure 4 NF Sets

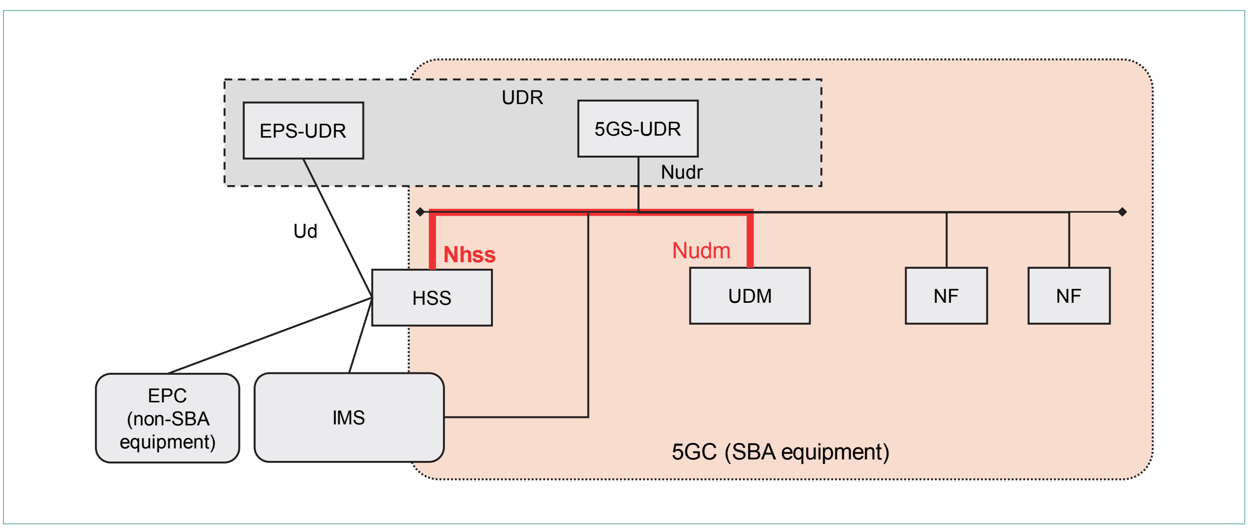

Figure 5 Architecture implementing user data linking between 5GC and EPC

*18 EPC: The core network on 3GPP mobile communication networks, mainly accommodating E-UTRA.

*19 HSS: The subscriber information database in 3GPP mobile communication networks. Manages authentication and location information.

of these are designed to store the necessary information in a repository*20. In 5GC, User Data Repository (UDR)*21 is specified as an NF to serve as the repository, and is designed to interact through the standard APIs specified between UDM and UDR.

HSS and UDM are designed to connect with EPC and 5GC respectively, but the Rel-15 specifications assumed that in practice, UDM and HSS would be integrated in the same device, so the link between them was not clearly specified. As such, when implementing independent HSS and UDM devices, no links are specified for 5GC equipment to access HSS information, or for EPC equipment to access UDM/UDR information.

Thus, to implement links between UDM and HSS, a new SBI was specified for HSS (Nhss), and HSS can access Nudm, which is a UDM API, through the SBI. This enables UDM to access information held by HSS, and HSS can access information held by UDM.

3) Expansion of U-Plane Configuration

The Session Management Function (SMF) manages Protocol Data Unit (PDU)*22 Sessions, managing the connection through N6*23 between Data Network (DN)*24 and User Plane Function (UPF)*25, through N4*26.

UPF also has a multi-level structure which can be configured between the Radio Access Network (RAN) and DN. An intervening UPF is called an Intermediary UPF (I-UPF) and the UPF connected with N6 and terminating the PDU Session is called a PDU Session Anchor UPF (PSA-UPF), but issues remain, such as how to allocate the SMF to control the I-UPF, and how to link a PSA-UPF to the managing SMF (**Figure 6**).

For example, the SMF is designed to manage a UPF for a specific region, and it is not clear how to allocate a new I-SMF or how the AMF and SMF will be linked when a UE moves out of the area managed by the SMF and UPF to which it initially connected, or when the UPF moves to a different

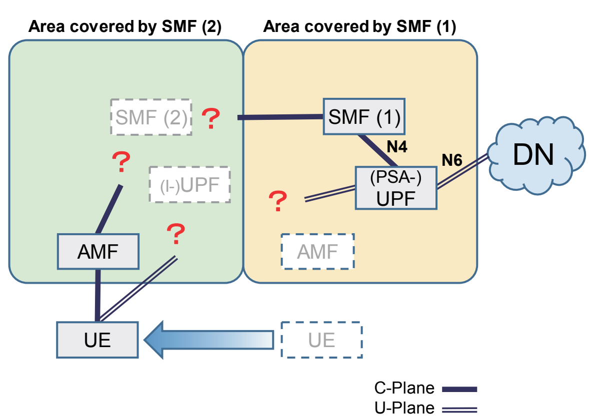

Figure 6 When the areas controlled by AMF and SMF are different, they cannot connect C-Planes directly and control is not possible.

*20 Repository: A system that stores application or system configuration data such as subscriber information or current area occupancy information in one place.

*21 UDR: A repository in 5GC.

*22 PDU: A unit of data processed by a protocol layer/sub-layer.

*23 N6: A reference point between a UPF (See *25) and a DN.

*24 DN: A user data network that 5GC connects with, such as an ISP or enterprise network.

*25 UPF: In 5GC, equipment that relays or terminates a PDU session U-Plane.

*26 N4: A reference point between a SMF and a UPF.

Public Land Mobile Network (PLMN)*27.

If the SMF is allocated in an enterprise network*28, the SMF that manages I-UPFs on the macro-network*29 was not clear, so in Rel-16, new AMF behavior is specified. When operations such as Mobility change*30 or Service Request*31 are performed, the AMF determines whether an I-SMF is needed when selecting the SMF. Specifically, the AMF determines the Servicing Area of the SMF through the Network Repository Function (NRF)*32, and then determines whether a new I-SMF must be selected based on the previous I-SMF, the Anchor SMF (A-SMF), and the location of the UE. The PDU Session can continue outside the Service Area managed by the A-SMF by re-establishing the PDU Session through the new I-SMF (**Figure 7**).

4) Enhancement of Load Balancing Functions between NF

In 5GC, in order to enable telecom operation based on the current load or NF state, notification of load information and the handling of load control is specified.

In Rel-15, load information was distributed through the NRF, and overload information is provided using standard Response codes adopted by the HyperText Transfer Protocol (HTTP). However, the former suffered delays going through NRF, and the latter only conveyed a single HTTP Response code, which was insufficient for directing congestion*33 control adequately. Thus, to enable more accurate and real-time notification of NF Producer*34 load information and overload status, a mechanism to notify NF Consumers*35 directly was adopted, by including the necessary information in a response signal from the NF Producer, using a custom header that is described below.

For load information, 3GPP used the new SBA and specified a new custom header (the 3gpp-Sbi-Lci header) that enables NF Producers to notify NF Consumers. This enables NF Consumers to obtain data and then make decisions, such as whether to select a different NF Producer to achieve stable

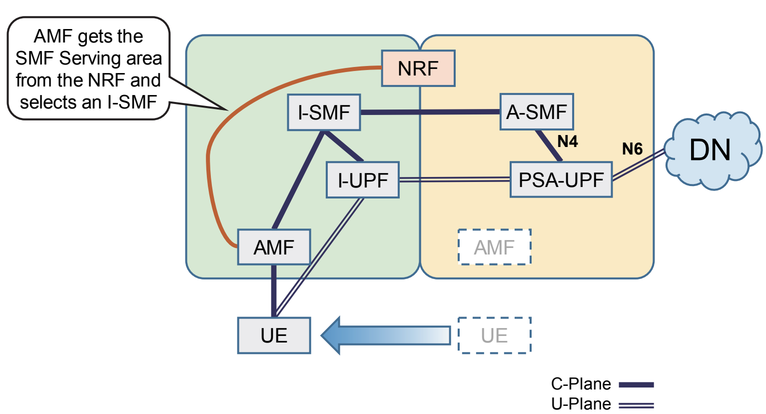

Figure 7 By selecting an I-SMF/I-UPF in the Serving Area, AMFs in different areas connect through an (A-)SMF

*27 PLMN: An operator that provides services using a mobile communications system.
*28 Enterprise network: In 5GC, a network that is limited to specific users or a specific use.
*29 Macro network: In 5GC, a network for users from the public.
*30 Mobility change: Moving across areas handled by the AMF in 5GC.
*31 Service Request: A procedure to recover communication when the radio is temporarily interrupted.
*32 NRF: Equipment that stores and provides information for NF Producer discovery.
*33 Congestion: A state in which demand for communication is concentrated over a short period of time, exceeding the processing capacity of communication and control servers and impairing ability to provide communications services.
*34 NF Producer: A NF that provides a NF Service.
*35 NF Consumer: A NF that uses a NF Service.

communication (**Figure 8**).

Similarly, another new custom header was added for overload information, enabling information to be sent in addition to the regular HTTP error responses. This enables NF Consumers to obtain more information than just the HTTP response codes, which were not sufficient for making decisions, and provides a mechanism that will promote load distribution over the whole network (**Figure 9**).

5) Enhancement of Network Slicing

One technical feature of 5GC, called network slicing [1], is able to partition network resources and build and optimize flexible networks that can provide various performance requirements such as high speed, high capacity, or connectivity for large numbers of devices, all on a single core network. Use of this network slicing feature is one way to provide control of network resources for smart factories and other environments that have particular requirements. For such cases, local businesses or individuals would hope to authenticate and gain access to the appropriate network slice through the usual authentication and authorization procedures used by telecommunications operators, so in Rel-16, the new Network Slice-Specific Authentication and Authorization (NSSAA) procedures were specified (**Figure 10**). Within the authentication and authorization process on the public network, the process for the relevant network slice is temporarily suspended, and then performed by the procedure described below. This authentication and authorization is performed by a new NF defined in Rel-16, the Network Slice Specific Authentication and Authorization Function (NSSAAF), which reduces any

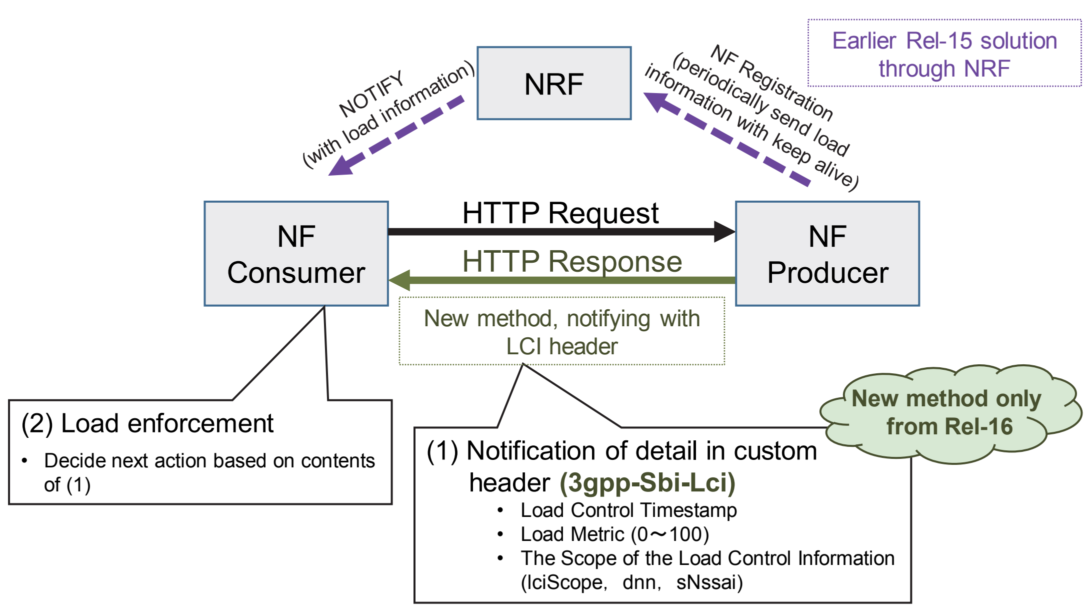

Figure 8　Notification of load information

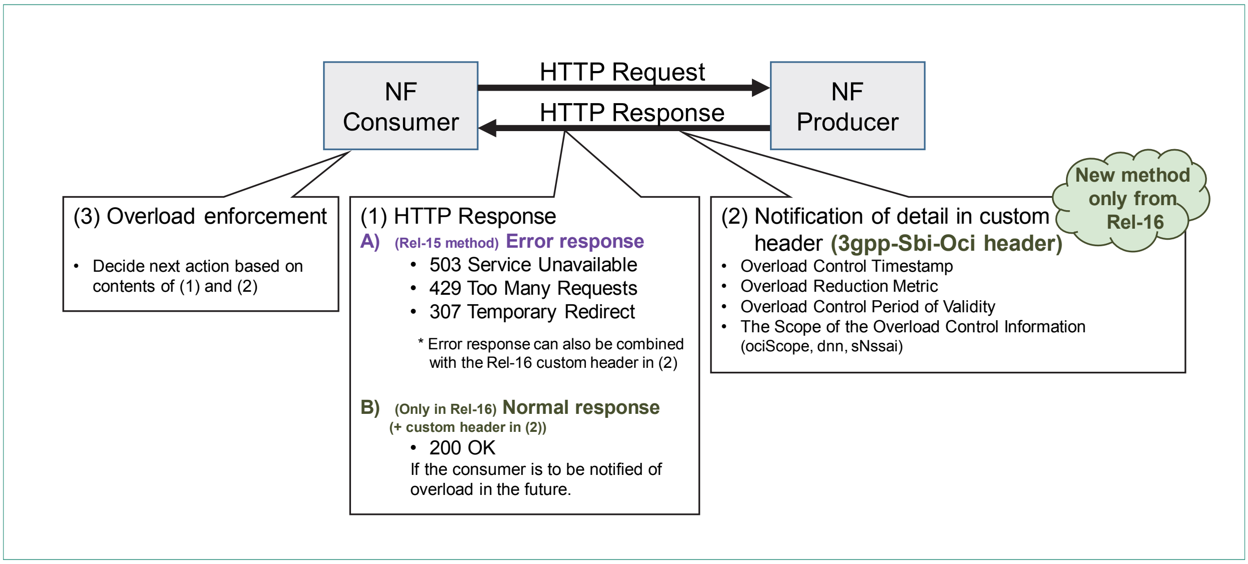

Figure 9　Notification of overload information

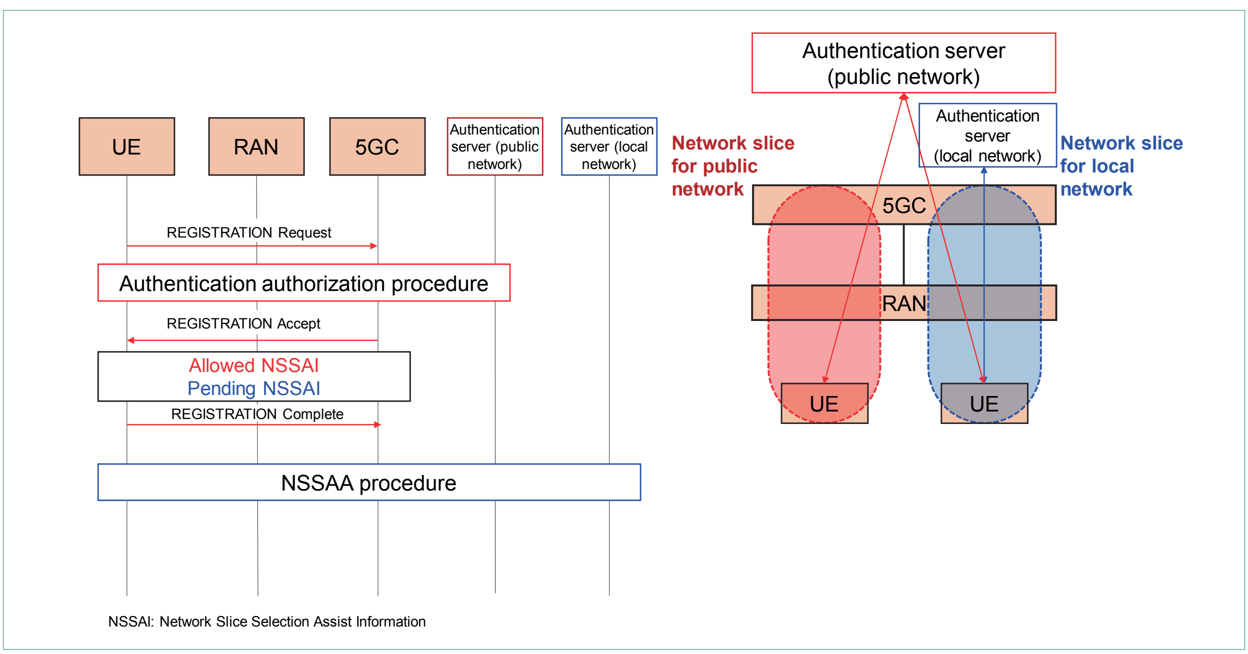

Figure 10　Authentication and approval procedures with NSSAA

effect on public network authentication and authorization servers. Note that the ID (EAP Identity) used in this authentication and authorization procedure can be obtained securely on a communication channel configured on the public network.

2.3 5G Support and Enhancement of Various Services

5GC supports various services that are provided by LTE, such as voice calls, but some of the services were not be supported or were only partially supported in Rel-15, considering issues such as expansion of 5GC areas when 5GC is first introduced, and effects on development of devices and network equipment. In Rel-16, these services will be provided at least to the level provided by LTE, or will have new, extended functionality for 5GC.

1) Location Services

Location services for 5GC were limited in Rel-15, only supporting uses such as for emergencies, but Rel-16 supports location services equivalent to those provided by LTE. Functions for interworking*36 between 5GC and EPC have also been enhanced, so that seamless location services can be provided in environments with a combination of 5G and LTE areas. As shown in **Figure 11**, the Location Management Function (LMF)*37 handles location services in 5GC, corresponding to the Evolved Serving Mobile Location Centre (E-SMLC)*38, which handles location services in EPC.

Note that for EPC, a non-standalone*39 form for providing NR is specified, and for this case Rel-16 defines an extended interface for NR base stations (gNB*40) to notify E-SMLC of location data.

2) 5G Voice Provision Method(s)

Since Rel-15, 5GC has followed EPC, supporting voice with an architecture that connects to the Internet protocol Multimedia Subsystem (IMS)*41. In Rel-15 of 5GC, three main forms are specified for provision of voice (**Figure 12**).

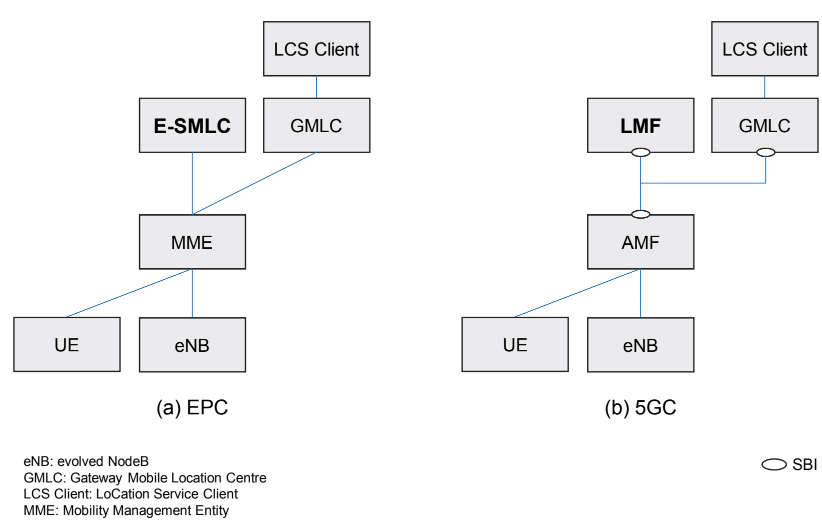

Figure 11 Examples of network configuration for location services in EPC and 5GC

*36 Interworking: Interoperation with a different communications system.

*37 LMF: A NF specified in 5GC that provides communication and control for location services.

*38 E-SMLC: Equipment specified in EPC that provides communication and control for location services.

*39 Non-standalone: A form of operation that provides services through a combination of NR and LTE areas, and does not provide a service area with NR alone.

*40 gNB: A radio base station that provides NR radio.

*41 IMS: A subsystem that provides IP multimedia services (e.g., VoIP, messaging, presence) on a 3GPP mobile communications network. Session Initiation Protocol (SIP) is used for the calling control protocol.

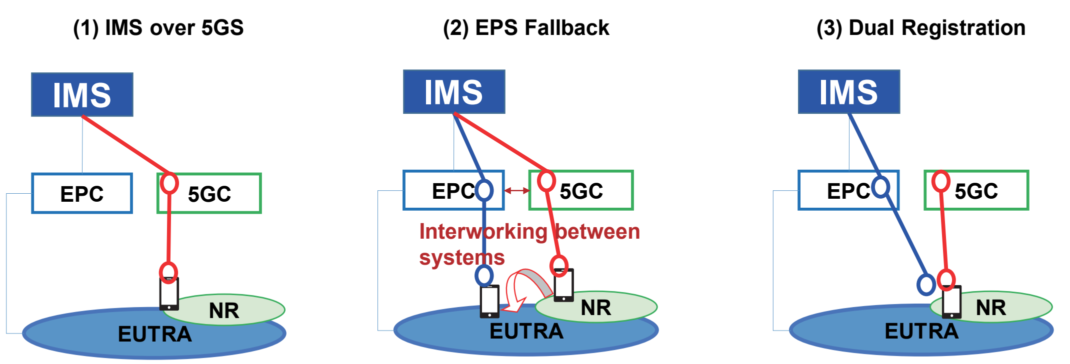

Figure 12 Example of voice provision configuration in Rel-15

(1) IMS over 5G System (5GS)*42: For devices that are in standby or calling on 5GS, a voice channel is configured directly in 5GS.
(2) Evolved Packet System (EPS)*43 fallback: Devices that are in standby or calling on 5GS are temporarily connected to LTE through handover*44 or redirection*45, and voice is provided by LTE.
(3) Dual Registration: The device is registered in both EPC and 5GC, which handles standby, and voice is provided by LTE.

For provision of voice using methods 1, "IMS over 5GS," or 2, "EPS fallback," control between IMS and 5GC is provided by Rx, Cx, and Sh interfaces between IMS and EPC, so each NF on the 5GC side must have these interfaces. SBA is a feature of 5GC, providing SBIs for communication between NF, so Rel-16 also specifies an option to apply these SBIs for the interfaces between IMS and 5GC.

3) Enhancement of Functions to Select Roaming Destinations

Steering of Roaming (SoR) is a function that enables the home operator to direct their roaming subscribers to the operator of the home operator's preference among the operators present at the roaming location. Provision of roaming services equivalent to those of EPC has been specified for 5GC since Rel-15, but SoR functionality has been enhanced in Rel-16.

Operators generally have contracts with several other operators (roaming partners) in a region in order to negotiate roaming user tariffs or to distribute and lower the risk of complete disconnection, including relay channels. Under normal operation, however, the home operator must distribute all roaming users among the roaming partners where they are roaming, making various adjustments for each operator, and SoR is used to control which roaming partner each subscriber should attach to.

*42 5GS: The network system in 5GC, comprised of communication devices (UE) and the radio access network to which they connect.

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

*44 Handover: The communication technology that performs switching between cells and base stations while maintaining communication between the UE and the network.

*45 Redirection: A communication technology that temporarily stops communication between UE and network, places the UE in standby, and then reconnects to a cell or base station using a reconnect request signal from the UE.

There have been various non-standard methods for achieving this from 2G through EPC, but there were issues with degraded user experience and reliable control (**Figure 13**). In 5GC, a new Non-Access Stratum (NAS)*46 signal is used to notify UE with an operator priority list, and functionality has been added for the UE to select the priority operator at any time (**Figure 14**).

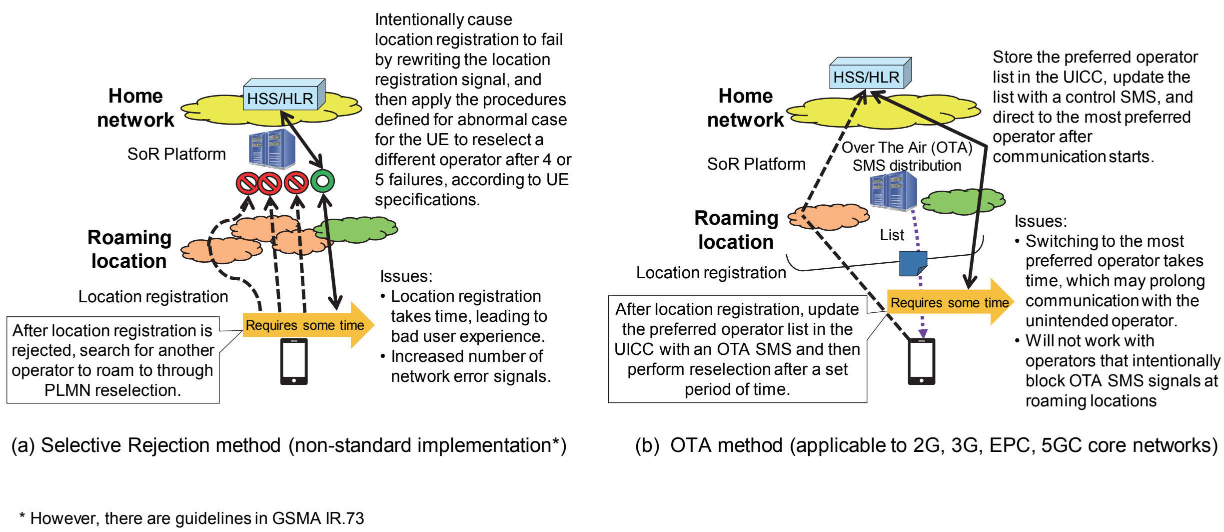

Figure 13　Existing SoR

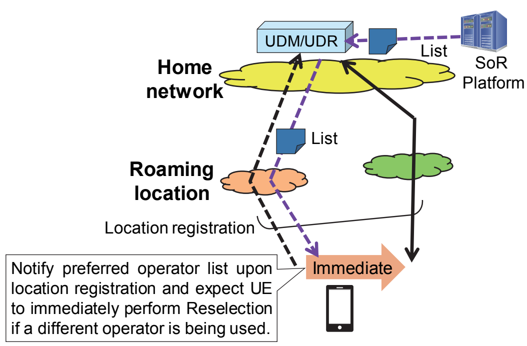

Figure 14　SoR using the NAS signal

*46　NAS: A functional layer between the UE and core network.

3. Conclusion

This article has described enhancements to 5GC specified in Rel-16, in terms of newly introduced functions, enhancements to 5GC platform functionality and enhancements to existing services. Discussion is underway at 3GPP on further extensions to the 5GC core network and mobile communication services for Rel-17 and beyond, and NTT DOCOMO will continue contributing to 3GPP standardization work, toward development of core networks for Beyond 5G and 6G.

REFERENCES

[1] A. Minokuchi et al.: "5G Core Network Standardization Trends" NTT DOCOMO Technical Journal, Vol.19, No.3, pp.48–54, Jan. 2018.

[2] K. Aoyagi et al.: "5G Advanced Technologies for Creating Industries and Co-creating Solutions," NTT DOCOMO Technical Journal, Vol.28, No.3, pp.71–89, Oct. 2020.

Technology Reports (Special Articles) 5G NR LTE

Special Articles on 3GPP Release 16 Standardization Activities

Advanced 5G Radio Technologies in 3GPP Release 16

6G Laboratories Satoshi Nagata Hiroki Harada
Communication Device Development Department Daiki Takeda
Radio Access Network Development Department Hideaki Takahashi

In June 2018, 3GPP issued its Rel-15 specifications, including specifications for the new radio access technology for 5G, called NR, and for advances to LTE technologies. In March 2020, commercial 5G services using NR were started in Japan. Further enhancements for NR and LTE have continued at 3GPP after Rel-15 was finalized, and the Rel-16 specifications were completed in June 2020. This article gives an overview of the NR and LTE specifications completed in Rel-16.

1. Introduction

Release 15 (hereinafter referred to as "Rel-15") of the 3rd Generation Partnership Project (3GPP) specifications for fifth-generation mobile communications systems (5G), including New Radio (NR) and Long Term Evolution (LTE), emphasized radio technologies for enhanced Mobile Broad-Band (eMBB). In addition to further advances for eMBB, Rel-16 advanced Ultra-Reliable and Low Latency Communication (URLLC), and specified enhancements that will promote Industrial Internet of Things (IoT), which will be used in creation of new businesses. This article describes the main technology enhancements specified in Rel-16 and gives background considered when studying them.

2. Directions for 5G Radio in the Rel-16 Specifications

Figure 1 shows the NR and LTE functions specified in 3GPP Rel-16, classified by the main usage scenarios for 5G, which are eMBB, URLLC, and massive Machine-Type Communications (mMTC).

As in Rel-15, Rel-16 has many functions for eMBB, and these are divided into functions for improving quality and performance, and functions to expand usage scenarios. NR as specified in Rel-15 focused on basic functionality to realize non-standalone*1 and standalone operations, and functionality for improving quality and performance was left for further study. As such, several of those functions were specified in Rel-16 based on experience gained creating the LTE specifications. At the same time, functions for expanding usage scenarios and markets were specified, such as utilization of unlicensed bands (described below) and extensions for more flexible base station deployment.

Enhancements for URLLC and mMTC are mainly for developing new industries, and there are functional enhancements for realizing various Industrial IoT usage scenarios. The main Rel-16 functionalities for each usage scenario are described below.

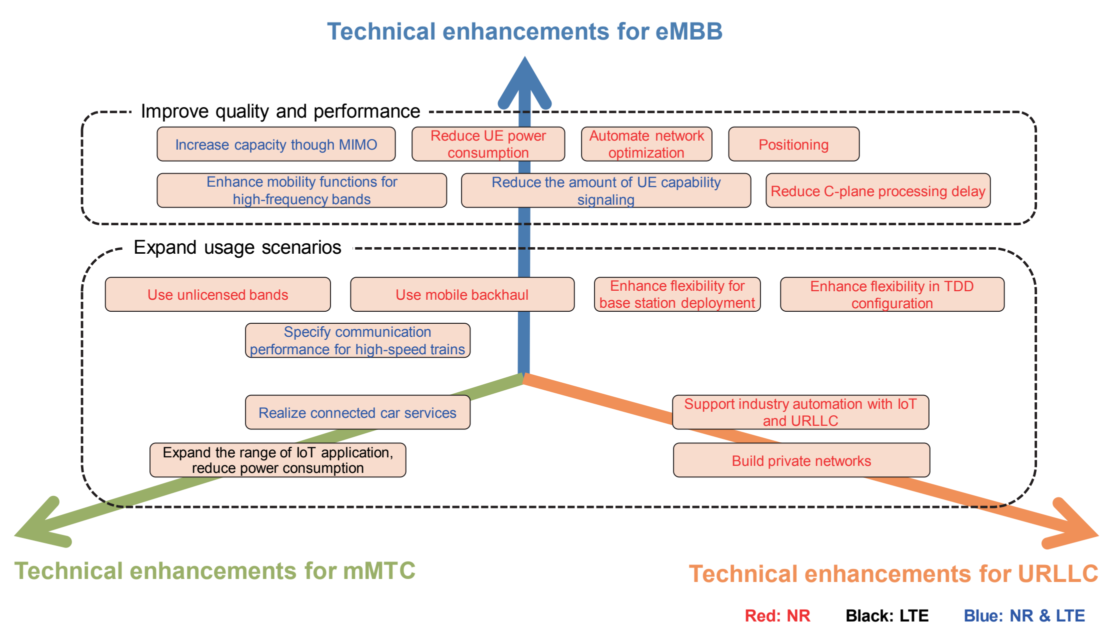

Figure 1 Major functionality specified in Rel-16 for NR and LTE

*1 Non-standalone: An operation format that provides services through a combination of NR and LTE areas. In this format, a service area cannot be provided by NR alone.

2.1 Technical Enhancements for eMBB

As shown in Fig. 1, functions are specified for seven objectives to improve quality and performance of eMBB. Functions have also been specified to satisfy five objectives for expanding the usage scenarios for eMBB.

1) Improving Quality and Performance

(a) Increase capacity through Multiple Input Multiple Output (MIMO)*2

Rel-15 specified several new MIMO functions for NR, such as antenna arrays*3 composed of multiple antenna panels, and multi-beam operation in high-frequency bands with analog beam forming*4, but these were enhanced further in Rel-16. For example, with Rel-15, there was no way to notify a UE of the configuration being used for communication at the base station, so it was not practical to apply distributed MIMO*5 communication using multiple antenna panels or transceiver points that are geographically separate. In Rel-16, a mechanism is specified for the UE to know when there are multiple antenna panels or transceiver points at the base station, and for configuring and communicating with each of them simultaneously, so high-ranked distributed MIMO communication can be used to increase speed and reliability.

(b) Enhance mobility functions for high-frequency bands

Basic mobility functions such as handover*6 were specified in Rel-15 NR, but there were still issues with mobility functions using analog beam forming in the high frequency bands, such as low reliability due to beam-sweep*7 delay. To realize stable, continuous communication, interruption time due to processing for handover and switching the Secondary Cell Group (SCG)*8 needed to be reduced, so in Rel-16, functional enhancements were made for handover on the same frequency and between different frequencies, and for switching the SCG. Specifically, the handover failure rate is reduced by enabling the UE to configure multiple handover candidate base stations rather than only one previously, and the communication interruption time is reduced by enabling the UE to communicate with both the handover source and target base stations simultaneously.

(c) Reduce UE power consumption

Improving UE battery life is an important aspect of raising user satisfaction, and features were specified in Rel-15 NR to reduce UE power consumption, including Discontinuous Reception (DRX)*9, which was also supported by LTE, and a new BandWidth Part (BWP) adaptation*10 function.

Some effective ways to further reduce power consumption include finding more opportunities for the UE to enter a sleep state by suspending operations such as Physical Downlink Control CHannel (PDCCH)*11 monitoring at finer granularity, and avoiding simultaneous performance of multiple processes. However, reducing power consumption with these sorts of operations can

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*2 MIMO: A signal transmission technology that uses multiple antennas for transmission and reception to improve communications quality and spectral efficiency.

*3 Antenna array: An arrangement of multiple antenna elements or panels forming an antenna group.

*4 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.

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

*6 Handover: The process of switching the base station connected to the UE.

*7 Beam sweep: A technology that switches through the beams that a base station can use in order, with the same signal, covering the entire area.

*8 SCG: With dual connectivity, the serving cell group used to communicate with the second of the two base stations connected to the UE.

increase communication delay and reduce achievable throughput.

As such, Rel-16 introduced functionality such as a mechanism to appropriately skip operations, such as periodic reception during DRX or measurements, based on instructions from the base station so that sleep can continue, and a function whereby the base station sends instructions to reduce the maximum number of MIMO layers*12 when high throughput is not required, enabling the UE to turn off some of its circuits. These functions enable flexible adaptation to requirements that differ depending on the UE or services being provided.

(d) Positioning

Positioning functions are an important application, but in Rel-15 NR they had limitations such as being reported based only on the cell ID*13. Rel-16 specifies dedicated functions for location and positioning with NR. In particular, a Positioning Reference Signal*14 on the downlink is specified for positioning, and various other positioning methods on the downlink and the uplink are specified, based on reference signal timing differences, on reference signal received power*15, on angle of arrival*16, and on the Rx-Tx time difference. Operators can use these positioning methods as appropriate, depending on the base-station deployment scenario, the frequencies being used, the positioning accuracy required and other factors. Support for NR positioning functions also enables implementation of more accurate positioning than LTE by utilizing NR features such as wide bandwidth and Massive MIMO*17.

(e) Reduce the amount of UE capability signalling

To meet the diverse demands for 5G, a wide range of functions have been specified for NR, and with them, the amount of signaling to indicate functions supported by UE (UE capabilities) has increased. Past 3GPP Releases have also introduced measures to reduce this signaling, within a scope that could be handled by radio protocols, but in practical terms, the amount of signaling was approaching the maximum bytes in a single data unit transmittable by radio, so a more drastic measure to reduce signaling in the entire system, including core network*18, was needed. The drastic measure that was taken is to register UE capabilities in a database and to assign an identifier to the UE capabilities in the database, as a mechanism to identify features supported by the UE.

(f) Reduce C-plane*19 processing delay

Rel-16 also includes functional enhancements to further reduce C-plane delay. For example, in Rel-15 NR, the Random Access CHannel (RACH)*20 procedure generally has four steps, so an exchange of four messages is required to establish communication. Rel-16 NR specifies a two-step RACH that reduces the procedure to two steps, reducing C-plane delay. This function was investigated in Rel-16 for scenarios with unlicensed

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

*10 **BWP adaptation:** A technology in NR for dynamically switching communication settings such as bandwidth or subcarrier intervals between the UE and serving cell. It can be used to reduce power consumption by, for example, reducing bandwidth when high-speed communication is not needed.

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

*12 **MIMO layers:** In MIMO, the number of multiplexed layers when multiplexing different signals on the same radio resources using spatial multiplexing with different antennas.

*13 **Cell ID:** Identifying information assigned to each cell.

*14 **Reference signal:** A known signal from base stations, configured in UE.

*15 **Reference signal received power:** Received power of a reference signal measured at the UE.

*16 **Angle of arrival:** The angle of arrival of the radio signal from the transmitter, as seen by the receiver. Generally measured by the difference in arrival times at two or more antennas.

bands using Listen Before Talk (LBT)*21, where overhead*22 due to multi-step message exchange is a concern, but it was also found to be useful in scenarios using licensed bands, so the specifications allow it to be used in all NR usage scenarios.

(g) Automate network optimization

The Minimization of Drive Test (MDT)*23 and Self Organizing Networks (SON)*24 functions were specified to automate optimization of area quality in LTE networks by having UE report observations of radio quality to the network, and then collecting this quality data from the UE and analyzing it on the network side. Operators can use the MDT and SON functions to improve quality while limiting the manual labor involved. These functions were not supported in the NR Rel-15 specifications, but there was demand for such functionality in Rel-16, which was anticipated for full commercial deployment of NR services, so specifications for new NR functions similar to MDT and SON were included in Rel-16. These new specification also support collection of quality data for each beam in multi-beam operation, which is a feature of NR, and acquisition of quality data when in non-standalone operation.

2) Expanding Usage Scenarios

(a) Use unlicensed bands

Since Rel-13, 3GPP has included specifications for Licensed Assisted Access (LAA)*25 for LTE to meet the demand for increased network capacity, enabling carrier aggregation to be used to bundle and use frequency bands licensed to operators (licensed bands) together with frequency bands not requiring licensing (unlicensed bands). In addition to LAA for NR, Rel-16 adds support for scenarios that were not supported for LTE, such as using unlicensed bands with NR alone, and Dual Connectivity (DC) using both licensed and unlicensed bands. Using DC rather than carrier aggregation enables operators to deploy base stations using unlicensed bands, independently of base stations using licensed bands. This mechanism that enables unlicensed bands to be used independently allows operators that do not have licensed bands to provide communication services. Note that supported unlicensed band frequencies include the 5 GHz band supported by LTE as well as the 6 GHz band.

(b) Use mobile backhaul

Normally, to expand and increase the density of the NR radio access network*26 requires increasing the density of base station deployment and similarly, expanding and increasing the density of the mobile backhaul network*27, which connects base stations to the core network. Rel-16 defines specifications for Integrated Access and Backhaul (IAB), which enables networks to be expanded and the density increased using wireless backhaul links based on NR, rather than requiring wired backhaul links. IAB nodes are relay nodes that use NR communication for both the backhaul and access

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

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

*19 C-plane: Control plane. A protocol used to transmit control signals for establishing or terminating communication and other operations.

*20 RACH: A common uplink channel that is used for transmitting control data and user data. It is shared by multiple users and is independently and randomly transmitted by users.

*21 LBT: A mechanism that enables a device to check whether another device is transmitting data before transmitting by radio.

*22 Overhead: Control information needed for transmitting/receiving user data, and radio resources used for purposes other than transmitting user data, such as reference signals for measuring received quality.

*23 MDT: A technology standardized by the 3GPP for gathering QoE information. Terminals send information to the network regarding incidents such as interruption of communication or failed handover as they occur, such as location and cause of the incident.

links. As parent nodes, they connect wireless backhaul links to other IAB nodes and also to base stations with functionality to accommodate IAB nodes, and they can accommodate UE as well as other IAB nodes [1]. A feature of IAB nodes is that they can provide wireless backhaul (X2*28 and Xn*29 interfaces) between base stations when operating NR in standalone and also in non-standalone using DC [2]. IAB nodes are also able to implement network synchronization between nodes that satisfies the requirements of Time Division Duplex (TDD)*30 systems, based on downlink signals and assist information received from parent nodes.

(c) Enhance flexibility for base station deployment

In addition to E-UTRA-NR DC (EN-DC)*31, NR standalone, and NR-E-UTRA DC (NE-DC) operating modes, Rel-15 NR specified a NR-NR DC (NR-DC) operating mode, although in limited form. Rel-16 specifies support for asynchronous NR-DC with a Master Cell Group (MCG) and SCG, which was not specified in Rel-15. For example, NR-DC using a Frequency Division Duplex (FDD)*32 band and a TDD band can be implemented without requiring synchronization between bands. Carrier aggregation function enhancements not specified in Rel-15 were also added, such as cross-carrier scheduling*33 between carriers with different sub-carrier*34 spacing and aperiodic Channel State Information-Reference Signal (CSI-RS) triggers*35. These enable high-frequency-band aspects such as data transmission and beam measurements to be controlled using the low-frequency band, which has higher reliability, when performing carrier aggregation with a low frequency band and a high-frequency band.

(d) Specify communication performance for high-speed trains

In LTE and NR specifications until Rel-15, communication performance was maintained for UE traveling at speeds under 300 km/h. However, we can expect increasing demand for stable communication in mobile environments traveling at speeds exceeding 300 km/h in Japan and other countries. Accordingly, Rel-16 specifies performance supporting speeds up to 500 km/h.

(e) Enhance flexibility in TDD configuration

Conventionally with TDD, when neighboring cells used the same frequency, it was typical to use the same ratio when allocating time resources for uplink and downlink communication, to mitigate interference between neighboring cells. However, traffic characteristics on uplink and downlink differ depending on location. For example, there tends to be more uplink traffic at a sports stadium, as users upload more video and photographs than in other areas. As such, there is demand to configure the TDD uplink-downlink ratio differently for each area, according to traffic characteristics in that area. However, interference needs to be controlled between

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*24 SON: A network installed with functions to self-configure and self-optimize its parameters.

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

*26 Radio access network: The network consisting of radio base stations situated between the core network and mobile terminals to perform radio layer control.

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

*28 X2: A reference point between eNB, defined by 3GPP.

*29 Xn: A reference point between gNB, defined by 3GPP.

*30 TDD: A bidirectional transmit/receive system. It achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions on the same frequency band.

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

TDD cells with different uplink-downlink ratios, so a mechanism was specified for UE to measure interference between cells, to report it to the network, and for the network to control the interference. Note that functions for UE to measure and report interference between TDD cells have been specified, but how the network will control such interference is implementation dependent.

2.2 Technical Enhancements for URLLC

1) Support Industry Automation with IoT and URLLC

In Rel-15, basic URLLC functions are supported, including a Transmission Time Interval (TTI)*36 structure to reduce delay, a Channel Quality Indicator (CQI)*37 and a Modulation and Coding Scheme (MCS)*38 table for communications requiring higher reliability.

Rel-16 NR includes enhancements for Augmented Reality (AR) and Virtual Reality (VR), which were considered in Rel-15, as well as for URLLC and Industrial IoT, for use cases such as factory automation, which requires 99.999999% reliability and latency in the range of 0.5 to 1 ms or less. One example of an enhancement to further reduce delay is to specify settings and UE behavior that could transmit control signals with more flexibility within the slot*39. By doing so, control signals can now be sent in a shorter time interval than with Rel-15. Enhancements that improve reliability include the introduction of a downlink control information*40 format that reduces payload*41 size and increases reliability, and increasing the number of redundant carriers for Packet Data Convergence Protocol (PDCP)*42 layer packet duplicate transmission control. These have increased transmission reliability on the radio segment.

2) Build Private Networks

There is increasing demand to build networks in closed areas, for scenarios such as machinery in a factory, inside a train car, or for smart-city devices, so that only certain devices can connect within a closed area. To meet these demands, 3GPP has introduced a mechanism that will enable existing communications operators or new operators to build independent, private networks, separate from the public networks, which are for mobile telephones and smartphones.

2.3 Technical Enhancements for mMTC

1) Expand the Range of IoT Application, Reduce Power Consumption

Rel-16 LTE specifies functional enhancements related to mMTC, the operation scenario that enables connection of large numbers of devices, including enhanced Machine Type Communication (eMTC)*43 for LTE and Narrow Band Internet of Things (NB-IoT)*44.

Most of the enhancements to eMTC and NB-IoT functions in Rel-16 LTE are extensions to existing functions. For example, the Wake-Up Signal is a function introduced in Rel-15, to reduce UE power consumption by skipping detection of paging signals*45. This was enhanced by specifying the Group Wake-Up Signal, which can issue instructions more finely, to groups of UEs, and reduce power consumption more efficiently. Functional

*32 FDD: A bidirectional communications mode that uses different frequencies and frequency bands for uplink and downlink communications.

*33 Cross-carrier scheduling: A method for directing transmission of data on a carrier using a different carrier.

*34 Subcarrier: An individual carrier for transmitting signals in a multi-carrier transmission scheme such as Orthogonal Frequency Division Multiplexing (OFDM).

*35 Aperiodic CSI-RS trigger: A method whereby a reference signal used to measure radio channel conditions is transmitted when needed, rather than periodically.

*36 TTI: Transmission time per data item transmitted via a transport channel.

*37 CQI: An index of reception quality measured at the mobile station, expressing propagation conditions on the downlink.

*38 MCS: A predetermined combination of data modulation and channel coding rate when performing Adaptive Modulation and Coding (AMC).

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

enhancements were also specified for cell measurement, such as enabling the Resynchronization Signal (RSS)*46 to be used for cell measurements, and enabling more-accurate eMTC cell measurements. Enhancements to various other existing functions are also supported, such as reducing control channel overhead and expanding Coverage Enhancement (CE) mode*47 functions, enabling a wider range of IoT use cases to be supported.

New functionality to be added in Rel-16 was also discussed, including scenarios where NR standalone operation, which is expected in the future, coexists with eMTC and NB-IoT. In particular, radio resource*48 scheduling functions were extended and functions were added to be aware of scenarios coexisting with NR, so that when NR standalone operation becomes more common in the future, eMTC and NB-IoT can operate with greater efficiency and flexibility. In addition to these enhancements to existing functions, new functions also continue to be added, such as Preconfigured Uplink Resources (PUR), which enable uplink data to be sent directly, while remaining in an IDLE state*49, so that devices spend most of the time in an IDLE state, reducing delay and power consumption for IoT device uplink data transmissions.

2) Realize Connected Car Services

Since Rel-14, 3GPP has specified Vehicle to Everything (V2X)*50 communication using sidelinks*51 based on LTE, and in Rel-15, new functions including carrier aggregation, multi-level modulation*52 and delay reductions were added. NR slidelinks were specified in Rel-16, not to replace the basic V2X services covered by LTE sidelinks, but to complement them by targeting advanced V2X services that require lower delay, higher reliability, high capacity or wide coverage. For Rel-16 NR sidelinks, various types of physical channel*53 and resource allocation were specified, as well as basic functions such as Hybrid Automatic Repeat reQuest (HARQ)*54 feedback, CSI feedback, and support for resource configuration functions for sidelinks that span Radio Access Technology (RAT) linking LTE and NR. Further enhancements to NR sidelink functions will be studied for Rel-17 and beyond, such as relay functions and location/positioning functions.

3. Conclusion

This article has described enhancements to 5G radio technologies as prescribed in 3GPP Rel-16 specifications. Some of the technical enhancements introduced here, for eMBB and for IoT and URLLC in support of industry automation, are described in more detail in other articles of this special feature (see [1] [3] [4]). In August 2020, 3GPP began work creating Rel-17, to further advance 5G radio. NTT DOCOMO will continue promoting 5G standardization, and contributing to further development of 5G standards.

REFERENCES

[1] Y, Matsumura et al.: "5G Advanced Technologies for Mobile Broadband," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.90–105, Jan. 2021.

[2] A. Minokuchi et al.: "5G Standardization Trends at 3GPP," NTT DOCOMO Technical Journal, Vol.19, No.3, pp.5–12, Jan. 2018.

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*40 Downlink control information: 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.

*41 Payload: The part of the transmitted data that needs to be sent, excluding headers and other overhead.

*42 PDCP: A sublayer of Layer 2 and protocol that performs encryption, integrity checks, reordering, header compression, etc.

*43 eMTC: An LTE communication specification for low data rate communication for IoT devices (sensors, etc.) using a narrow bandwidth.

*44 NB-IoT: An LTE communication specification for low data rate communication for IoT devices (sensors, etc.) using a narrower bandwidth than eMTC.

*45 Paging signal: A radio signal for notifying a mobile terminal that is in the standby state of an incoming call or network information update.

*46 RSS: A function that sends a cell resynchronization signal, separate from existing synchronization signals, to reduce the time and power needed to resynchronize UE and cell.

*47 CE mode: A UE state in which it receives a signal transmitted repeatedly to expand coverage.

[3] K. Aoyagi et al.: "5G Advanced Technologies for Creating Industries and Co-creating Solutions," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.71–89, Jan. 2021.

[4] T. Takada et al.: "Performance Enhancement Technologies in High-speed Moving Mobile Environments in LTE/NR Release 16," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.106–110, Jan. 2021.

*48 Radio resource: Unit of time or frequency range allocated to each user for communication purposes.

*49 IDLE state: A state in which dedicated resources between the mobile terminal and the radio network are released.

*50 V2X: A generic name for direct Vehicle-to-Vehicle (V2V) communication, direct Vehicle-to-Infrastructure (V2I) communication between vehicle and roadside radio communication devices, direct Vehicle-to-Pedestrian (V2P) communication, and Vehicle-to-Network (V2N) wide-area communication via base stations in a cellular network such as LTE or 5G.

*51 Sidelink: A communication link for communication between UE, without passing through a base station.

*52 Multi-level modulation: A modulation system that includes two or more bits of information in one symbol.

*53 Physical channel: In a radio interface, channels that are separated in terms of a physical resource such as frequency or time.

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

Technology Reports (Special Articles) URLLC Vertical Network V2X

Special Articles on 3GPP Release 16 Standardization Activities

5G Advanced Technologies for Creating Industries and Co-creating Solutions

Core Network Development Department Kenichiro Aoyagi Atsushi Minokuchi
Radio Access Network Development Department Kohei Harada Tianyang Min
6G Laboratories Yuki Takahashi Shohei Yoshioka

The use of 5G technologies is now being envisioned in a variety of industrial fields beyond the mobile communications industry such as smart factories and connected cars now being promoted in various countries. There is also much expectation that 5G connections will not only improve system performance but also help create new industries and solve social problems. This article describes the background to various studies related to industry collaboration in 3GPP Rel-16 and discusses solutions targeting mainly collaborations with industry partners.

1. Introduction

Fifth-generation mobile communications system (5G) technologies are expected to become platform technologies that can support a variety of industries and society in general and provide new value without being limited to conventional mobile communication services. As described in the opening article [1] of these Special Articles, enhancements to use cases and services play an important role in the expansion of 5G technologies. For 3rd Generation Partnership Project (3GPP) Release 16 (hereinafter referred to as "Rel-16") specifications, technical studies were conducted on enhancing 5G keeping in mind collaboration with new partners and technology fusion particularly in fields such as smart factories and connected cars.

This article describes the background to 3GPP Rel-16 studies on solutions that mainly target industry collaboration (hereinafter referred to as "industry collaboration solutions") and the elemental technologies for achieving those solutions.

2. Background to Studies on Industry Collaboration Solutions

Industry collaboration solutions studied for 3GPP Rel-16 came out of the needs and technical requirements of a variety of industry groups that were studying the Smart Factory, Vehicle to Everything (V2X)*1, etc. The following summarizes three examples of industry collaboration solutions.

2.1 Smart Factory

The Smart Factory concept has been attracting attention as an industry collaboration solution. A "smart factory" means a factory that connects all sorts of equipment within the factory to a network, visualizes equipment operation and product quality, and automates equipment operation with the aim of achieving smooth manufacturing processes. The Smart Factory envisions Control-to-Control (C2C) communication between control equipment and motion control*2 systems all connected to a network and demands real-time and high-reliability communications for controlling all of these devices. One means of communication for satisfying such requirements is wired communications, but this approach hinders flexibility in making changes to a manufacturing line. Against this background, the use of 5G with its ultra-reliable and low-latency features has been attracting attention.

In addition, the 5G Alliance for Connected Industries and Automation (5G-ACIA) was established in 2018 as a business organization to study the application of 5G technologies to industrial use cases such as factory automation. About 60 companies from the communications industry and manufacturing industry have come to participate in this alliance as of 2020. At 5G-ACIA, studies are being conducted on requirements for latency and data rate deemed necessary for industrial use cases applying 5G technologies such as factory automation, on how to connect a network operated by a communications operator to a network specialized for industrial use, etc. A white paper compiling a number of results from these technical studies has already been released [2].

2.2 V2X

V2X, or the use of wireless communications in the automobile industry, is another example of an industry collaboration solution. In V2X, sensor data shared between vehicles and all sorts of things can be useful in achieving services related to safe and efficient automobile operation. Amid this recent interest in V2X services, verification trials have been progressing through cooperation between the automobile industry and wireless communications industry [3]. In 2016, the 5G Automotive Association

*1 V2X: A generic name for Vehicle-to-Vehicle (V2V) direct communications between cars, Vehicle-to-Infrastructure (V2I) direct communications between a car and roadside devices (radio communications equipment installed along a road), Vehicle-to-Pedestrian (V2P) direct communications between vehicles and pedestrians, and Vehicle-to-Network (V2N) wide-area communications via base stations in a cellular network such as LTE or 5G.

*2 Motion control: In the automation of production processes, the high-precision moving and rotating of production equipment parts by a specific control method. Frequently used in positioning control and multi-axis robot control in automated factories.

(5GAA)*3 was established as a business organization to promote discussions and collaboration between both industries. As of 2020, more than 130 enterprises have come to participate in this organization.

5GAA consists of seven Working Groups (WGs). For example, WG1 discusses use cases and requirements, and as a result of this work, 5GAA has compiled a white paper on requirements for self-driving cars such as turning right or left when the car crosses into an oncoming lane [4]. 5GAA also submits opinions to 3GPP on such use cases and requirements [5].

Based on such information and opinions, 3GPP has been specifying a V2X standard that is expected to be a radio technology for achieving V2X services (**Figure 1**). (V2X is also called "Cellular V2X" outside of 3GPP to distinguish it from other V2X technologies. This term will be used below.) Cellular V2X can be divided into two types: Vehicular-to-Network (V2N), or base station – terminal communications, and sidelink, or terminal – terminal communications. Here, the Long Term Evolution (LTE)/New Radio (NR)*4 standard specified up to Rel-15 can be used for V2N while the LTE standard specified in Rel-14 and Rel-15 can be used for sidelink communications. In NR Rel-16, technologies for achieving use cases requiring even higher communication performance were studied and specified.

2.3 Local 5G

Various types of requirements for local 5G in Japan are not being directly reflected in 3GPP studies, but in this article, we take them up since

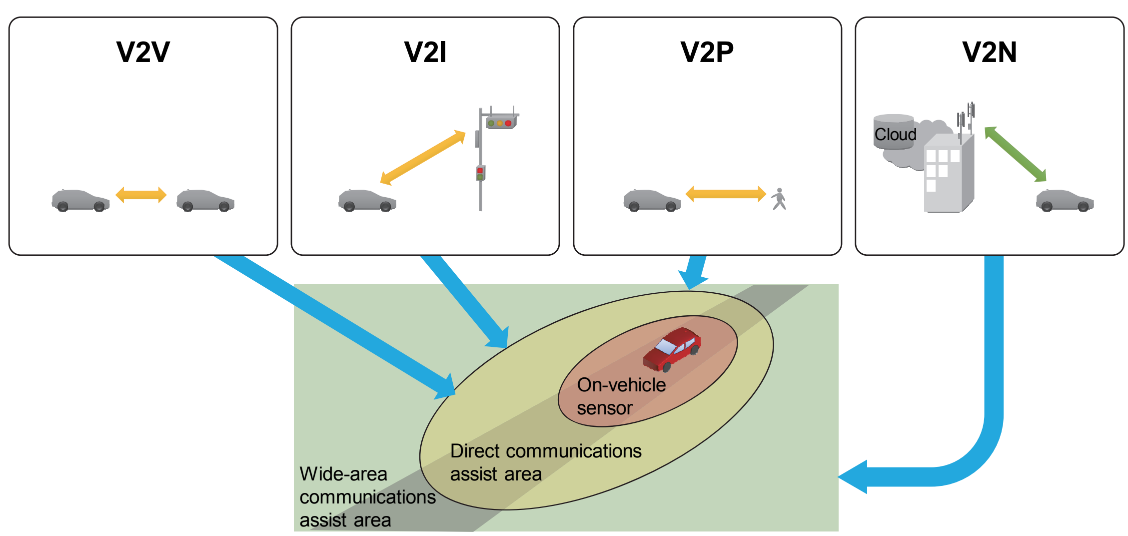

Figure 1 Cellular V2X concept

*3 5GAA: An association founded by automotive and telecommunications players to study and promote connected car services using 5G.

*4 NR: Radio system standard formulated for 5G. Compared with 4G, NR enables high data rate using high frequency bands (e.g. sub-6 GHz bands and 28 GHz band) and low-latency and high-reliability communications for achieving advanced IoT.

they can be treated as technologies related to the practical use of some of the industry collaboration solutions described here. Local 5G in Japan can be positioned as 5G systems constructed and operated according to the environment and needs of specific local governments, factories, research facilities, etc. For example, local 5G can be used to construct a network that appropriates the inter-user network and radio resources*5 in a limited space or area to meet specific requirements such as ultra-low latency. It can also be used to provide flexible 5G environments to secure emergency communications at the time of a crisis or to deal with a variety of regional characteristics and environments such as an aging population and other demographics. In this way, local 5G is expected to bring innovative changes to the social infrastructure, create new business fields, and solve a variety of social problems (**Figure 2**).

3. Elemental Technologies for Industry Collaboration Solutions

Each of the three industry collaboration solutions described above consists of various technical requirements (**Table 1**).

However, in addition to these requirements, even more diverse and complex requirements can

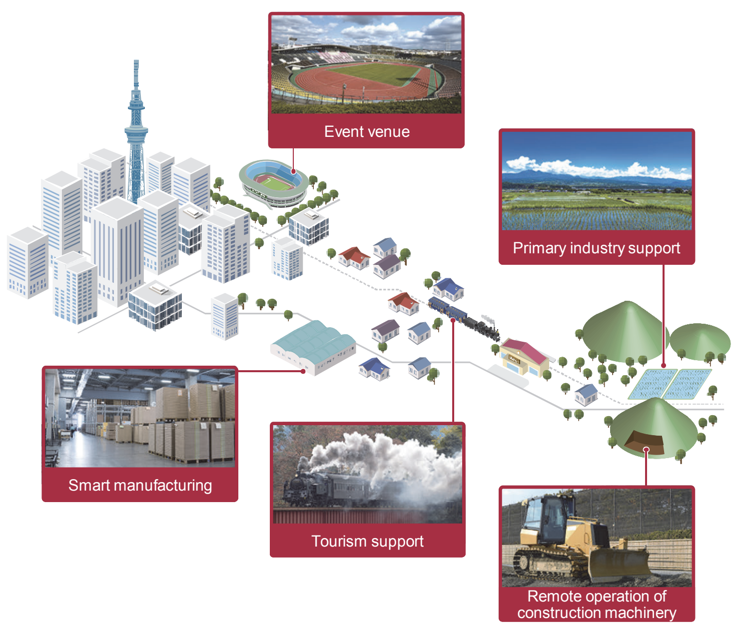

Figure 2 Local 5G concept

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

Table 1 Rel-16 technologies applied to industry collaboration solutions (examples)

	Smart Factory	V2X	Local 5G
URLLC	○	○	
TSN	○		
NPN	○		○
D2D (sidelink)		○	
5G-LAN Type Service	○		
Private Slice		○	○
Predictive QoS		○	

○ Main application example

be anticipated such as those for smart grid*6 systems. Thus, in Rel-16, the following functional enhancements and advancements were made as elemental technologies for achieving industry collaboration solutions in addition to NR and platform technologies of the 5G system. This was done to satisfy diverse technical requirements taking into account special environments such as closed areas.

3.1 URLLC

At 3GPP, the main features of 5G are taken to be (1) enhanced Mobile BroadBand (eMBB), (2) massive Machine Type Communications (mMTC), and (3) Ultra-Reliable and Low Latency Communications (URLLC). Among these, technologies for achieving high reliability and low latency have been made into specifications for achieving the industry collaboration solutions described above. At 3GPP, requirements for NR Rel-16 URLLC are defined for individual use cases. For example, the target values for factory automatic motion control*7 are "latency of 2 ms or less and reliability of 99.9999 or greater when sending a 20-byte packet." The following describes NR Rel-16 URLLC that has been made into specifications for satisfying these requirements.

1) Technical Enhancements for Low Latency Communications

(a) Intra-UE uplink prioritization

When data and signals with different latency and reliability requirements are sent from User Equipment (UE) in uplink communications toward control devices in a factory, cases can be envisioned in which collisions occur and critical control data arrive late. For example, in the event that an in-factory robot has left its designated area, it would be necessary for a monitoring sensor to send data on that situation to the control center so that it can shut down the robot immediately. The requirements for transmitting such a control signal at the time of an emergency are more stringent than those of an ordinary control signal in terms of latency

*6 Smart grid: A power distribution network that incorporates radio sensors in the power system to autonomously monitor, control, and optimize the supply side and demand side in real time.

*7 Factory automatic motion control: An automatic control system for strictly controlling the operation (movement, rotation, etc.) of production machines in a factory in specific cycles. This system can be incorporated, for example, in large printing machines and packaging machines.

and reliability, so that data must be sent on a priority basis. For this reason, the operations to be performed when multiple uplink transmissions having different levels of priority within the UE are about to collide have been specified for the physical layer*8 and higher layers*9.

- Prioritization on the physical layer

  Functions were specified on the physical layer for assigning levels of priority to uplink channels and signals such as the Physical Uplink Control Channel (PUCCH)*10, Physical Uplink Shared Channel (PUSCH)*11, and Sounding Reference Signal (SRS)*12 and for prioritizing the uplink transmissions with high priority. Specifically, two levels of priority—high priority and low priority—are supported here, and the priority level of PUCCH and PUSCH are set by dynamic indication based on Downlink Control Information (DCI)*13 and by higher-layer signaling*14. The priority level of SRS, meanwhile, is always set to low priority. In the case that high-priority and low-priority uplink transmissions have been scheduled in the same Orthogonal Frequency Division Multiplexing (OFDM) symbols*15, the low-priority uplink transmission will be dropped and only the high-priority uplink transmission will be performed.

- Prioritization on higher layers

  A new function called "intra-UE overlapping resource prioritization" was introduced in the upper layers as well. In the event that a configured grant*16 transmission collides with a dynamic grant*17 transmission or another configured grant transmission, this function compares the level of priority of the associated logic channels*18 and prioritizes the logic channel having transmission data with the highest level of priority. For a transmission given a low-priority status by the above process, the UE can save it if a Media Access Control Protocol Data Unit (MAC PDU)*19 has already been created and schedule it for retransmission to the base station. However, if a transmission set to low priority happens to be a configured grant, the base station cannot recognize the MAC PDU saved by the UE and cannot therefore schedule a retransmission. For this reason, a new function called "autonomous transmission" was introduced for autonomously resending the MAC PDU saved by the UE.

(b) Inter-UE uplink prioritization

In a factory, it can be assumed that multiple control terminals may simultaneously try to send data having different latency and reliability requirements. It is therefore necessary at such a time to prioritize the communications of a control terminal that is sending data with stringent latency and reliability requirements to prevent those data from arriving late. For this reason, uplink

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

*9 **Higher layers:** All layers positioned above the physical layer such as MAC, PDCP, Radio Link Control (RLC), S1 Adaptation Protocol (S1AP), and X2 Adaptation Protocol (X2AP).

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

*11 **PUSCH:** Physical channel used for sending and receiving data packets in the uplink.

*12 **SRS:** Uplink reference signal for measuring channel quality and reception timing etc. with the base station.

*13 **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.

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

cancellation and uplink transmission power control were specified to perform inter-UE prioritization of uplink channels.

Uplink cancellation is a function that cancels a low-priority uplink transmission previously scheduled for a certain UE if a high-priority uplink transmission then comes to be scheduled for another UE using the same resources. In this process, a UE will be indicated via DCI of resources targeted for cancellation and the transmission of PUSCH or SRS scheduled to use those resources will be dropped. The level of priority that can become a target for cancellation can be set through higher-layer signaling.

Uplink transmission power control, meanwhile, is a function that performs prioritization by increasing the transmission power of UE transmitting high-priority PUSCH. Here, the target transmission power for a high-priority PUSCH will be indicated by DCI format 0_1 or 0_2.

The uplink-cancellation function described above increases the load on UE for which low-priority uplink transmission was previously scheduled. On the other hand, uplink transmission power control increases the load of UE for which high-priority uplink transmission has been scheduled.

(c) PDCCH enhancements

A control terminal in a factory that seeks to send or receive data having stringent requirements with respect to latency must receive scheduling information from the base station in a short interval. An enhancement for receiving the Physical Downlink Control Channel (PDCCH)*20 in a short interval was therefore made. In NR Rel-15, the interval in which UE can receive the PDCCH is defined in terms of slot*21 units. In NR Rel-16, on the other hand, one slot is divided into multiple spans (each a combination of multiple OFDM symbols) making it possible to receive PDCCH in each span. A span may consist of a combination of two OFDM symbols, four OFDM symbols, or seven OFDM symbols. This capability is supported only for an OFDM subcarrier*22 of 15 kHz or 30 kHz. For example, given a subcarrier interval of 15 kHz and a span consisting of two OFDM symbols, the UE can receive PDCCH at seven times the frequency compared with the PDCCH receiving interval in NR Rel-15. PDCCH is used in the scheduling of the Physical Downlink Shared Channel (PDSCH)*23 to the UE and the scheduling of PUSCH and PUCCH, so in NR Rel-16, it can be sent and received in shorter intervals than that of NR Rel-15, which should make for low latency.

(d) PUCCH enhancements

When a control terminal in a factory receives PDSCH from the base station, it is desirable that a Hybrid Automatic Repeat reQuest-ACKnowledgement (HARQ-ACK)*24 be transmitted in a more flexible and faster manner to ensure high reliability and low latency. In NR Rel-15, HARQ-ACK indicating

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*15 OFDM symbols: A multi-carrier modulation format where information signals are modulated with orthogonal subcarriers. A type of digital modulation scheme where information is split across multiple orthogonal carriers and transmitted in parallel. It can transmit data with high spectral efficiency.

*16 Configured grant: A mechanism for allocating PUSCH resources beforehand from the base station on a user-by-user basis so that UE can transmit PUSCH by those resources if uplink data is generated without having to transmit a Scheduling Request (SR).

*17 Dynamic grant: A mechanism for allocating transmission resources for uplink data after a UE requests scheduling and receives DCI from the base station.

*18 Logic channels: Channels that divide transmission information by application.

*19 MAC PDU: A protocol data unit on the MAC layer. PDU expresses protocol data including the header and payload (see *47).

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

transmission in a certain slot is grouped together as a HARQ-ACK Codebook (CB)*25. In addition, one PUCCH resource from among eight PUCCH-resource candidates is selected and transmitted in slot units.

In NR Rel-16, in contrast, a certain slot can be divided into multiple OFDM symbol units enabling HARQ-ACK CB to be transmitted within such a unit. For example, when dividing a slot into seven OFDM symbol units, a maximum of two HARQ-ACK CB can be transmitted in one slot (14 OFDM symbols). Here, eight PUCCH-resource candidates can be set for each symbol unit after division. This approach improves flexibility in specifying PUCCH resources to be used in transmitting HARQ-ACK CB and promotes low latency.

(e) PUSCH enhancements

A control terminal in a factory that seeks to perform uplink communications must first receive scheduling information from the base station. However, to improve the reliability of communications in the air interface, it can be assumed that a control terminal will transmit the same data multiple times. Transmitting scheduling information multiple times for the same data, however, creates overhead*26 that can increase latency over the entire system. For this reason, NR Rel-15 supported a function for transmitting PUSCH repeatedly with the same channel configuration across multiple slots based on the scheduling obtained from a single PDCCH. With this scheme, however, continuous transmission may not be possible depending on the channel configuration, and latency may increase as a result. The number of repeated transmissions here can be set through higher-layer signaling.

Now, in NR Rel-16, this function has been upgraded to enable repeated transmission of consecutive OFDM symbols. In the case that a certain transmission here is scheduled across the boundary between slots, that transmission will be divided in a slot-by-slot manner. In this way, PUSCH can be transmitted with low latency while improving reliability. Moreover, in addition to static setting of the number of repeated transmissions by higher-layer signaling, dynamic indication of the number of repeated transmissions by DCI has been introduced thereby enabling repeated transmission of PUSCH in a flexible manner.

(f) Scheduling enhancements

Scheduling enhancements were made to reduce conflicts between diverse URLLC traffic periods and configured-grant/Semi-Persistent-Scheduling (SPS) configuration*27 periods by enabling multiple configured grants (maximum 12 grants) and SPS (maximum 8 instances) to be set in one cell. Additionally, to reduce signaling overhead, collective deactivation*28 of multiple previously set configured grant type2*29/SPS configurations by PDCCH was enabled. Furthermore, to support the scheduling of URLLC traffic having

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

*22 Subcarrier: Individual carrier for transmitting signals with multi-carrier transmission such as OFDM.

*23 PDSCH: Physical channel for sending/receiving data packets in the downlink.

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

*25 HARQ-ACK CB: A set of bits when transmitting multiple HARQ-ACK bits on a single uplink channel.

*26 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, as well as redundant transmission of such control information and reference signals.

*27 SPS configuration: A scheduling technique for performing semi-persistent resource allocation.

*28 Deactivation: The act of deactivating transmission by radio resources set by RRC.

extremely short periods (for example, the control traffic period generated by a packaging machine*30 is under 1 ms), the NR Rel-16 SPS shortest transmission period was set to 0.125 ms as an enhancement over the 10 ms shortest transmission period of NR Rel-15.

2) Technical Enhancements for Improving Communications Reliability

In NR Rel-15, packet duplication transmission control on the Packet Data Convergence Protocol (PDCP)*31 layer was introduced as technology for improving communications reliability in the radio interface [6]. Then, to further improve communications reliability in the radio interface, PDCP-layer packet duplication transmission control was enhanced in NR Rel-16. Differences in PDCP-layer packet duplication transmission control between NR Rel-15 and NR Rel-16 are shown in **Figure 3**. As shown, NR Rel-15 PDCP-layer packet duplication transmission control enables duplicate transmission by setting two carriers by Radio Resource Control (RRC)*32. On the other hand, NR Rel-16 PDCP-layer packet duplication transmission control

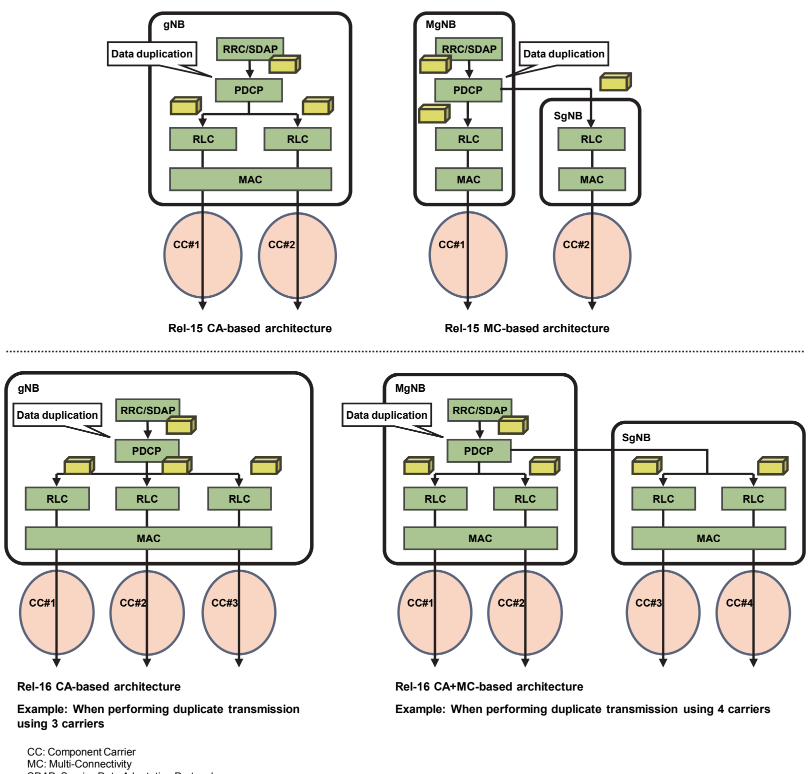

Figure 3 Differences in duplicate transmission between Rel-15 and Rel-16

*29 Configured grant type2: A transmission method that allocates PUSCH resources beforehand (periodically) from a base station and that activates a PUSCH transmission by PDCCH using those resources at any time.

*30 Packaging machine: A machine that automatically performs packaging operations. Packaging processes include filling, sealing, labeling, and wrapping of a product.

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

*32 RRC: Layer 3 protocol that controls radio resources in the radio network.

enables duplicate transmission by setting a maximum of four carriers from among Master gNB (MgNB)*33 and Secondary gNB (SgNB)*34 carriers by RRC. Since a maximum of four carriers can be set here, duplicate transmission becomes possible by selecting, for example, only three carriers as shown at the bottom left of the figure or all four carriers as shown at the bottom right of the figure. Moreover, given that the condition of the radio interface in which the UE is communicating can change dynamically due to radio quality, congestion, etc., the ability to control the carriers to be used for duplicate transmission in a dynamic manner as needed was specified the same as in NR Rel-15. For the case in which some carriers are not needed for duplicate transmission, this type of control can turn duplicate transmission in a certain carrier OFF to prevent a drop in resource usage efficiency.

Functional enhancements were also specified in Rel-16 on the core network*35 side in relation to URLLC communications. To improve reliability on the U-plane*36, the reliability of the data path can be guaranteed through flexible setting of redundant paths*37 according to various requirements such as network configuration (**Figure 4**). Enhancements were also made for the case of terminal mobility such as improvements in latency in relation to handover*38 and a function for monitoring Quality of Service (QoS).

3.2 TSN

Time Sensitive Network (TSN) is technology for achieving time synchronization in real-time communications between communications equipment as in Internet of Things (IoT) systems and for achieving low-jitter communications. IEEE TSN is the TSN standard in IEEE 802*39 composed of a variety of

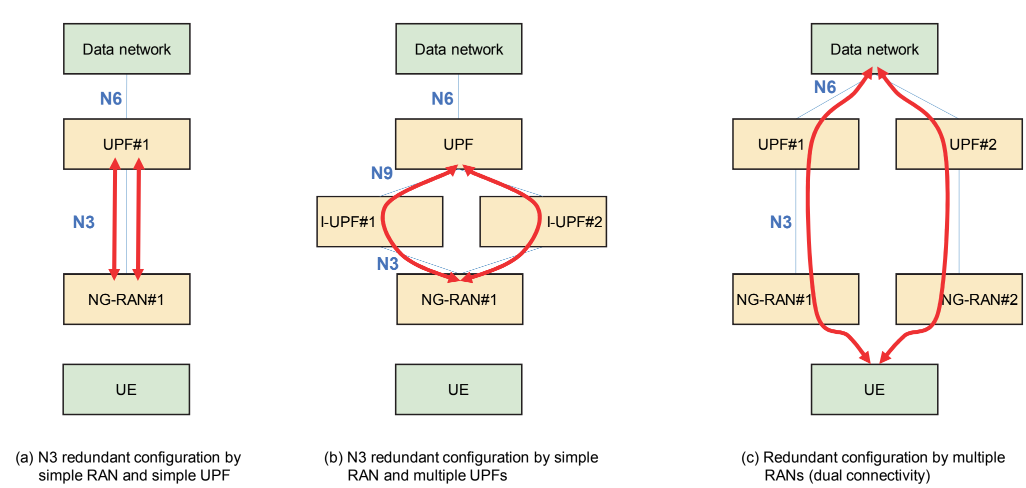

Figure 4 Redundant paths in URLLC

*33 **MgNB:** The gNB that serves as master node in Dual Connectivity (DC).

*34 **SgNB:** The gNB that serves as secondary node in DC.

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

*36 **U-plane:** The part of the signal sent and received in communications, which contains the data sent and received by the user.

*37 **Redundant paths:** The setting of multiple transmission paths for transmitting and receiving the same data to improve the reliability of communications.

*38 **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal moves from the coverage area of one base station to another.

*39 **IEEE 802:** IEEE Committee that defines standards related to LAN and Metropolitan Area Network (MAN). Commonly known as LAN/MAN Standards Committee (LMSC).

enhanced communication standards based on Ethernet.

A smart factory requires high-accuracy time synchronization. For example, the requirement for end-to-end synchronization accuracy in motion control is under 1 μs. In Rel-16, functional enhancements were made to apply feature technologies of the NR/5G system to TSN and to achieve Time Sensitive Communication (TSC) that performs precise time synchronization and low-jitter communications in a 5G system.

First, as a configuration for achieving TSN in an NR/5G system, the entire NR/5G system is taken to act as a bridge in TSN and the Central Network Controller (CNC)*40 in TSN adopts a fully centralized model*41 to control inter-port communications (**Figure 5**). This bridge adopts some of the techniques in IEEE 802.1Q*42 for inter-port traffic scheduling. Communication paths are set via this bridge between each unit of terminating equipment (such as IoT terminals) and the TSN Grand Master (GM) that performs integrated management of TSN system time. Here, the bridge takes on some of the burden of time synchronization control and supports some parts of IEEE802.1 AS*43.

In other words, a variety of network control technologies in an NR/5G system such as high-speed and large-capacity NR plus URLLC, QoS, security, etc. can be applied within this TSN bridge. A high-quality, high-reliability TSN that applies 5G feature technologies can therefore be constructed while achieving flexible equipment layout even in a complex environment such as a factory (**Figure 6**).

Additionally, to achieve high-accuracy time synchronization between UE and gNB, a function was specified to enable the base station to broadcast/unicast high-accuracy 5G system reference timing (time granularity: 10 ns) to a UE as a solution on

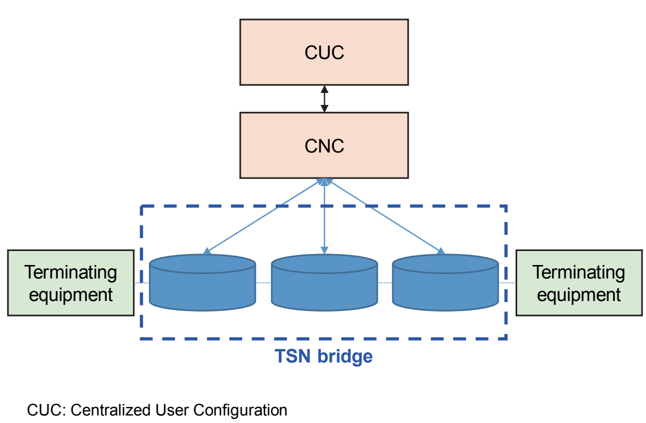

Figure 5 TSN fully centralized model

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*40 **CNC:** A component that controls a TSN bridge in TSN.

*41 **Fully centralized model:** A TSN model. A model for managing terminating equipment and applications in an integrated manner in a Centralized User Configuration (CUC).

*42 **IEEE 802.1Q:** A standard related to a network based on bridges and bridge configurations in a Local and Metropolitan Area Network.

*43 **IEEE802.1 AS:** A standard related to time synchronization control in a Local and Metropolitan Area Network.

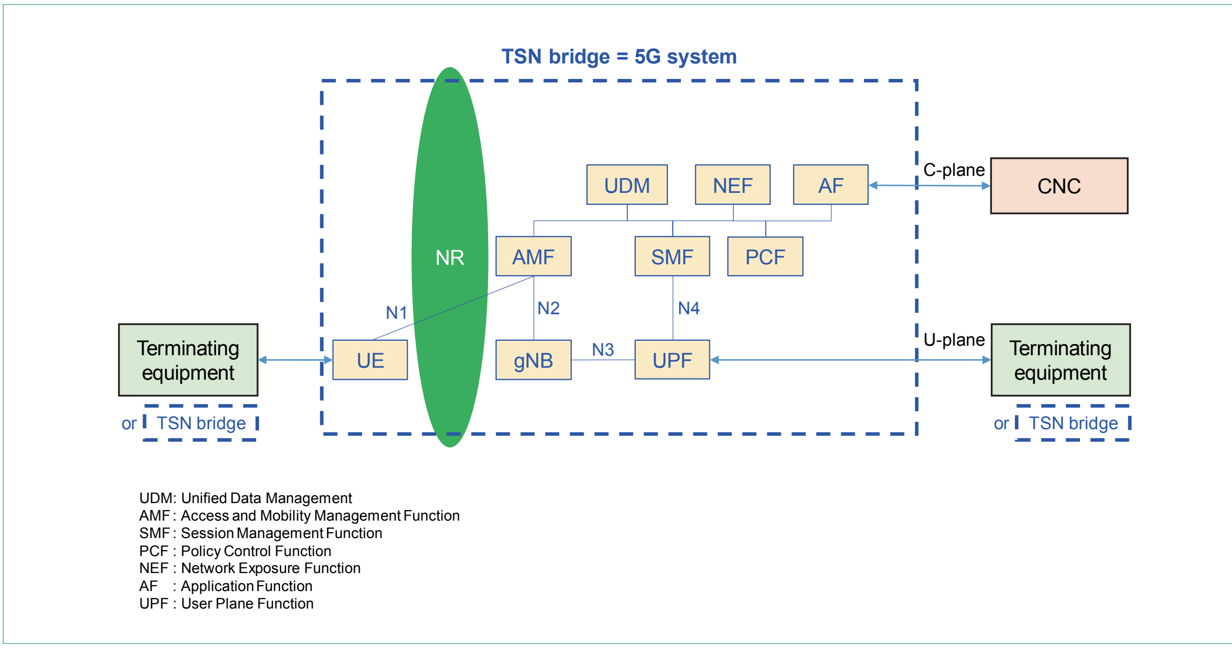

Figure 6 Example of a configuration applying a 5G system to a TSN bridge

the Radio Access Network (RAN)*44 side. A function has also been introduced on the UE side for making autonomous requests to the base station for 5G system reference timing to deal with synchronization offsets within the terminal. The base station, meanwhile, can obtain traffic-related Time Sensitive Communication Assistance Information (TSCAI) from the core network at QoS flow*45 setup and handover time. TSCAI includes arrival times and periodicity information for traffic having stringent latency requirements, which makes it useful for achieving efficient base station scheduling.

IEEE TSN uses the Ethernet frame*46 format, so it can be assumed that Ethernet frames will be transferred between UE and gNB when a 5G system plays the role of a TSN Bridge. It is also assumed here that the payload*47 size of such an Ethernet frame is small compared with header size. To therefore reduce overhead, an Ethernet Header Compression (EHC)*48 function in the PDCP sublayer has been specified in NR Rel-16. The principle of header compression, as in the case of Robust Header Compression (RoHC)*49, is to have the receive side save header elements whose contents do not change and associated Context ID (CID)*50 in memory so that the transmission of those saved elements can be omitted and to have decompression performed on the receive side. Please see a 2014 article in this journal [7] for details on RoHC control. The procedural flow of EHC is shown in **Figure 7**. Referring to steps (a) – (c) in the figure, header compression is performed in the following way.

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*44 RAN: A network consisting of radio base stations and radio-circuit control equipment situated between the CN (see*35) and mobile terminals.

*45 QoS flow: An IP flow unit that differentiates between QoS classes (communication service quality (allowed latency, packet loss rate, etc.)) in a Protocol Data Unit (PDU) session tunnel set up between a base station and the core network.

*46 Ethernet frame: Data format used for Ethernet LAN communications.

*47 Payload: The part of the transmitted data that needs to be sent, excluding headers and other overhead.

*48 EHC: A PDCP sublayer function for compressing the header of an Ethernet frame transmitted between UE – gNB. Compresses, in particular, the transmit MAC address, receive MAC address, payload type, Q-Tag (option) in the header part of an Ethernet frame. Any Ethernet frame length can be compressed.

*49 RoHC: A technique for compressing the RTP/IP/UDP header specified in RFC documents.

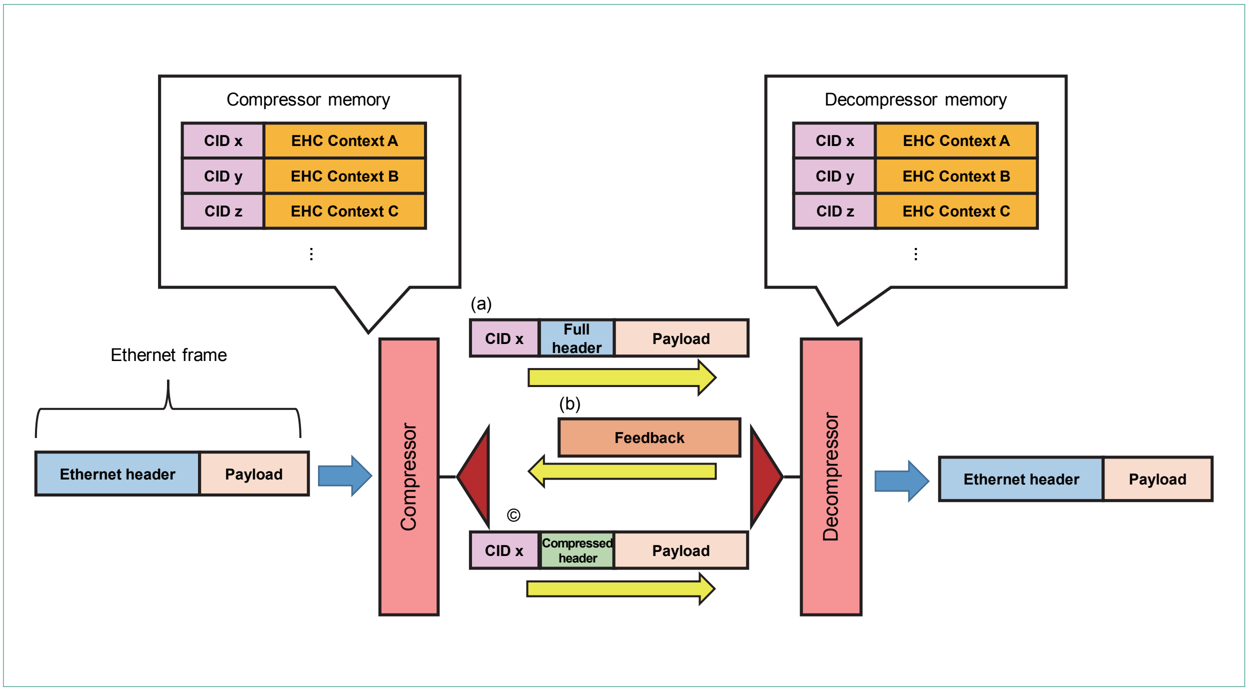

Figure 7 EHC compression/decompression procedure

(a) The transmit side sends the full header*51 of a certain packet and CID associated with that full header to the receive side.

(b) To notify the transmit side that it has saved that context*52 in memory, the receive side sends it feedback on saved context.

(c) After receiving the feedback, the transmit side considers that the receive side has saved that context and proceeds to compress the header and to send the data.

Ethernet header compression can be applied in either the downlink or uplink direction, so for a downlink, the transmit side would be evolved NodeB (eNB)*53 or gNB while the receive side would be a UE.

3.3 NPN

In contrast to a Public Network (PN) provided by a telecom operator for universal use by the general public, a Non Public Network (NPN) refers to technology for configuring a closed network that appropriates radio resources such as frequency as well as base stations and network resources and limits access to specific users or groups. In addition, the appropriation of radio/network resources in this way contributes to improved performance in terms of high-speed, large-capacity, and ultra-low-latency communications compared with a PN. In Rel-16, two NPN architecture formats are specified: Public Network Integrated NPN (PNI-NPN) that constructs dedicated-network base stations as a part of an operator's 5G PN and Standalone NPN

*50 CID: An ID assigned to identify context (see *52). The receive side restores a header based on the received CID, uncompressed header elements, and context corresponding to that CID stored in local memory.

*51 Full header: The header part of an Ethernet frame before compression in the PDCP entity. It consists of the transmit MAC address, receive MAC address, Ethernet frame length or Ethernet payload type, and Q-Tag (option).

*52 Context: The content of Ethernet header elements stored in receive-side memory. An ID is assigned to each context.

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

(SNPN) that constructs a network independent of the operator's network (**Figure 8**).

1) PNI-NPN

PNI-NPN is network architecture that accommodates an NPN within a network the same as a 5G Core Network (5GC) that accommodates a PN (Fig. 8 (a)). This format applies Closed Access Group (CAG) as access control. Here, UE tries to access an upper cell that judges access rights by cross-checking the CAG ID sent from that cell through broadcast system information*54 against a list of CAG IDs that are accessible on the UE side for setting and saving. However, UE with no CAG ID settings is "cell barred" meaning that it cannot access that cell and cannot be a target of cell selection processing. At the same time, NPNUE residing in the PNI-NPN is allowed to access the PN by setting an operator code (Public Land Mobile Network (PLMN)*55 ID), the same as in a PN.

The core network manages a CAG list accessible to UEs based on contract information, etc. and "CAG only" information that determines whether access to the PN described above is allowed and provides this information to the UE. Furthermore, by notifying base stations of the CAG list described above and "CAG only" settings, a base station can use that information in access control to a CAG cell for the UE in connected mode, e.g., by handover.

2) SNPN

In contrast to PNI-NPN that is accommodated in the core network of a PN, SNPN is accommodated in a core network configured in a standalone

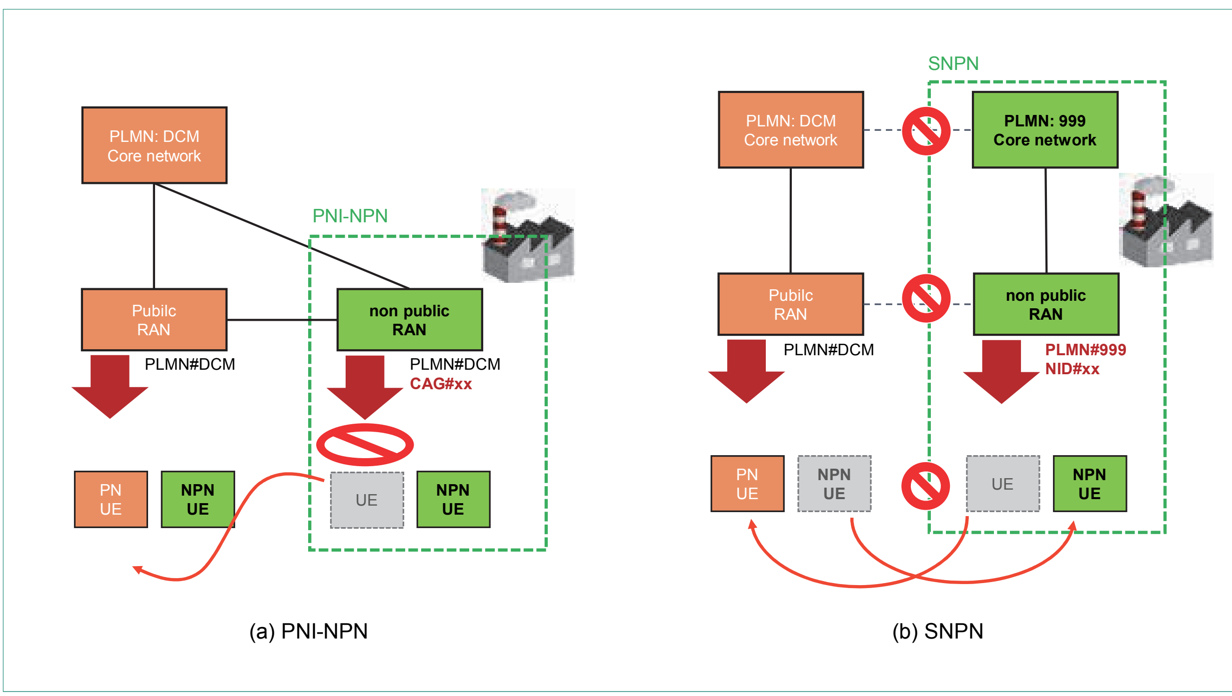

Figure 8 NPN configurations

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*54 **Broadcast system 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.

*55 **PLMN**: An operator that provides services using a mobile communications system.

manner independent of the PN (Fig. 8 (b)). In a SNPN, a Network ID (NID) is set separately from a PLMN ID, and a UE set with that NID proceeds to select that NID in operator selection processing activated when terminal power is turned on. In other words, an NPNUE residing in a SNPN differs from an NPNUE residing in a PNI-NPN and cannot move to a PN set with a different PLMN ID. An SNPN cell can be identified by a combination of a PLMN ID and NID provided by system information. In addition, authentication processing in a SNPN is carried out independent of the PN. Here, Extensible Authentication Protocol Transport Layer Security (EAP-TLS)*56 that uses an authentication key obtained from the terminal can be applied to the authentication system. In this case, the terminal can reside in the network without using a Universal Subscriber Identity Module (USIM)*57, which enhances the flexibility of compact terminals used in IoT and similar systems and makes it easy for a vendor or other enterprise to construct a proprietary network.

3.4 V2X

1) V2X Architecture

In anticipation of applying 3GPP mobile radio systems to connected cars and other systems, V2X system architecture using NR/5G systems has been specified in NR Rel-16. The use of network slicing*58, a feature technology of 5GC, is also expected, and a value indicating a V2X application has been newly specified in the Slice/Service Type (SST) value, which is an information element that selects a network slice.

2) V2X Lower-layer Specifications

Among communications in cellular V2X, all specifications prescribed up to NR Rel-16 can be used for V2N. The abovementioned standard for URLLC, in particular, has been discussed and specified assuming connected cars as one of the targeted use cases. Meanwhile, for sidelink communications, the following has been specified based on a NR Rel-15 base station – terminal communications system [8] and a LTE sidelink communications system.

(a) Feature functions of NR sidelink communications

NR sidelink communications has been studied as a means of satisfying high performance requirements for communication speed, reliability, and latency, and new structures and functions have been adopted relative to LTE sidelink communications.

- Radio frame*59 structure: Multiple OFDM subcarrier intervals (15 kHz, 30 kHz, 60 kHz, 120 kHz) can be applied. This is the same as base station – terminal communications in NR Rel-15 in which a wide subcarrier interval is effective in tracking high-speed movement and reducing latency.
- Communication types: Three types of communication are specified on the physical layer: broadcast, groupcast, and unicast. LTE sidelink communications specified only the broadcast type, which made it necessary to set overly safe values for communication parameters to ensure

*56 EAP-TLS: An authentication protocol specified by IETF that issues a digital certificate on both the client side and server side to enable mutual authentication.

*57 USIM: An IC card used to store information such as the phone number contracted with a mobile operator. A subscriber identity module used for mobile communications in 3GPP W-CDMA/LTE and 5G applications.

*58 Network slicing: A network format provided in 5GC. Technology that logically or physically divides network equipment and network resources according to service requirements such as use cases, business models, etc.

*59 Radio 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.

communication quality. However, newly specified groupcast and unicast types enable appropriate communications based on the channel state with limited communication targets, which leads to better resource utilization efficiency while maintaining communication quality. These new communication types are also effective in avoiding unnecessary decoding processing in UEs other than the communication targets. One example of applying a newly specified communication type would be the use of groupcast in vehicles platooning. This would enable efficient communications among the vehicles making up a platoon.

- Traffic types: Various elemental technologies have been specified assuming periodic and aperiodic traffic. In the case of unpredictable and highly urgent data, they enable transmission that satisfies high performance requirements for reliability and latency. For example, if the possibility arises that an automobile accident is imminent, immediate communications among nearby vehicles could prevent that accident from occurring. In this regard, LTE sidelink communications have been specified assuming only periodic traffic.
- Retransmission function: Retransmission has been specified based on feedback (HARQ feedback) on the physical layer. Improved performance in terms of reliability and latency is expected with each data transmission, and from a system point of view, avoiding retransmission beyond what is necessary leads to improved system performance overall. This function is specified in addition to blind retransmission adopted in LTE sidelink communications.
- Multiple Input Multiple Output (MIMO)*60, higher order modulation: NR sidelink communications can perform up to two layers of transmission. Additionally, as a data modulation scheme*61, 256 Quadrature Amplitude Modulation (256QAM)*62 has been specified. 256QAM increases the amount of data that can be transmitted in a certain time-frequency resource, which improves data rate. In NR Rel-16 specifications, the sharing of video between vehicles is envisioned as a use case. MIMO/256QAM is expected to be one of the functions making such a use case possible.

(b) Inter-terminal synchronization

Inter-terminal synchronization is necessary for achieving sidelink communications using the above structures and functions. This synchronization is performed using the same structure and procedure as LTE sidelink communications. That is to say, signals are transmitted and received based on the timing of a Global Navigation Satellite System (GNSS)*63, eNB/gNB, or UE (vehicle, etc.) synchronization signal*64. The UE synchronization signal is specified with the structure

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*60 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.

*61 Data modulation scheme: Technology for transmitting and receiving multiple signals at the same time using certain time/frequency/space resources. In 256QAM (see *62), there are 256 combinations of amplitude and phase and transmitting one of those combinations enables 8 bits to be transmitted together.

*62 256QAM: A type of modulation scheme. 256QAM modulates data bits through 256 different amplitude and phase signal points. A single modulation can transmit 8 bits of data.

*63 GNSS: Generic name for satellite positioning systems such as GPS and Quasi-Zenith Satellite System (QZSS).

*64 Synchronization signal: A physical signal that enables detection of the synchronization source identifier, and frequency and reception timing required by the mobile terminal to start communications.

shown in **Figure 9**.

(c) Resource allocation

In a state in which inter-terminal synchronization has been established, the UE transmitting data uses the resources determined by either of two resource allocation techniques (Mode 1, Mode 2) to transmit that data.

In Mode 1, the UE uses the resources provided by the gNB, which can indicate either periodic or aperiodic resources.

In Mode 2, in contrast, the UE autonomously selects the resources that it needs. Specifically, it receives resource reservation information from other UEs and selects available resources based on the information. Resource reservation can be applied to either periodic or aperiodic resources. Also specified is a function for reevaluating whether previously selected resources can indeed be used immediately before attempting to use them and a function for reselecting resources if previously reserved resources are reserved by another UE. These functions are effective in avoiding collisions in transmitted or received signals between terminals, which suggests that required communication quality can be satisfied even in the case that resources are autonomously selected by each UE.

We note here that for both resource allocation techniques, resources are allocated in units of slots the same as in LTE sidelink communications.

(d) Control-channel/shared-channel structure

Using the allocated resources, the UE

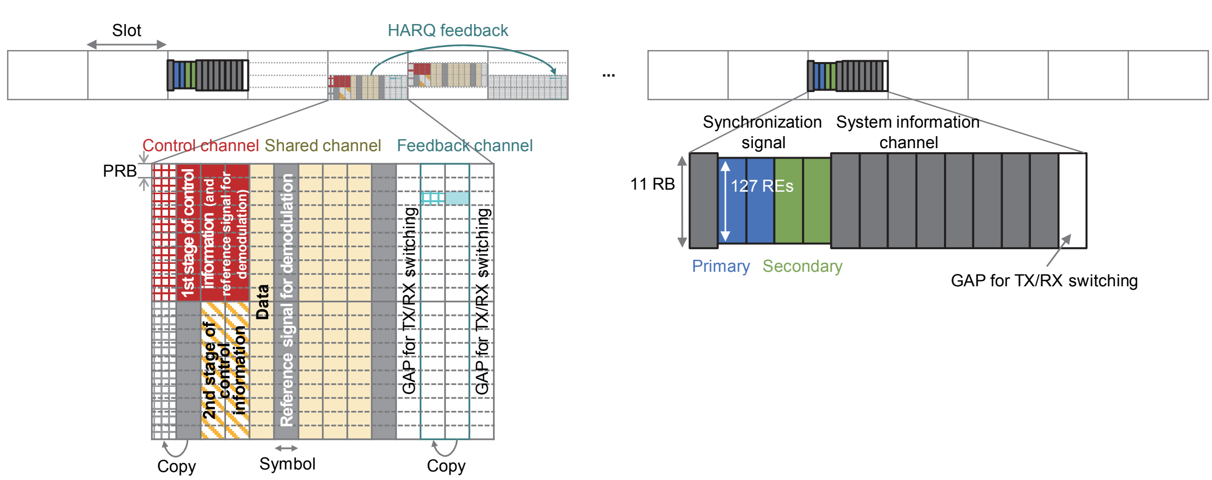

Figure 9　Example of a physical channel configuration for sidelink use

transmits data and associated control information to another UE. The physical channel*65 used here for transmitting information and data consists of the control channel and shared channel shown in Fig. 9, where the former contains the 1st stage of control information and the latter the 2nd stage of control information plus data.

The control channel is positioned at the front of the slot to reduce latency. The 1st stage of control information contains information indicating that other UEs will perform blind decoding*66, which is necessary to receive and decode the 2nd stage. The 2nd stage of control information contains various types of information including that necessary for the UE receiving the 1st stage to receive and decode the data. Resource reservation information described above is contained in the 1st stage of control information while communication type, destination information, etc. are contained in the 2nd stage. Dividing control information into two stages in this way enables flexible control of the resources used in transmitting each stage of control information based on channel state while improving resource usage efficiency and received quality. Furthermore, by enabling the 2nd stage format to be changed while treating the 1st stage format as common ensures forward compatibility.

(e) Retransmission based on feedback information on the physical layer

A UE receiving data addressed to itself via a groupcast or unicast can transmit feedback information to the originating UE. As shown in Fig. 9, HARQ feedback is performed on a dedicated physical channel and the resources available for the channel as shown are provided with a specific slot period. A resource for HARQ feedback with respect to certain received data is uniquely determined by the transmission resource for that data and by transmission source/destination information. This mechanism does not require UE blind decoding while avoiding feedback-channel collisions even for Mode 2 described above. Additionally, for Mode 1, HARQ feedback can be sent to the gNB from the originating UE transmitting the data. The gNB can then schedule retransmission based on the received feedback information.

(f) Other functions

Functions other than those described above have also been specified to satisfy various requirements. These include Channel State Information (CSI) feedback*67, power control based on downlink/sidelink path loss*68, and congestion control*69. Additionally, for V2N in which one side is either LTE or NR, a function has been specified for allocating sidelink resources to the other side.

3.5 Other Related Technologies

1) 5G-LAN Type Service

Functions for managing communications within a specific group, group management that defines a 5G Virtual Network (VN) group*70, User Plane

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

*66 Blind decoding: Receive-side UE processing that attempts to receive and decode a signal that may have been transmitted regardless of whether that transmission actually occurred.

*67 CSI feedback: In communications between two units of equipment, technology for transmitting a reference signal from one unit, receiving that signal and measuring channel quality from that signal on the other unit, and reporting that quality to the transmitting unit. The reported information can then be used to decide on various transmission parameters with the aim of improving communications quality and spectral efficiency.

*68 Path loss: Propagation path loss estimated from the difference between the transmitted power and received power.

Function (UPF) call back*71 that performs in-house communications, inter-UPF interface N19, etc. are being introduced within individual factories, offices, etc.

2) Private Slice

While the previously described PNI-NPN is ranked as technology that can achieve an appropriation/division of radio resources (base stations, frequencies), the use of network slicing is also envisioned as a means of achieving end-to-end resource division that includes the core network. 5GC Rel-16 specifies Network Slice Specific Authentication and Authorization (NSSAA) that enhances the network slicing function and independently applies authentication and authorization procedures within a specific network slice. For details on this technology, please see a separate article in this issue [9].

3) Predictive QoS

In autonomous driving and similar fields, there is a need for collecting and analyzing high-definition video data captured by on-vehicle cameras in real time. It is therefore important to be able to predict the quality of communications in the area corresponding to that vehicle's driving route and time period. In Rel-16, the Network Data Analytic Function (NWDAF)*72 specified for 5GC makes it possible to analyze various types of data accumulated within the network and to predict future communications quality. Processing for obtaining information such as analysis results from external servers and applications via the Network Exposure Function (NEF)*73 has also been specified. For details on this technology, please see a separate article in this issue [9].

4. Conclusion

This article described industry collaboration solutions under the NR/5G system specified in 3GPP Rel-16. Rel-17 and beyond is expected to provide for the use of big data and AI, drones, etc. in addition to adding functional enhancements to the various industry collaboration functions described in this article. As described in the opening article [1] of these Special Articles, enhancements to use cases and services with an eye to Beyond 5G and 6G can be viewed as an important element in the evolution of 5G technologies. Going forward, NTT DOCOMO aims to contribute to the further evolution of 5G.

REFERENCES

[1] S. Nagata et al.: "5G Evolution Directions and Standardization Trends," NTT DOCOMO Technical Journal, Vol.22, No.3 pp.44–48, Jan. 2021.

[2] 5G-ACIA: "5G for Automation in Industry," Jul. 2019.

[3] J. Abe et al.: "NTT DOCOMO Initiatives for the Connected Car Era," NTT DOCOMO Technical Journal, Vol.21, No.4, pp.28–36, Apr. 2020.

[4] 5GAA: "White Paper C-V2X Use Cases Methodology, Examples and Service Level Requirements," Jun. 2019.

[5] 3GPP RP-181530: "LS on Prioritised Use Cases and Requirements for consideration in Rel-16 NR-V2X," Sep. 2018.

[6] K. Tokunaga et al.: "VoLTE for Enhancing Voice Services," NTT DOCOMO Technical Journal, Vol.16, No.2, pp.4–22, Jul. 2014.

[7] A. Umesh et al.: "5G Radio Access Network Standardization Trends," NTT DOCOMO Technical Journal, Vol.19, No.3, pp.36–47.

[8] K. Takeda et al.: "NR Physical Layer Specifications in 5G," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.49–61, Jan. 2019.

[9] K. Aoyagi et al.: "Overview of 5G Core Network Advanced Technologies in 3GPP Release 16," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.49–61, Jan. 2021.

*69 Congestion control: Technology for prohibiting a certain UE from using an excessive amount of resources mainly for the case of UE autonomous selection of transmission resources. Judging whether transmission should be allowed or denied depends on channel availability and the UE's transmission conditions.

*70 5G VN group: A terminal group that provides virtual and private communications in 5G LAN-type services.

*71 UPF call back: In UPF that terminates the U-plane with a terminal, the setting of a communications path with another terminal without making an outside connection such as with the Internet.

*72 NWDAF: A network function specified in 5GC that returns the results of collecting and analyzing various types of data within the network.

*73 NEF: A network function specified in 5GC that provides an API to external servers and applications outside of 3GPP specifications.

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

6G Laboratories Yuki Matsumura Shinya Kumagai
Daisuke Kurita
Radio Access Network Development Department Tianyang Min Kohei Harada

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

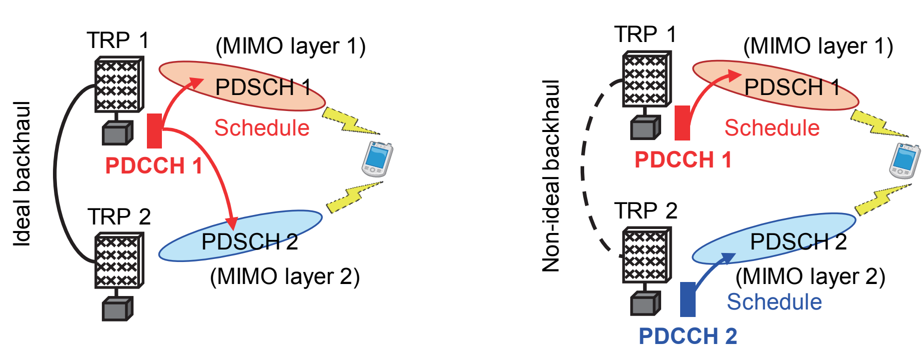

Figure 1 PDSCH distributed MIMO transmission with two cooperating TRPs

*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,

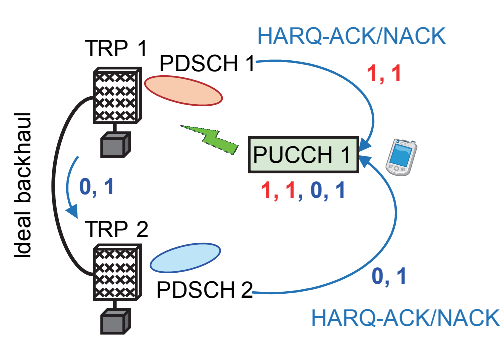

Figure 2 HARQ ACK/NACK transmission to two TRPs

*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.

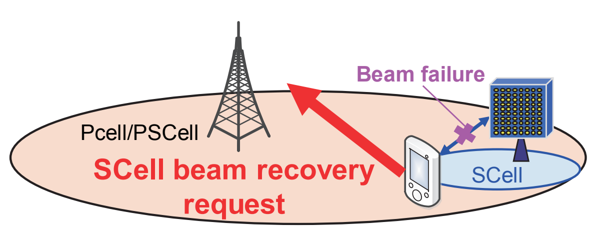

Figure 3　SCell beam failure recovery

*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.

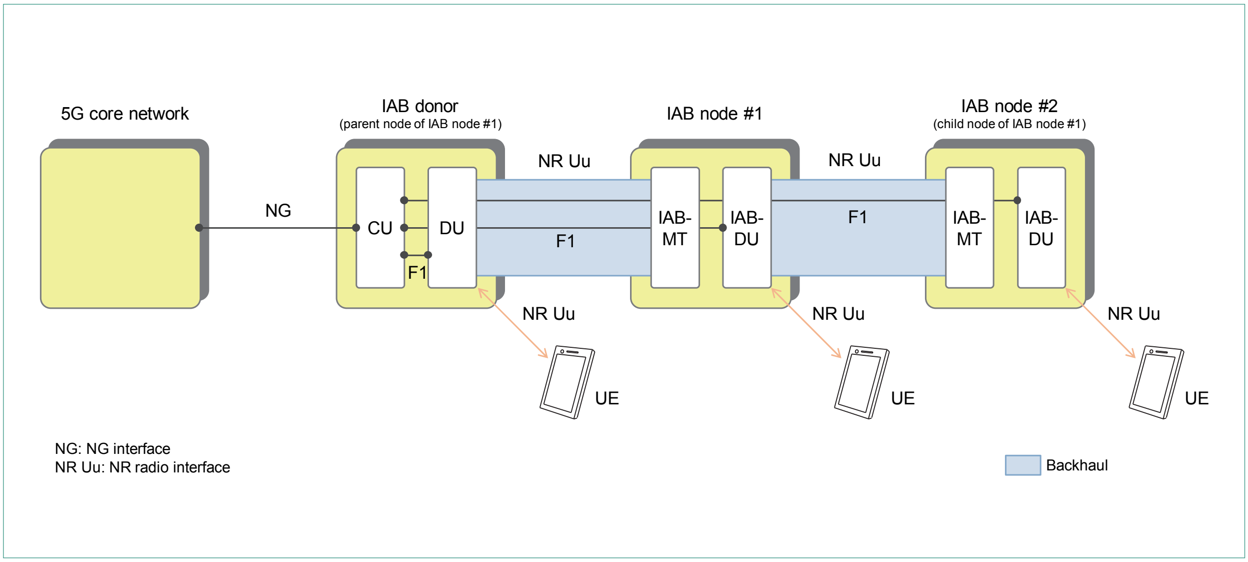

Figure 4 Basic IAB architecture

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.

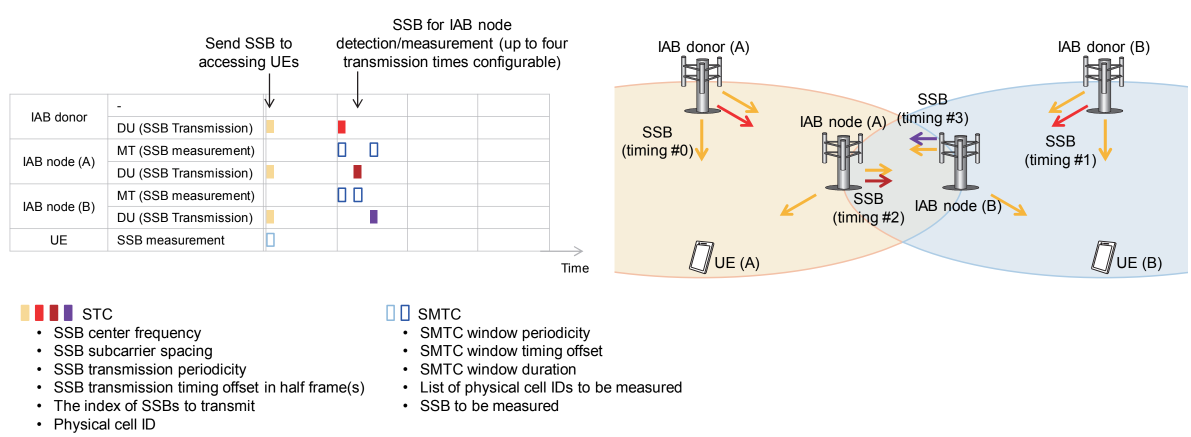

Figure 5 IAB node STC and SMTC configuration example

*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

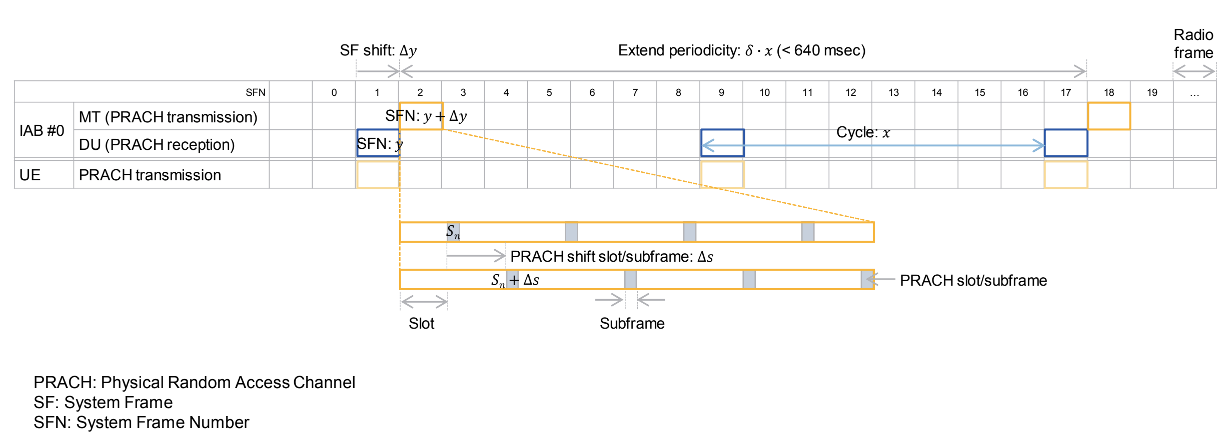

Figure 6 IAB-MT RACH transmission timing configuration example

*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.

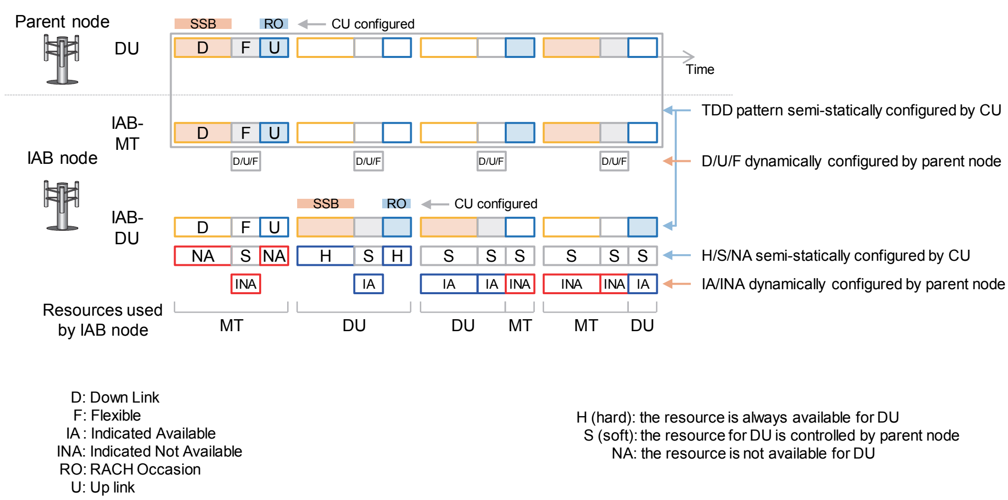

Figure 7 Overview of IAB node resource management example

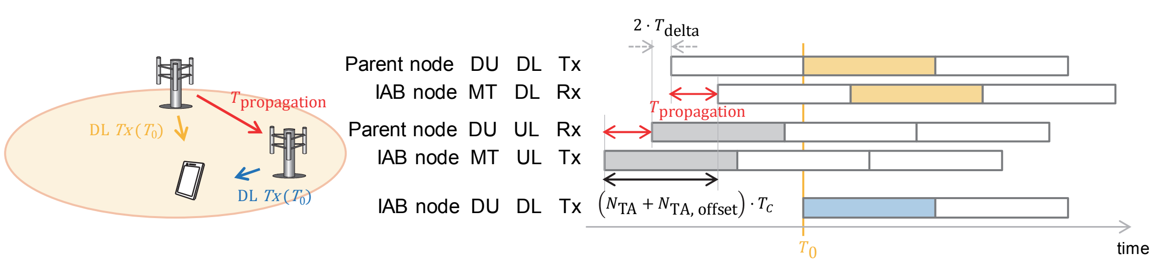

Figure 8 Overview of IAB-MT transmission timing synchronization

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

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*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

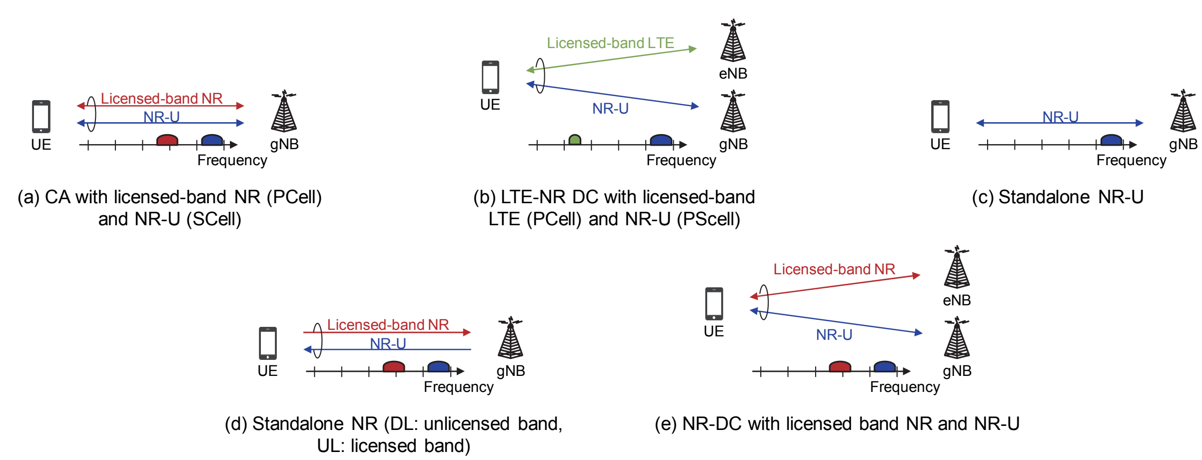

Figure 9 NR-U deployment scenarios

*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

*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.

*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

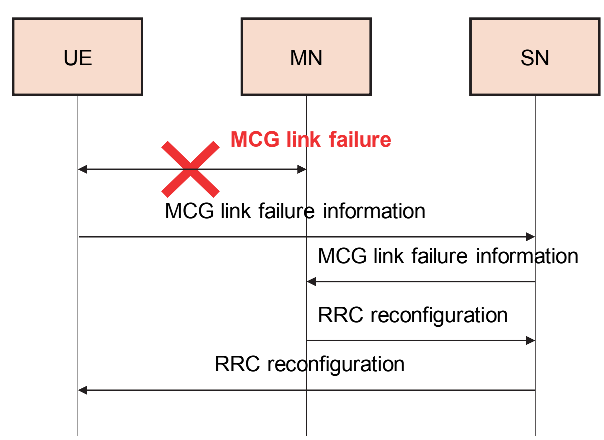

Figure 10 Fast MCG link recovery

*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 $P_{\mathrm{Total}}^{\mathrm{NR-DC}} = \mathrm{MIN}\ \{P_{\mathrm{EMAX,\ NR-DC}},\ P_{\mathrm{PowerClass}}\} + 0.3\mathrm{dB}$. For dynamic power sharing, $P_{\mathrm{Total}}^{\mathrm{NR-DC}} = \mathrm{MIN}\{P_{\mathrm{EMAX,\ NR-DC}},\ P_{\mathrm{PowerClass}}\}$. $P_{\mathrm{EMAX,\ NR-DC}}$ 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.

REFERENCES

[1] S. Nagata et al.: "Advanced 5G Radio Technologies in 3GPP Release 16," NTT DOCOMO Technical Journal, Vol.22, No.3, pp.62–70, Jan. 2021.

[2] K. Takeda et al.: "NR Physical Layer Specifications in 5G," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.49–61, Jan. 2019.

[3] 3GPP TS38.340 V16.0.0: "NR; Backhaul Adaptation Protocol (BAP) specification," Mar. 2020.

[4] 3GPP TS38.401 V16.2.0: "Technical Specification Group Radio Access Network; NG-RAN; Architecture description," Jul. 2020.

[5] H. Harada et al.: "Broadband Frequency Technologies in LTE-Advanced Release 13," NTT DOCOMO Technical Journal, Vol.18, No.2, pp.52–61, Oct. 2016.

Technology Reports (Special Articles) 3GPP Release 16 LTE/NR HST

Special Articles on 3GPP Release 16 Standardization Activities

Performance Enhancement Technologies in High-speed Moving Mobile Environments in LTE/NR Release 16

Radio Access Network Development Department Takuma Takada Naoto Iizasa
Communication Device Development Department Shoichi Higuchi

Japan, China, and other countries are studying new train services traveling at speeds exceeding 300 km/h. To provide stable mobile communication services in such high-speed mobile environments, new LTE and NR specifications were studied for 3GPP Rel-16. This article describes technologies introduced in Rel-16 to realize stable communication quality in environments with anticipated speeds up to 500 km/h, and related discussion.

1. Introduction

Recently, in Japan, China, and other countries, progress is being made to introduce transportation facilities that achieve speeds higher than Shinkansen bullet trains. The 3rd Generation Partnership Project (3GPP) is holding discussions on preserving mobile communication quality in such high-speed mobile environments. 3GPP Release 14 (here in after referred to as "Rel-14") already gives specifications for implementing improvements to LTE communication quality in environments with speeds comparable to Shinkansen bullet trains [1]. With the new mobile communication system added in Rel-15, called New Radio (NR) [2], use of NR in high-speed mobile environments can be expected to increase. Generally, the effects of Doppler frequency shift*1 become strong with high frequencies and moving at high speeds. A reference signal is used to compensate for this Doppler frequency shift, but the signals used by NR are different than those used by LTE, so further study was required for NR.

With this background, the Rel-16 specifications were defined to preserve LTE and NR communication quality on the uplink and downlink at speeds of up to 500 km/h.

*1 Doppler frequency shift: Shift in carrier-wave frequency due to the Doppler Effect.

This article describes technologies introduced in the Rel-16 specifications for achieving stable communication quality in environments at speeds of up to 500 km/h, and related discussion.

2. Issues in High-speed Mobile Environments

2.1 Doppler Frequency Shift Compensation

In high-speed mobile environments, the amount of Doppler frequency shift increases with increases in both frequency and traveling speed, and the phase rotation*2 that this produces in the received signal can greatly affect communication quality. This effect would be large when traveling at speeds up to 500 km/h, and the main frequencies currently being used with NR, the 3.7 GHz band (n77*3, n78) and the 4.5 GHz band (n79), are even higher than those used by LTE, further increasing the effect. As such, the issue was discussed at 3GPP, including differences with LTE. Note that discussion of the 28 GHz, millimeter-wave band (n257) was not in the scope of high-speed wireless interface for Rel-16.

Generally, when there is Doppler frequency shift, it causes phase rotation in the time domain. Both the base station and the user equipment use a reference signal to measure and compensate for phase rotation due to Doppler frequency shift. As the time-domain interval between reference signals is decreased, more-rapid phase fluctuations can be tracked, and larger Doppler frequency shifts can be corrected. Note that the original phase can be recovered for phase rotations up to inversion (up to +/-180 deg.).

With LTE, Doppler frequency shift is estimated by user equipment using the Cell-specific Reference Signal (CRS)*4, which it receives from the base station with the downlink signal, and by base stations using the DeModulation Reference Signal (DM-RS)*5 [2], which the base station receives from the user equipment with the uplink signal.

On the other hand, with NR, base stations do not transmit the CRS, so user equipment estimates Doppler frequency shift using the Tracking Reference Signal (TRS)*6 [2], which is sent periodically by the base station. Similar to LTE, NR base stations estimate Doppler frequency shift using a DM-RS, which they receive with the uplink signal, but the DM-RS intervals, the symbols*7, and the number of Resource Elements (RE)*8, are different than with LTE, so the conditions for correcting for Doppler frequency shift are different.

NR has also defined new, wider subcarrier*9 spacings of 30 and 60 kHz, in addition to the subcarrier spacing of 15 kHz as in LTE, so it may be necessary to compensate for larger Doppler frequency shifts than with 15 kHz subcarriers. In particular, with a 15 kHz subcarrier spacing as shown in **Figure 1**, downlink NR communication has an interval of four symbols between TRS. This is wider than the three symbols with LTE CRS, so the range of Doppler frequency shift that can be corrected will be smaller.

On the other hand, with a 30 kHz subcarrier spacing, the interval between TRS is four symbols, which is equivalent to an interval of two symbols with a 15 kHz subcarrier spacing, so the range of Doppler frequency shift that can be corrected is larger than with LTE. Looking at the NR uplink, there is a wider range of choices for subcarrier spacing, and settings for the density and position of the Physical Uplink Shared CHannel (PUSCH)*10 DM-RS are more flexible [2], so by placing the DM-RS at

*2 **Phase rotation**: The change in phase that occurs in a signal passing through a radio channel.

*3 **n77**: A Time Division Duplex (TDD) frequency band defined NR (3,300 to 4,200 MHz).

*4 **CRS**: Reference signal for measuring cell quality, specific to each cell.

*5 **DM-RS**: A reference signal used for channel estimation, used for decoding data transmitted on the uplink and downlink.

*6 **TRS**: A reference signal used for tracking fluctuations in time and frequency on the downlink.

a smaller interval than is used for LTE, it is possible to compensate for larger Doppler frequency shifts.

2.2 Base Station Deployment Configurations

To maintain communication quality in high-speed mobile environments, special base station deployment scenarios suitable for high-speed mobile environments as well as normal environments were proposed and discussed for 3GPP Rel-14. Discussion of base station deployment configurations were also held for Rel-16, based on the earlier discussions and covering functions and characteristics of NR.

An overview of base station configurations discussed for Rel-16 is shown in **Figure 2**. The Single

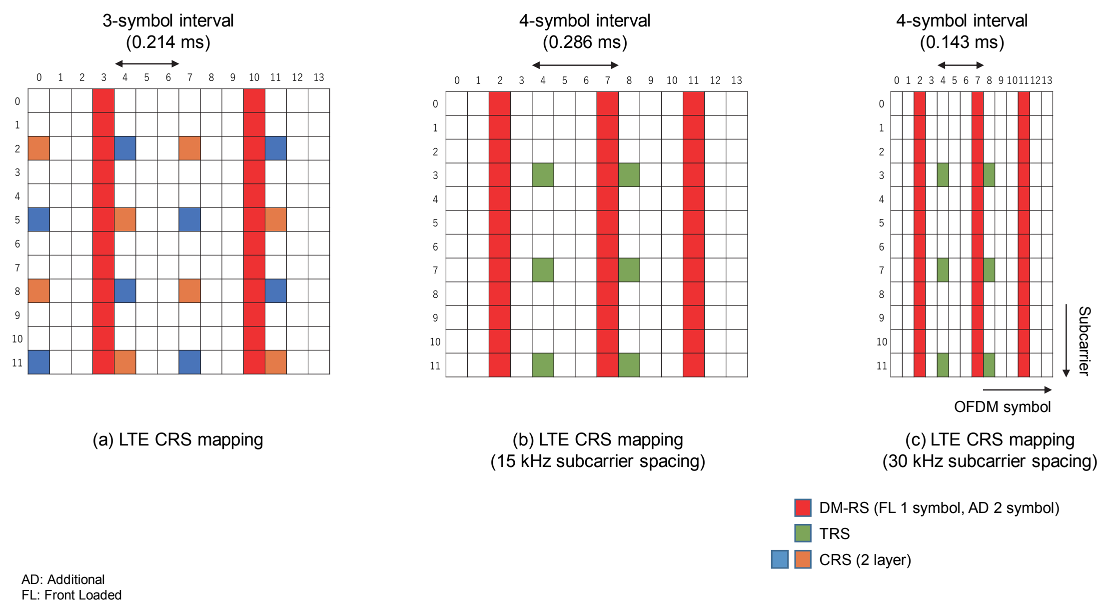

Figure 1　Comparison of LTE and NR downlink reference signal intervals

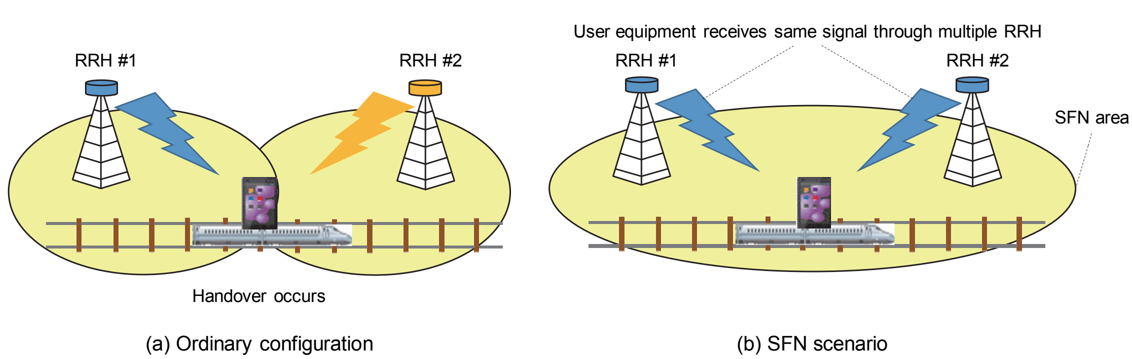

Figure 2　Base station deployment for high-speed mobile environments

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*7　Symbol: A time unit of transmitted data, consisting of multiple subcarriers with Orthogonal Frequency Division Multiplexing (OFDM). Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK).

*8　RE: A component of the downlink resource composed of one subcarrier and one OFDM symbol.

*9　Subcarrier: An individual carrier used for transmitting signals in a multi-carrier transmission scheme such as OFDM.

*10　PUSCH: Data transmitted on the uplink.

Frequency Network (SFN)[*11] scenario was also discussed for Rel-14 [1]. It deploys multiple Remote Radio Heads (RRH)[*12] in succession, each transmitting and receiving the same signal at the same frequency, so that the area covered by all of them can be considered a single cell. As such, switching from one RRH to the next does not require handover[*13], so this deployment scenario is excellent for high-speed mobile environments. On the other hand, this deployment scenario requires simultaneous tracking of received signals that have positive and negative Doppler frequency shifts.

3. Introduced Requirements and Their Effects

Reception performance requirements and test conditions for LTE and NR in Rel-16 and prior to Rel-16 are shown in **Table 1**. Considering the issues discussed above, Rel-16 NR defines test conditions assuming DM-RS with an arrangement of three symbols, so that channel estimation[*14] can be

Table 1 Reception requirement and test conditions introduced for high-speed trains

Release	Communication direction	Base station deployment configuration	LTE			NR		
			Traveling speed	Tolerable Doppler frequency shift	Frequency*1	Traveling speed	Tolerable Doppler frequency shift	Frequency*1
Rel-15 and earlier	Downlink (user equipment reception)	Ordinary configuration	300 km/h	750 Hz	2.7 GHz	300 km/h	750 Hz (15 kHz subcarrier spacing)	2.7 GHz
							1,000 Hz (30 kHz subcarrier spacing)	3.6 GHz
		SFN scenario	350 km/h	875 Hz	2.7 GHz	No requirement		
	Uplink*2 (Base station reception)	Ordinary configuration SFN scenario	350 km/h	1,340 Hz	2.06 GHz	No requirement		
Rel-16	Downlink (user equipment reception)	Ordinary configuration	500 km/h	972 Hz	2.1 GHz	500 km/h	972 Hz (15 kHz subcarrier spacing)	2.1 GHz
							1,667 Hz (30 kHz subcarrier spacing)	3.6 GHz
		SFN scenario	500 km/h	972 Hz	2.1 GHz	500 km/h	870 Hz (15 kHz subcarrier spacing)	1.88 GHz
							1,667 Hz (30 kHz subcarrier spacing)	3.6 GHz
	Uplink*2 (Base station reception)	Ordinary configuration SFN scenario	500 km/h	1,944 Hz	2.1 GHz	500 km/h	1,740 Hz (15 kHz subcarrier spacing)	1.88 GHz
							3,334 Hz (30 kHz subcarrier spacing)	3.6 GHz

*1 Value computed from the traveling speed and the tolerable Doppler frequency shift.
*2 For the uplink, to synchronize with the downlink signal with added Doppler frequency shift, a larger Doppler frequency shift must be considered.

*11 SFN: A network consisting of master and relay stations all using the same transmission frequency.

*12 RRH: One component of base station equipment installed at a distance from the Base Band Unit (BBU) using optical fiber or other means. It serves as radio equipment for transmitting/receiving radio signals.

*13 Handover: A technology for switching base stations without interrupting a call in progress when a terminal moves from the coverage area of one base station to another.

*14 Channel estimation: The process of estimating the amount of fluctuation in received attenuation and phase rotation in the received signal when a signal is transmitted over a radio channel.

done reliably at speeds of up to 500 km/h. The SFN scenario discussed above has also been defined, in addition to the ordinary deployment scenarios, and reception requirements have been introduced, accounting for the maximum Doppler frequency shift that can be corrected, for the TRS on the downlink and the DM-RS on the uplink. With the introduction of these stipulations, it will be possible to maintain communication quality at speeds up to 500 km/h, and we can expect LTE and NR areas to be created and quality improved within Shinkansen bullet trains and other high-speed trains.

4. Conclusion

This article has described new standard specifications in 3GPP Rel-16 for improving communication quality in high-speed mobile environments and their characteristics. This functionality will help maintain communication quality in high-speed mobile environments such as Shinkansen bullet trains. NTT DOCOMO will continue to promote the study of specifications that consider issues and demand in real environments.

REFERENCES

[1] T. Takada et al.: "Performance Enhancement Technologies in High-speed Moving Mobile Environment in LTE-Advanced Release 14," NTT DOCOMO Technical Journal, Vol.19, No.3, pp.64–70, Jan. 2018.
[2] K. Takada et al.: "NR Physical Layer Specifications in 5G," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.49–61, Jan. 2019.

NTT DOCOMO Holds "5G Evolution & 6G Summit"

To promote the Research and Development (R&D) of fifth-generation mobile communications system (5G), its enhancements (5G Evolution), and the sixth-generation mobile communications system (6G), "5G Evolution & 6G Summit" was held on July 29 and 30, 2020 (Part 1) and August 27 and 28, 2020 (Part 2) on the web. This summit came to be viewed by many companies, universities, and individuals.

Launched as a commercial service in Japan in March 2020, 5G is expected to drive the creation of new services and help find solutions to social problems in a variety of fields. Here, to respond in a flexible manner to a wide range of requirements that differ from field to field, further enhancements to 5G will be needed. At the same time, discussions on 6G have already begun in Japan and other countries aiming to launch commercial services around 2030. To this end, studies are being conducted on

Figure 1 Part 1 website information

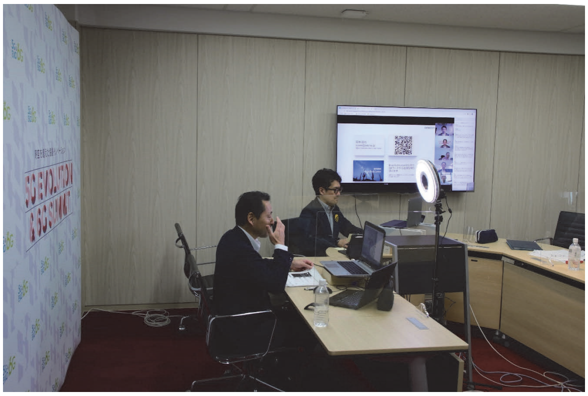

Photo 1 Part 1 back office (presentation side)

Photo 2 Part 1 back office (secretariat side)

Table 1 Panel discussions

Theme	Speakers
Human-augmentation/VR	Takeshi Ando Panasonic Corporation Masahiko Inami The University of Tokyo Hironao Kunimitsu gumi Inc. Tetsuya Mizuguchi Enhance Experience Inc.
Brain technologies	Kenichiro Iwasaki H2L, Inc. Takeshi Ogawa Advanced Telecommunications Research Institute International (ATR) Ryohei Hasegawa National Institute of Advanced Industrial Science and Technology (AIST) Ryosei Wakabayashi neumo, Inc.
Regional revitalization	Naoki Ota New Stories Ltd. Yuya Nishimura MIRATUKU Incorporated NPO Shoukei Matsumoto Buddhist Monk, Founder of "Mirai no Jushoku-Juku" project (temple management school)
Radio/network technologies	Tadashi Ogami NEC Corporation Takeshi Onizawa Nippon Telegraph and Telephone Corporation Takashi Dateki Fujitsu Ltd.
Space	Hiroyuki Iwamoto Japan Aerospace Exploration Agency (JAXA) Hidetaka Aoki SPACETIDE Shinichi Nakazato SKY Perfect JSAT Group Yuya Nakamura Axelspace Corporation

achieving even higher transmission speeds and capacities, extending coverage, lowering power consumption and costs, lowering latency, improving reliability, achieving massive-connectivity and sensing capabilities, and creating new use cases fitting 6G.

With the aim of promoting worldwide R&D in 5G enhancements and 6G, this summit presented exhibitions on NTT DOCOMO studies and invited outside experts in radio technologies and future 5G/6G use cases to participate in panel discussions.

During the two days of Part 1, the summit held five talks and five panel discussions. The talks on the first day covered the topics of "Directions in 5G Evolution & 6G," "Requirements and Use Cases of 5G Evolution & 6G," and "Technology Developments and Study Areas in 5G Evolution & 6G." These talks included 6G whitepaper updates released on July 17, 2020 just prior to this summit.

On the second day, NTT DOCOMO Executive Vice President Naoki Tani gave a talk on "NTT DOCOMO R&D toward 5G Enhancements and 6G." This was followed by panel discussions on use cases envisioned for the 6G era under the themes of human augmentation and Virtual Reality (VR), brain technologies, regional revitalization, radio/network technologies, and space. Passionate discussions ensued on each of these themes and on expectations for 6G. In addition, many viewers were able to watch these panel discussions online and ask questions and give comments using a chat system, which made for

Figure 2　Part 2 website information

Figure 3　Part 2 screenshots of text chat system

Table 2　Part 2 exhibitions

Network technologies		Use cases
5G Evolution & 6G Overall Image	Coverage Extension: Reflective Plate	Mobile SCOT Remote Medicine Experience
HAPS	Coverage Extension: Repeater	Remote Control of Construction Equipment
94 GHz Band Transmission Power Amplifier	Undersea Ultrasonic High-speed Wireless Transmission Technology	Transmission of High-presence Sensations Using 8K Video
150 GHz Transmission System	Use of Satellite Communications for Extreme Coverage Extension	Variable-rate Video Transmission
National R&D Project on Millimeter-wave High-speed Mobility	Analog RoF-Mobile Front Haul for Extreme Distributed Antennas	In-vehicle Infotainment Experience
Bended Dielectric Waveguide as Leaky-wave Antennas	Extreme-high-speed IC Technology for 300 GHz Band Radio Transmission	Sense-of-presence Communication Experience
AI for RAN (AI-based radio network)	OAM-MIMO Radio Multiplexing Transmission Technology	Introduction to Activities and Conversations with Experts in Human Augmentation (3 videos)
NOPHY (Non orthogonal PHY)	Multi-radio Proactive Control Technology: Cradio	Introduction to Activities and Conversations with Experts in Brain Technologies (2 videos)
Smart Factory: Social Implementation	Virtual Massive MIMO (VM-MIMO) Technology	
Smart Factory: High-accuracy Simulations	Introduction to Activities and Conversations with Experts in the Space Industry (2 videos)	
Smart Factory: Enhanced Transmission Technologies		

Photo 3 Part 2 back office (answering questions from inside/outside NTT DOCOMO)

Photo 4 Part 2 back office (secretariat side)

very lively discussions.

Part 2 of the summit featured the presentation of about 40 exhibitions and demonstrations on network technologies and use-case development in relation to 5G Evolution & 6G as promoted by NTT DOCOMO and partner companies. Being an online summit, viewers were able to make use of explanatory videos, a text chat system for exchanging messages and engaging in Q&A sessions, and a voice-chat system for interacting with presenters similar to an offline exhibition. These videos and chat systems helped viewers to obtain a deep understanding of the technologies presented. Additionally, through web content controllable by mouse operations, many online visitors were able to gain an intuitive understanding of use cases as well as to view video archives of the talks, panel discussions and interviews with the experts on the themes taken up in Part 1, etc.

Today, in the era of the COVID-19 pandemic, it is far from easy to hold real exhibitions. At NTT DOCOMO, we are nevertheless committed to collaborating with diverse partners and engaging in energetic discussions through summits such as this one and other future activities. We will continue to promote R&D toward the evolution of mobile communications.

REFERENCE

[1] NTT DOCOMO News Release: "NTT DOCOMO Holds '5G Evolution & 6G Summit—Enhanced 5G and Future 6G Technologies Released on the Web,'" Jul. 2020 (in Japanese).

KDD CUP 2020 Winners

On August 27, 2020, 14 individuals from the NTT DOCOMO Group became 3rd, 4th, and 7th place winners in three different sections of KDD CUP 2020, an international data analysis competition. These were Keiichi Ochiai and Hiroaki Tanaka of Research Laboratories, Norihiro Katsumaru, Katsuaki Kawashima, Akihiro Kawana, Daisuke Koizumi†1, Toshiki Sakai, Takuya Chida†2, Tsukasa Demizu, Yusuke Fukushima, Keita Yokoyama, Ryoki Wakamoto, and Masato Hashimoto of Service Innovation Department, and Hiroyuki Suzuki of DOCOMO Technology, Inc.

The KDD CUP is a data analysis competition held at the Knowledge Discovery and Data Mining (KDD) international conference sponsored by the Association for Computing Machinery (ACM) in the United States. It is the world's foremost and longest-running data analysis competition that was first held in 1997 in an era absent of concepts like "big data" and "data scientists."

This is a world conference that uses publically released big data to hold various types of competitions in the accuracy of data analysis. KDD CUP 2020 was divided into six sections drawing the participation of corporations, groups, individuals, and more than 4,000 teams from around the world. The following summarizes the awards given to the above individuals.

- 3rd place in Reinforcement Learning Competition: Development of AI for Repositioning of Taxis in Mobility-on-Demand (Tsukasa Demizu, Norihiro Katsumaru, Hiroyuki Suzuki)

  This section is a competition in maximizing the income efficiency of each driver by using reinforcement learning to reposition idle vehicles by AI. The 3rd-place winning team of Demizu et al. developed AI that self-learns income trends by time and area through reinforcement learning based on prior research and proposes a dispatching pattern for maximizing income. The team was successful in performing high-accuracy and stable dispatching control by constructing a vehicle-operation simulator from provided data on past dispatching results and travel records and in having AI learn from that data with good efficiency.
- 4th place in Machine Learning Competition: Development of AI for Attacking with False Data and Defending (Keiichi Ochiai, Hiroaki Tanaka, Akihiro Kawana, Takuya Chida, Keita Yokoyama, Daisuke Koizumi)

  This section deals with AI that classifies the relationships among objects as in an academic-paper citation network. It is a competition in developing two AI techniques: an attacker that mixes in false data to make AI perform erroneous classifications and a defender that correctly classifies objects even after being attacked with false data.

  The Ochiai team developed an attack that applies a technique mainly used in image recognition that causes erroneous recognition by making only a slight change to data. It also developed a defense that uses a neural-network technique developed for using data in a network of relationships among objects. The team was successful in maintaining a high-degree of classification accuracy by adapting these techniques to 600,000 data objects provided by the sponsor.
- 7th place in Machine Learning Competition: Development of AI for Retrieving Products of Interest to the User in Product Searches on

E-commerce Websites (Toshiki Sakai, Ryoki Wakamoto, Yusuke Fukushima, Katsuaki Kawashima, Masato Hashimoto)

This section is a competition in developing a technique for retrieving images of products to be clicked on by a user based on text input by the user in a product search on an e-commerce website.

The team improved a deep learning technique called Bidirectional Encoder Representations from Transformers (BERT) widely used in language processing such as translation and developed AI for linking objects included in images with words in the search string. Additionally, by using information on words that express types of objects included in images, the team developed AI that learns correspondences between search strings and images. Using these AI algorithms, the team was successful in identifying images of products to be clicked on with high accuracy.

NTT DOCOMO has been participating in the KDD Cup continuously since 2016. This year marks two consecutive wins following its 1st place win in 2019 and the third time it has been a winner at this competition. NTT DOCOMO employs many data scientists, and amid regular collaborations with business partners, we aim to solve a variety of issues by making effective use of AI and big data. These activities can be linked to this year's winning performance at the KDD Cup.

NTT DOCOMO intends to make full use of the world-class AI and big-data-analysis technologies recognized by the KDD Cup to expand business projects using AI and big data and promote initiatives for solving key social problems.

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†1 Currently on temporary assignment to DOCOMO Technology, Inc.
†2 Currently on temporary assignment to NTT Security Japan

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Editorial Correspondence
NTT DOCOMO Technical Journal Editorial Office
R&D Strategy Department
NTT DOCOMO, INC.
Sanno Park Tower
2-11-1, Nagata-cho, Chiyoda-ku, Tokyo 100-6150, Japan
e-mail: dtj@nttdocomo.com