NTT DOCOMO

Technical Journal

vol.19 No.3 | Jan.2018

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NTT docomo

IoT-driven Evolution and Business Innovation

General Manager of IoT Business Department
General Manager of Connected Car Business Office
(concurrent post)

Naoki Tani

A variety of initiatives have begun throughout society to research, develop, and provide solutions to social problems with an eye to Society 5.0*1 (Super Smart Society). These initiatives seek to create and make use of innovative technologies making up a "fourth industrial revolution" based on the Internet of Things (IoT), big data, Artificial Intelligence (AI), and robotics. As described in its Medium-Term Strategy 2020 "Declaration beyond" announced in April 2017, NTT DOCOMO aims to merge networks and services and create new value by enhancing and evolving IoT, AI, and the fifth-generation mobile communications system (5G) scheduled for launch in 2020. In the IoT era when everything is connected, it is important that new added value be created from data obtained from the physical world while incorporating the evolution of technology. Such added value can mean dramatic increases in operational efficiency through cost reductions and effective use of resources or business creation through the provision of new services and value. However, a survey conducted in Japan revealed that only 12% of domestic companies had introduced IoT as of fiscal year 2016 and that the majority of those companies had done so with the aim of becoming more efficient through so called visualization. It can therefore be said that there is still much more room for growth in this area.

Under these circumstances, I'd like to introduce three NTT DOCOMO initiatives for promoting business innovation and creating a prosperous and enriching future through IoT.

(1) Value creation through construction of new platforms

There are three main approaches to doing this. The first gives birth to value through a mechanism that connects diverse enterprises and industries beyond their traditional boundaries and continues to enhance that value. For example, in the construction industry, NTT DOCOMO is working with Komatsu Ltd., SAP Japan Co., Ltd. and OPTiM Corporation to jointly plan and operate a new platform called LANDLOG. This platform will provide a centralized means of collecting, storing, and analyzing all sorts of data possessed by multiple construction firms with the aim of achieving safe and highly productive construction sites. These data may consist of site operating status, earth and materials status, on-site topography, etc. obtained from construction machinery, dump trucks, measurement equipment, drones, and personnel. The second approach is regional revitalization featuring a wide variety of use cases achieved through horizontal expansion. For example, NTT DOCOMO is conducting a trial together with Hakusan City, Ishikawa prefecture and Kanazawa Institute of Technology (KIT) on creating new lifestyles and fostering innovation with the aim of transforming rural areas (satoyama) into smart cities through collaboration among the industrial, academic, and public/private sectors. This trial is based at the KIT Hakusanroku Campus now under construction as part of the IoT Acceleration Lab, Regional Edition. The third approach is platform building on a global scale. In addition to our "docomo M2M platform" for Machine to Machine (M2M) applications, we have been expanding the coverage area of our embedded Subscriber Identity Module (eSIM) solution for globally expanding corporate users to enable more convenient use of IoT mechanisms. In June of 2017, for example, NTT DOCOMO and China Mobile announced their development of the world's first multi-vendor eSIM system based on GSMA 3.1 in China, which has been expressing much interest in Japanese enterprises.

(2) Value creation though NTT DOCOMO's strengths and their evolution

The second initiative is to create new value by combining the data possessed by NTT DOCOMO with other data and AI technology given the company's role as a value creator through ongoing refinement and evolution of its core strengths. For example, in the area of next-generation mobility services, NTT DOCOMO has conducted a trial in Tokyo and Nagoya City on an "AI taxi" system that uses AI to predict customer demand by combining various types of data such as NTT DOCOMO population statistics and taxi operations data. We have also been conducting a trial since the end of last year on an AI-based bus operation system that enables efficient on-demand running of buses by using AI to support dispatching and routing. Furthermore, by combining the various types of value created by the above test systems, NTT DOCOMO has begun a trial on an autonomous bus service at Kyushu University. Finally, since April 2017, NTT DOCOMO has been offering vehicle-related firms "AI infotainment," a platform that personalizes car navigation systems with the application of AI in the area of vehicle-oriented services.

(3) Value creation through evolution of network technologies

The third initiative is to make various types of network preparations to support diverse market needs as the application of value-creating IoT expands through the evolution of network technology and expectations of network capabilities diversify. For example, NTT DOCOMO has been holding a Low Power Wide Area (LPWA) technology trial with partner firms since April 2017 beginning with the testing of LoRa®*2 use cases. There are also plans to hold sequential trials on extended Discontinuous Reception (eDRX) known as cellular IoT as well as on LTE-M and NarrowBand IoT (NB-IoT) to assess market needs, technology maturity, and use cases. In this way, NTT DOCOMO plans to provide network technology evolving from LPWA to 5G as solution packages tailored to customer needs.

As I've described above, NTT DOCOMO is promoting business innovation through IoT from a variety of perspectives, but the main point here is that close interaction with R&D and co-creation with partners leads to the creation of new value. Going forward, we welcome the challenge of promoting IoT-driven evolution and business innovation in collaboration with a diversified group of partners.

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*1 Society 5.0: A new economic society advocated by the government to enrich people's lives through maximum use of ICT as the next stage in world history following the hunter-gatherer society, agricultural society, industrial society, and information society.

*2 LoRa®: A radio system based on LPWA technology using frequency bands not requiring a radio station license (unlicensed radio spectrum). The LoRa Alliance, an industry association established in 2015 centered about Semtech, a leading semiconductor maker in the United States, proposes LoRa specifications and open standards for global use. LoRa is a registered trademark of Semtech Corporation.

NTT DOCOMO
Technical Journal
Vol.19 No.3 Jan. 2018

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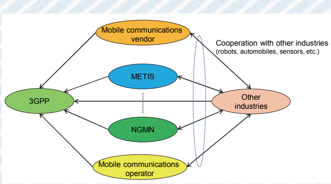

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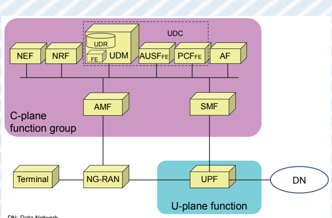

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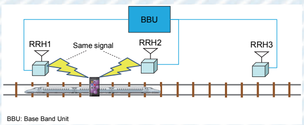

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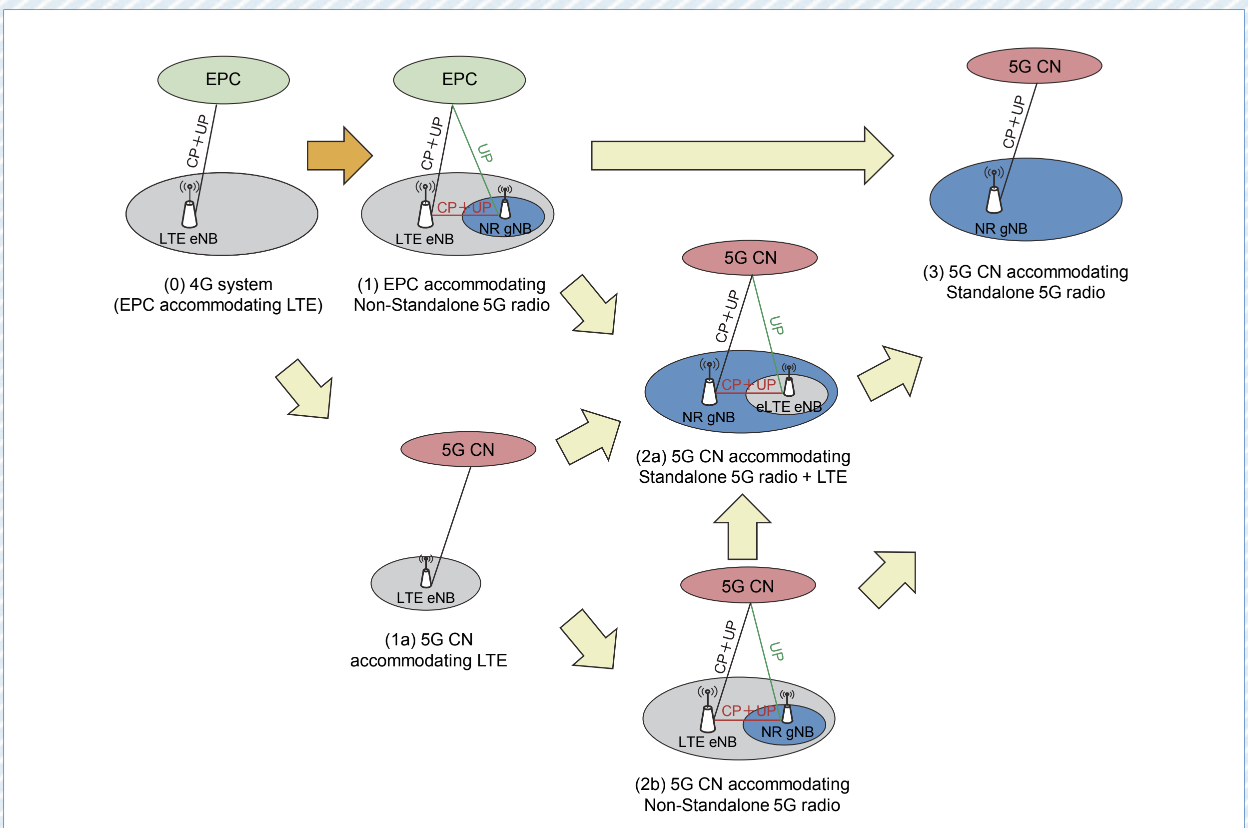

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Special Articles on 5G Standardization Trends Toward 2020

5G Standardization Trends at 3GPP

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NTT DOCOMO is conducting a variety of technical studies and joint experiments with the aim of launching the fifth-generation mobile communications system (5G) in 2020. The 3rd Generation Partnership Project (3GPP), the international body that formulates international standards and specifications for 5G, has been promoting studies since 2015 on 5G service requirements and component technologies for radio access and the core network. This article describes the overall 5G standardization schedule, 5G requirements and use cases, features of 5G radio and the core network for achieving those requirements, and deployment scenarios.

1. Introduction

The 3rd Generation Partnership Project (3GPP), the international body that formulates standards for mobile communications systems, is moving forward with studies on the fifth-generation mobile communications system (5G).

In addition to high data rates and large capacity as taken up in LTE and LTE-Advanced, new requirements and required values for 5G are being studied from a variety of perspectives such as low latency and high reliability, diverse terminal connectivity, and diverse industry support. Specific use cases applying 5G can be envisioned, such as Virtual Reality (VR)*1, advancement and automation of industry through a massive number of Internet

† Currently Mirai Translate, Inc.

*1 VR: Technology that creates a virtual space using computer graphics on a PC or other computer.

of Things (IoT) devices, and wireless communications for vehicles known as Vehicle-to-Everything (V2X)*2 as in autonomous driving.

In this article, we introduce the 5G standardization schedule centered about 3GPP and describe 5G requirements and use cases at 3GPP, the features of 5G radio and the core network*3 for achieving those requirements, and deployment scenarios.

2. 5G Standardization Schedule

2.1 ITU-R

The International Telecommunication Union Radiocommunication Sector (ITU-R)*4 began preparing 5G technology performance requirements in 2016 and will be accepting proposals for a radio interface satisfying those requirements from 2017 to 2019. Then, on the basis of these radio-interface proposals, the plan is to prepare ITU-R Recommendations for the radio interface from 2019 to 2020. We note here 5G standardization trends at ITU-R are described in more detail elsewhere in these Special Articles [1].

2.2 3GPP

At 3GPP, the plan is to proceed alongside the ITU-R schedule and formulate 5G standards in a stepwise manner through multiple Releases up to the end of 2019. Studies for Release 14 were conducted from 2016 to the beginning of 2017. These included a basic study or Study Item (SI)*5 on a new 5G-specific radio communication system called New Radio (NR) having no backward compatibility with the existing LTE and LTE-Advanced systems and a study and evaluation of candidate component technologies. Next, Release 15, which is scheduled for completion by the middle of 2018, will include a detailed specifications study or Work Item (WI)*6 and formulation of the initial 5G standard called Phase 1. In addition, the plan for Release 15 is to complete basic specifications for Non-Standalone*7 operation combining LTE and NR by December 2017 and basic specifications for Standalone*8 operation based only on NR by June 2018. The assumption here is that Release 15 specifications will enable countries around the world to proceed with 5G deployment.

Continuing on, the plan for Release 16 scheduled for completion by the end of 2019 is to continue with a detailed specifications study and to prepare the second version (Phase 2) of the 5G standard.

At 3GPP, the systematic submission of radio interface proposals to ITU-R based on these stepwise specifications studies is being studied.

3. Main Requirements for 5G

In addition to high data rates and large capacity as required of existing mobile communications technologies, 5G requirements have been studied at 3GPP taking into account the creation of new markets. The following describes main use cases and requirements studied with 5G in mind.

3.1 5G Use Cases

At 3GPP, main 5G features consist of enhanced Mobile BroadBand (eMBB), massive Machine Type Communications (mMTC), and Ultra-Reliable and Low Latency Communications (URLLC). At ITU-R, these three features are taken to be key usage scenarios of the IMT-2020 system [1]. Moreover, in

*2 V2X: Generic name for vehicle-to-vehicle and vehicle-to-infrastructure communications.

*3 Core network: A network consisting of switches and subscriber-information management equipment. Mobile terminals communicate with the core network via the radio access network.

*4 ITU-R: The Radiocommunication Sector of the ITU, which is an international organization in the telecommunications field. It conducts studies required to revise international regulations for radio communications and conducts research on radio communications technology and operation.

keeping with these 5G usage scenarios, use cases are also being established at the service level. For example, use cases for which reduced latency is a requirement as in telemedicine and autonomous driving have been newly specified for 5G. A total of 74 use cases including the above and requirements for each use case are summarized in 3GPP Technical Report (TR) 22.891 [2]. These use cases can be grouped into the five categories listed in **Table 1**.

3.2 5G Requirements

1) Radio Access Technology Requirements for Each Usage Scenario

Main requirements for 5G radio access technology (5G NR) for each usage scenario have been determined at 3GPP as listed in **Table 2** [3]. For eMBB, the peak data rate has been set to 20 Gbps and 10 Gbps in the downlink and uplink, respectively as target values. Furthermore, in comparison with LTE-Advanced, the goal here is to achieve a three-fold gain in spectrum efficiency*9, higher mobility speeds, and low-latency radio transmission. Next, for mMTC, the distance from the base station at which a data rate of 160 bps can be provided on the uplink is taken to be the cell radius, which can be defined in terms of propagation losses*10 according to distance from the base station (maximum coupling loss*11 of 164 dB). Other targets include a battery life beyond 10 years and a radio system that can accommodate an even greater number of devices. Finally, for URLLC, a very low latency of 0.5 ms (one-way radio transmission delay) has been set as a target value.

Table 1 Requirements and main use cases grouped by category

Category	Related specifications	Requirements	Main use cases
eMBB	TR22.863 TS22.261	High data rate, high traffic density, diverse coverage, high user mobility	Indoor, hotspots, wide area
CriC	TR22.862 TS22.261	High reliability and low latency, high reliability, high availability, and low latency, very low latency, high accuracy positioning	Virtual presence, tactile Internet, remote control, telemedicine, remote first-aid, drone control
MIoT	TR22.861 TS22.261	Improved operation, diversified connectivity, and improved resource-usage efficiency in relation to IoT	Improved IoT device initialization, large-capacity support, wearable device communication, bio-connectivity, wide area monitoring
NEO	TR22.864 TS22.261	System flexibility, scalability, mobility, efficient content delivery, and improved security, plus diverse backhaul/access considerations and migration/interworking considerations	*Common system requirements independent of services
eV2X	TR22.886 TS22.186	High data rate, high reliability, high availability and low latency, wide area coverage	Autonomous driving, convoy driving, remote driving

CriC: Critical Communications
MIoT: Massive IoT
TS: Technical Specification
eV2X: enhanced V2X
NEO: NEtwork Operation

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

*6 WI: The work of "deciding the functions that should become specifications and preparing detailed specifications for those functions."

*7 Non-Standalone: An operation format in which terminals connect to a mobile communications network via multiple radio technologies.

*8 Standalone: An operation format in which terminals connect to a mobile communications network via a single radio technology.

Table 2　5G NR main requirements

Use-cases	Key performance indicator	NR		LTE-Advanced		LTE (Release 8)	
		DL	UL	DL	UL	DL	UL
eMBB	Peak data rate	20 Gbps	10 Gbps	1 Gbps	500 Mbps	100 Mbps	50 Mbps
	Peak spectral efficiency	30 bps/Hz	15 bps/Hz	30 bps/Hz	15 bps/Hz	3~4 ×HSDPA (Release 6)	2~3 ×HSUPA (Release 6)
	C-plane latency	10 ms		Less than 50 ms		Less than 100 ms	
	U-plane latency	4 ms		Reduced U-plane latency compared to Release 8		Less than 5 ms	
	Cell/TRxP spectral efficiency (bps/Hz/TRxP)	3 times higher than LTE-Advanced		—		—	
	Area traffic capacity(bps/m^2)	3 times higher than LTE-Advanced		—		—	
	User experienced data rate (bps)	3 times higher than LTE-Advanced		—		—	
	5% user spectrum efficiency (bps/Hz/user)	3 times higher than LTE-Advanced		Cell edge user throughput (bps/Hz/cell/user)		User throughput	
				0.12 (2×2 ANT)	0.04 (1×2 ANT)	2~3 ×HSDPA	2~3 ×HSUPA
	Target mobility speed (relates also to URLLC, mMTC)	500 km/h		350 km/h		350 km/h	
	Mobility interruption time (relates also to URLLC, mMTC)	0 ms		—		—	
mMTC	Coverage	Max coupling loss 164 dB		Max coupling loss 164 dB (NB1)		—	
	UE battery life	Beyond 10 years		Up to 10 years		—	
	Connection density	1,000,000 devices/km^2		60,680 devices/km^2		—	
URLLC	U-plane latency	0.5 ms		—		—	
	Reliability	10^{-5} for 32 bytes with U-plane latency of 1 ms		—		—	

2) Overall Performance Requirements for the 5G System

Performance requirements for the system on the whole including 5G NR and the core network have been specified for different use cases [4]. These requirements include data rate, latency, reliability, traffic density, and connection density. For example, the experienced data rate on the downlink has been set to 1 Gbps, but very high requirements have been set for end-to-end latency such as 10 ms for intelligent transport systems as in V2X, 5 ms for remote control, and 0.5 ms for tactile Internet.

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

*10　Propagation losses: The amount of attenuation in the power of the signal emitted from the transmitting station till it arrives at the reception point.

*11　Coupling loss: The propagation loss according to distance from the base station used to define the cell radius, which is the distance from the base station at which a certain data rate can be provided.

In addition, the following three requirements are representative of those specified for the 5G system overall.

(a) Network slicing*12 support

A network can be composed of one or more network slices in which each network slice has the functionality of a complete, independent network. Each network slice can satisfy different functional or performance requirements and accommodate a specific group of users or type of service. One terminal will be able to connect to multiple network slices simultaneously.

(b) Diverse access support

The 5G core network shall be able to accommodate satellite and fixed broadband access in addition to Evolved Universal Terrestrial Radio Access (E-UTRA)*13 and 5G NR.

(c) Efficient provision under diverse conditions

To provide 5G, consideration is also being given to making essential equipment more power efficient and using network resources more efficiently. In 5G, particular attention is being given to the provision of low-latency services and studies are being made on network configurations that arrange gateway*14 equipment at the edge of the network close to mobile terminals. Low-cost provision is also being considered for markets requiring only minimal service levels as in areas with limited access to power.

3.3 Recent Trends in Studies on 5G Service Requirements

To meet the demands of industry, 3GPP Service and System Aspects 1 (SA1) has been conducting studies in Release 16 towards addition or revision of use cases and requirements related to railways and power. At the same time, coordination with the automobile industry is progressing through information exchanges and discussions with the 5G Automotive Association (5GAA)*15. Coordination with fixed networks, meanwhile, is moving forward at 3GPP SA2 through discussions with Broadband Forum*16 and other organizations in anticipation of Release 16 specifications.

4. Features of NR and 5G Core Network

The following describes the respective features of NR and the 5G core network for satisfying the 5G requirements described above.

4.1 NR Features

One key feature of NR is support of Non-Standalone operation, which is an operation format that provides service in combination with an LTE/LTE-Advanced area without having to provide an NR area by itself.

Existing LTE/LTE-Advanced networks are already providing services over broad areas using the 2 GHz and 800 MHz frequency bands. In contrast, it is assumed that 5G in its initial deployment stage will be rolled out using new high-frequency bands such as the millimeter wave band. A scenario consisting of local rollouts from areas with high demand is therefore being considered. If such a network using new spectrum for NR can be operated together with an LTE/LTE-Advanced network using existing frequency bands, it should be possible to provide more satisfying communications

*12 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.

*13 E-UTRA: An air interface used for advanced wireless access schemes in 3GPP mobile communication networks.

*14 Gateway: A node having functions such as protocol conversion and data relaying.

*15 5GAA: An association founded by automotive and telecommunications players to promote studies on connected car services using 5G.

for the user than providing services locally by NR only. Furthermore, from the viewpoint of an operator expanding its service area, Non-Standalone operation providing 5G in combination with LTE/LTE-Advanced enables NR to be added on locally within an existing service area and to be expanded gradually according to demand. This is the most promising provision format at the 5G initial deployment stage. Against this background, Non-Standalone operation is attracting attention from NTT DOCOMO and other operators around the world studying early deployment of 5G. A consensus has been reached on formulating specifications for Non-Standalone operation by December 2017 ahead of those for Standalone operation. Technical details of Non-Standalone operation are described elsewhere in these Special Articles [5].

4.2 Features of 5G Core Network Accommodating NR

Both a system that extends Evolved Packet Core (EPC)*17 and a system for deploying a newly specified 5G core network are being studied as core networks accommodating NR. In particular, studies on the 5G core network with the aim of achieving the 5G service requirements described above have begun with the plan of completing specifications as 3GPP Release 15 in June 2018. The 5G core network has the following four main features:

- Reorganization of functions among terminals, the Radio Access Network (RAN) *18, and the core network
- Introduction of service-based architecture
- Support of network virtualization
- Introduction of network slicing and simultaneous connection of multiple gateways

These component technologies are described elsewhere in these Special Articles [6].

5. NR and 5G Core Network Deployment Scenarios

Scenarios for deploying and expanding NR and the 5G core network against the existing fourth-generation mobile communications system (4G) are being studied at 3GPP. We point out here that 3G and LTE deployment was achieved by a single scenario that newly introduced both the RAN and core network (the scenario directly connecting scenario (0) to scenario (3) in **Figure 1**). In contrast, the deployment of NR and the 5G core network can leverage the capability of providing NR by Non-Standalone operation as described above and the capability of accommodating LTE by the 5G core network. These features make it possible to provide multiple deployment scenarios as shown in Fig. 1.

Among the scenarios shown in Fig. 1, scenario 1 that accommodates Non-Standalone NR by EPC is the most promising at the time of initial 5G deployment. As a result, the strong demand from telecom operators in countries aiming for an early NR deployment has led to a consensus on drafting the standards and specifications needed for scenario 1 as early as possible. Non-Standalone NR accommodated by EPC is also the method initially proposed by NTT DOCOMO for providing NR with an eye to early 5G deployment. This format of accommodating Non-Standalone NR by EPC has the following advantages:

- Maintains the stable quality of the coverage area already serviced by LTE/LTE-Advanced

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*16 Broadband Forum: An international organization that aims to promote the spread of broadband networks.

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

*18 RAN: The network situated between the core network and mobile terminals consisting of base stations and other equipment for controlling the radio layer.

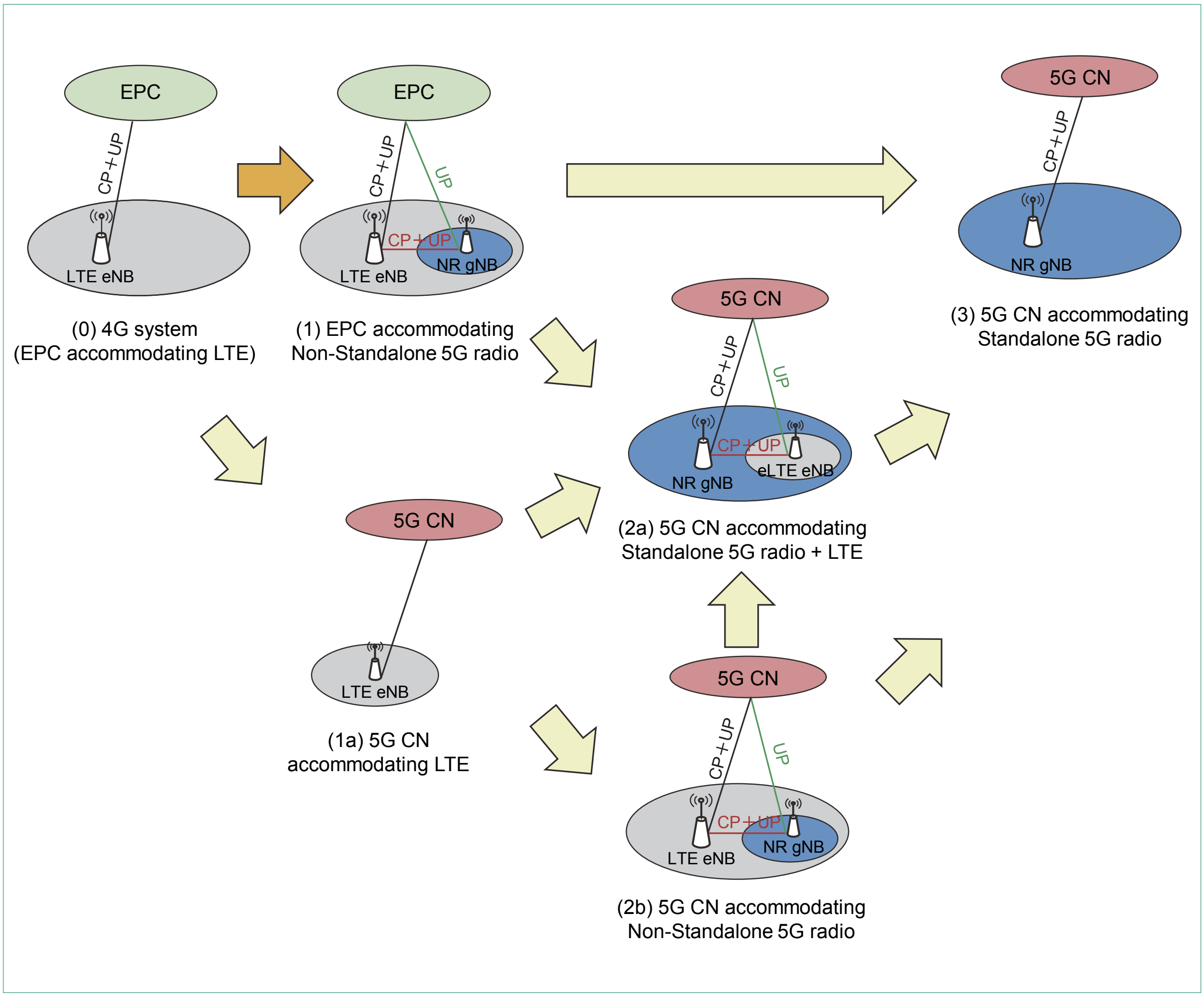

Figure 1　5G Radio/core network deployment scenarios

- Uses EPC having stable operation appropriate for achieving eMBB
- Minimizes the number of new design items and test items at time of 5G deployment

This approach is expected to lower the hurdle to NR deployment while enabling early and stable deployment to an extent not possible with a totally new deployment of the 5G core network. With Non-Standalone NR accommodated by EPC, we can expect the scale of changes to be limited by using EPC in its existing state for the most part. In addition, recent studies at 3GPP are including support for functions that will enable low latency even with EPC accommodation.

After NR provision by EPC-accommodated Non-Standalone operation (scenario (1)), the 5G core network can be introduced and a variety of scenarios can be provided in terms of LTE and NR area expansion as shown in Fig. 1 (scenarios (1a), (2a), (2b), and (3)). In this way, telecom operators can deploy NR and the 5G core network using an optimal set of scenarios in line with their business plans.

6. Conclusion

In this article, we described the overall 5G standardization schedule, 5G requirements and use cases, and the features of NR and the 5G core network for achieving those requirements. Component technologies of NR and the 5G core network are also described in these Special Articles [5] – [7].

At present, studies are proceeding at 3GPP toward the provision of functions specified by Phase 1 in the form of Release 15. The plan is to study functional extensions for some of these functions as Phase 2 in Release 16 and beyond.

NTT DOCOMO is contributing to 5G standardization efforts at 3GPP and aims to contribute to further development of 5G standards into the future.

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Technology Reports | 5G | Requirements | Evaluation Conditions

Special Articles on 5G Standardization Trends Toward 2020

3GPP Defined 5G Requirements and Evaluation Conditions

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Standardization of the new radio interface for fifth-generation mobile communications systems (5G) is advancing at the 3GPP. Before starting discussions on the specifications of the 5G radio interface, the 3GPP defined the requirements and evaluation conditions for 5G. This article provides an overview of the 5G requirements and scenarios defined by the 3GPP together with an explanation of the evaluation conditions, including channel models, used for evaluating 5G requirements.

1. Introduction

There is great anticipation of fifth-generation mobile communications systems (5G), which are the next generation following LTE and LTE-Advanced, the fourth-generation (4G), and which will handle the explosive increase in mobile communications traffic and the diversification of services in the year 2020 and beyond. In addition to realizing high system performance, 5G will also require extensibility for a wide range of services. To meet these demands in a timely fashion, NTT DOCOMO began activities in 2010 targeting 5G commercialization by 2020, taking a lead in the discussion of 5G technical concepts and requirements [1]. These discussions were held by 5G promotional organizations and research projects that were formed later in several regions around the world in 2012 and 2013, and the discussion results are being consolidated by organizations including the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)*1 project in Europe, the Next Generation Mobile Networks (NGMN)*2 alliance, the Association of Radio Industries and Businesses 2020 and Beyond Ad Hoc (ARIB 20B AH)*3 group in Japan, the 5G Forum*4 in Korea, and the International Mobile Telecommunications (IMT)-2020 Promotion Group*5 in China [2] - [4]. The International Telecommunication Union - Radiocommunication sector (ITU-R)*6 has also studied its vision for mobile communication systems in 2020 and beyond. The results of this study are summarized in the recommendation, ITU-R M.2083, published in September, 2015 [5]. One main result of this report is the identification of three typical usage scenarios for 5G. These are (1) enhanced Mobile BroadBand (eMBB), (2) massive Machine Type Communications (mMTC), supporting massive numbers of simultaneous connections, and (3) Ultra-Reliable and Low Latency Communications (URLLC).

Amid this activity, the 3rd Generation Partnership Project (3GPP), a standardization organization for mobile communications systems, held the 3GPP RAN Workshop on 5G in September 2015, to begin the study of 5G. Also, prior to initiating discussions on 5G radio interface specifications, Study Items (SI)*7 were initiated related to 5G scenarios, requirements and channel models*8. These extended channel models used earlier for 6 GHz and below, to be used with high frequencies above 6 GHz, so that technologies designed for high-frequency bands can be evaluated. The SI for 5G scenarios and requirements was held from December 2015 (70th TSG-RAN meeting) through December 2016 (73rd TSG-RAN meeting), and the results are documented in Technical Report (TR) 38.913 [6]. The channel model SI was discussed from September 2015 (69th TSG-RAN) through June 2016 (72nd TSG-RAN) and the results are documented in TR 38.900 [7]. This article describes the current status of discussions on 5G requirements and evaluation conditions, including channel models, as defined by the 3GPP.

2. 5G Requirements and Target Performance Values

In the SI related to scenarios and requirements, Key Performance Indicators (KPI)*9 and target performance values for 5G were discussed, and many 5G requirements and target values from various organizations, enterprises and research projects in the mobile communications industry, as well as proposals from other industries were considered, as shown in **Figure 1**. In particular, KPI target values were set for mMTC and URLLC, which relate to the Internet of Things (IoT), giving full consideration of future services in industries other than mobile communications, such as automotive, robotics, and sensors. The results consist of 19 KPIs for 5G as well as a wide range of network and service requirements. The KPIs and related target values

*1 METIS: EU research project laying the foundation of 5G wireless technology. Ran from November 2012 to April 2015. Participants included communication vendors, mobile carriers, and universities. A successor project, METIS-II ran from July 2015 to June 2017.

*2 NGMN: An organization composed of NTT DOCOMO and other vendors and operators, which is creating a vision and roadmap for next-generation mobile communications networks.

*3 ARIB 20B AH: ARIB is an organization, subordinate to the Ministry of Internal Affairs and Communications (MIC), that sets standards for systems using the radio spectrum in the fields of communications and broadcasting in Japan. ARIB 20B AH is an ad hoc group established under ARIB to create a vision for next-generation mobile communications systems after 2020.

*4 5G Forum: The main organization promoting activities toward implementation of 5G in Korea.

*5 IMT-2020 Promotion Group: The main organization promoting activities toward implementation of IMT-2020 (5G) in China.

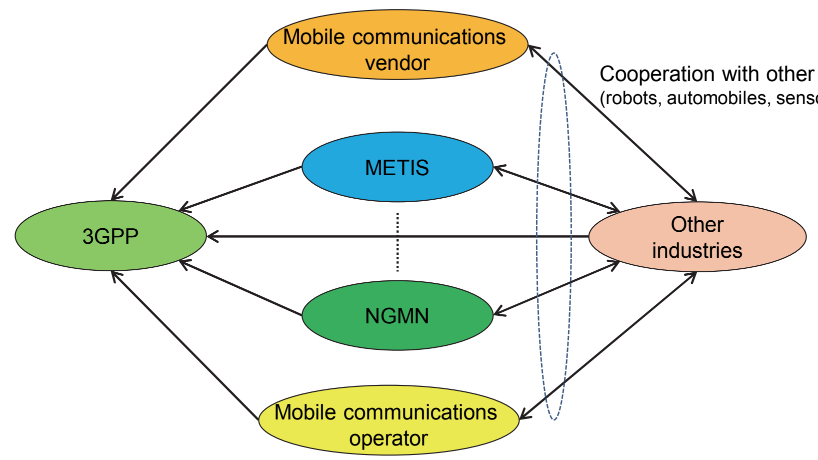

Figure 1 Overview of 3GPP role of consolidating 5G requirements and evaluation conditions from various other organizations and industries

are shown in **Table 1** [6]. Please refer to TR 38.913 for detailed definitions of each KPI [6].

1) KPIs for eMBB Usage Scenarios

For eMBB usage scenarios, the main KPIs are improvements on the average (TRxP) spectral efficiency*10 and the 5% user spectral efficiency*11, which stipulate system performance in the same way as LTE-Advanced, and support for high-speed mobility. For eMBB, target values were set for approximately three times improvement in spectral efficiency, based on the requirement values set previously for IMT-Advanced*12. The use of wide-band and high frequencies and carrier aggregation spanning multiple bands is anticipated, so requirements for peak user data rates were added and target values set at 20 Gbps on the downlink and 10 Gbps on the uplink. In addition to the above, KPIs for low power consumption were also set to prevent increases in power consumption in networks and terminals as system capacity and user throughput increase. These were added as design principle requirements for the 5G radio interface.

2) KPIs for mMTC Usage Scenarios

The main KPIs for mMTC usage scenarios are to increase the connection density, expand coverage, and increase battery life. Considering the wide spread of IoT terminals, a target value for connection density of one million devices/km^2, or one device/m^2, was set for urban environments. This is approximately 16 times the design value (approx. 60k devices/km^2) set for Narrow Band (NB) - IoT*13 in the LTE-Advanced standards. Regarding battery life, terminals are required to operate for 10 to 15 years without changing or charging of batteries.

3) KPIs for URLLC Usage Scenarios

URLLC usage scenarios require both high reliability and low latency simultaneously. Latency is specified as latency in the U-Plane [6], requiring

*6 ITU-R: The Radiocommunication Sector of the ITU, which is an international organization in the telecommunications field. It conducts studies required to revise international regulations for radio communications and conducts research on radio communications technology and operation.

*7 SI: Work on a particular feature requiring study of feasibility and specifications.

*8 Channel model: A model simulating the behavior of radio waves, used for evaluating the performance of wireless communications systems.

*9 KPI: The main indices for measuring user or system performance.

*10 Average (TRxP) spectral efficiency: The average number of data bits that can be sent per unit time, unit frequency bandwidth, cell, and Transmission Reception Point (TRxP). The units are bps/Hz.

*11 5% user spectral efficiency: The number of data bits that a user can send per unit time and unit frequency bandwidth at the 5% point on a user throughput Cumulative Distribution Function (CDF). The units are bps/Hz.

Table 1 5G KPIs and target values at the 3GPP

Usage scenario	KPI	Target values	
		DL	UL
eMBB	Peak data rate	20 Gbps	10 Gbps
	Peak spectral efficiency	30 bps/Hz	15 bps/Hz
	Control plane latency	10 ms	
	User plane latency	4 ms	
	Average (TRxP) spectral efficiency (bps/Hz)	3 times higher than IMT-Advanced*	
	Area traffic capacity (bps/m²)	Related to average (TRxP) spectral efficiency	
	User experienced data rate (bps)	Related to 5% user spectral efficiency	
	5% user spectral efficiency (bps/Hz/user)	3 times higher than IMT-Advanced*	
	Target maximum mobility speed	500 km/h	
	Mobility interruption time (Also related to URLLC and mMTC)	0 ms	
	Network energy efficiency (Also related to URLLC and mMTC)	Required as design principle (No quantitative requirement)	
	UE energy efficiency (Also related to URLLC and mMTC)	Required as design principle (No quantitative requirement)	
	Bandwidth (Also related to URLLC and mMTC)	No requirement from 3GPP	
mMTC	Coverage	Max coupling loss 164 dB	
	UE battery life	Beyond 10 years	
	Connection density	1,000,000 device/km²	
	Latency of infrequent small packets	10 s	
URLLC	User plane latency	0.5 ms	
	Reliability	$1\text{-}10^{-5}$ success probability for 32 bytes within 1 ms user plane delay	

TRxP: Transmission Reception Point
＊ITU-R Report M.2134

0.5 ms or less on both the uplink and the downlink. The target value for reliability is to send 32-byte data packets within 1 ms with $1 - 10^{-5}$ (99.999%) probability of success.

3. 5G Evaluation Conditions

The SI for scenarios and requirements also studied evaluation scenarios (environments) and evaluation

*12 IMT-Advanced: A standard positioned as the successor to IMT-2000 at ITU-R. It calls for data rates of about 100 Mbit/s for high mobility and 1 Gbit/s for low mobility.

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

conditions for evaluating each of the requirements. This resulted in specifications for multiple deployment scenarios for each usage scenario, requiring support for a wide range of environments and frequency bands. For example, several usage scenarios were envisioned for eMBB, so a wide range of Base Station (BS) Inter-Site Distance (ISD) ranges (from 20 to 5000 m) and a wide range of frequency bands (center carrier frequencies*14 of 700 MHz to 70 GHz) need to be evaluated. In particular, the number of frequency bands in a given usage environment is not limited to one, and in most usage scenarios, both a low frequency band (e.g. 4 GHz) and a high frequency band (e.g. 30 GHz) must be evaluated.

3.1 eMBB

The eMBB deployment scenarios and main evaluation conditions are shown in **Table 2**. It was agreed that average spectral efficiency and 5% user spectral efficiency are to be evaluated in the Indoor Hotspot*15, Dense Urban, Rural, and Urban Macro user environments. The main differences among these user environments are in applicable frequency bands, cell layout (determined by ISD), user distribution and mobility speed.

For mobility, speeds of 500 km/h are to be supported, faster than the 350 km/h maximum value set for IMT-Advanced, considering maximum speeds for high-speed trains. For evaluation of mobility, linear cell layouts with base stations in a straight line are specified, anticipating cell layouts used for high-speed trains. Scenarios are specified for base stations connecting directly to terminals within a train car, and also relay-based communication

Table 2 Deployment scenarios and main evaluation conditions related to eMBB

Deployment scenarios	Main features		
	Carrier frequency	Cell layout	User distribution
Indoor hotspot	30 GHz or 70 GHz or 4 GHz	ISD = 20 m, open office, one floor	100% indoor (3 km/h)
Dense urban	4 GHz + 30 GHz (macro + micro layers)	ISD = 200 m, hexagonal grid layout for macro layer, random drop for micro layer	80% indoor (3 km/h), 20% outdoor (30 km/h)
Rural	700 MHz or 4 GHz (ISD = 1,732 m case) 700 MHz + 2 GHz (ISD = 5 km case)	ISD = 1,732 m or 5 km, hexagonal grid layout	50% outdoor vehicles (120 km/h) and 50% indoor (3 km/h)
Urban macro	2 GHz or 4 GHz or 30 GHz	ISD = 500 m, hexagonal grid layout	20% outdoor in cars (30 km/h) 80% indoor in houses (3 km/h)
High speed (High-speed train)	4 GHz or 30 GHz	ISD = 1,732 m, linear cell layout	User speed up to 500 km/h
Extreme long distance coverage in low density areas	Below 1 GHz, e.g., 700 MHz	At least 100 km range (Up to 150 km – 300 km range) isolated macro cell	User speed up to 160 km/h

*14 Center carrier frequency: The center carrier frequency in a frequency band used for communication. A carrier frequency is a radio wave that is modulated in order to transmit information.

*15 Hotspot: An indoor office, plaza in front of a train station or other location where concentrated traffic can be generated.

scenarios in which communication is done through antennas installed on a train car.

Both 4 GHz and 30 GHz frequency bands are to be evaluated. Also, the target value for maximum coverage of an isolated cell, for deployment of large cells in developing countries and areas with low population density, is at least 100 km.

A key technology for realizing these eMBB requirements in the eMBB usage environments is Massive Multiple Input Multiple Output (Massive MIMO)*16, which uses large numbers of antenna elements [7]. The maximum number of transceiver antenna elements for Massive MIMO expected at base stations and terminals for each frequency band are shown in **Table 3**.

3.2 mMTC

For mMTC, evaluation scenarios were specified with base stations installed for macrocell*17 arrangements in urban environments, using low carrier frequencies of 6 GHz and lower, and supporting terminals distributed indoors and outdoors. A list of evaluation conditions is given in **Table 4**.

Terminals such as smart meters*18, sensors, and industrial robots are expected, so generally, traffic is of low density. As such, 3GPP specifies evaluation for capacity and connection density of 20 to 200 bytes of uplink data occurring intermittently

Table 3　Numbers of Massive MIMO transceiver antenna elements for eMBB related deployment scenarios

Parameters	Values
Number of BS antenna elements	700 MHz: Up to 64 Tx/Rx 4 GHz (& 2 GHz) : Up to 256 Tx/Rx 30 GHz: Up to 256 Tx/Rx 70 GHz: Up to 1024 Tx/Rx
Number of UE antenna elements	700 MHz: Up to 4 Tx/Rx 4 GHz (& 2 GHz) : Up to 8 Tx/Rx 30 GHz: Up to 32 Tx/Rx 70 GHz: Up to 64 Tx/Rx

Tx: Transmitter
Rx: Receiver

Table 4　List of evaluation conditions related to mMTC

Parameters	Values
Carrier frequency	700 MHz (2,100 MHz as optional)
Deployment scenario	Urban Macro: ISD = 500 m or 1,732 m 20% of outdoor users (3 km/h) + 80% of indoor users (3 km/h)
Physical layer packet size	Follow 3GPP TR45.820 or use 40 bytes fixed packet size
Traffic model	Non-full buffer with small packets (with Poisson arrival)
BS antenna elements	2 or 4 Rx ports (8 Rx ports as optional)
UE antenna elements	1 Tx

*16 Massive MIMO: MIMO transmission formats use multi-element antennas at both transmitter and receiver to spatially multiplex the radio signal. Massive MIMO is a technique that is able to realize narrow radio wave beam forming, to compensate for carrier losses when using high frequency bands or to transmit more streams at the same time, by utilizing large-scale antennas with even more elements. This can achieve high speed data communications while securing the desired service area.

*17 Macrocell: In mobile communications systems, a cell is the area covered by a single base station antenna. A macrocell generally covers a relatively large area with radius of 500 m or more.

*18 Smart meter: A device that enables real-time measurement and visualization of electricity usage.

following a Poisson distribution*19, using a File Transfer Protocol (FTP)*20 or similar model. The target for packet loss rates*21 supported for each terminal is 1% or less. In addition, low terminal cost is extremely important to enable large-scale spread of mMTC terminals. To achieve this, very simple transmission circuits and a single transmission antenna for the uplink are anticipated. mMTC transmission packets are small and the ratio of control signal to data signal tends to be large, so for efficient data transmission, it is important to reduce the amount of control signal. As such, transmitting uplink data without allocating base station resources and using control signals was studied. If base station resources are not allocated and control is not used, uplink data signal collisions among users could occur, so use of non-orthogonal multiple access*22 technology on the uplink to increase its capacity*23 was studied to keep packet errors due to such collisions below a specified level [8]. Also, mMTC coverage is to be evaluated under conditions of 200 bytes transmitted per terminal per day, with coupling losses*24 of a maximum of 164 dB.

Requirements for mMTC are expected to be achieved through extension of LTE-Advanced NB-IoT and eMTC requirements [9]. For example, part of the evaluations showed that by using the NB-IoT bandwidth extension technology, it should be possible to meet connection density requirements [10].

3.3 URLLC

For URLLC, the data signal must be transmitted with very low latency and high reliability. A list of evaluation conditions is given in **Table 5**. In addition to the indoor hotspot environment evaluation scenario, which uses carrier frequencies of 6 GHz or lower and all terminals are indoors, an evaluation scenario with base stations arranged in macrocells in an urban environment, supporting terminals distributed both indoors and outdoors,

Table 5　List of evaluation conditions related to URLLC

Parameters	Values
Carrier frequency	700 MHz and 4 GHz (FDD and TDD)
Deployment scenario	Urban macro: ISD = 500 m, 20% Outdoor in cars (30 km/h) + 80% Indoor (3 km/h) or Indoor hotspot: ISD = 20 m, Up to 12 BS per 120 m × 50 m, 100% Indoor (3 km/h)
SNR range	-5 dB to 20 dB
Physical layer packet size	e.g., 32, 50, 200 bytes
Traffic model	Non-full buffer with small packets (with Poisson arrival) or periodic packet arrivals
BS antenna elements	Up to 256 Tx/Rx, 2/4/8 Tx/Rx ports as starting point
UE antenna elements	Up to 8 Tx/Rx, 2/4 Tx/Rx ports as starting point

FDD: Frequency Division Duplex
TDD: Time Division Duplex

*19 Poisson distribution: When counting discrete events occurring within a given time period, the discrete probability distribution of the characteristic probability variable *X*.

*20 FTP: A protocol that is generally used for transferring files over a TCP/IP network such as the Internet.

*21 Packet loss rate: The probability that transmission of a packet will not complete within a specified timer interval (e.g.: from 10 ms to 10 s).

*22 Non-orthogonal multiple access: A technology in which multiple terminals share communication resources that are not orthogonal to increase data capacity.

*23 Link capacity: The transmission speed attainable on a single link.

*24 Coupling losses: The total power losses occurring between the transmitter and receiver.

was studied. Latency was studied based on a theoretical calculation incorporating processing delay, transmission delay, and retransmission delay [11]. On the other hand, for reliability, a packet success probability was defined based on block error rate within a set period of time elapsed from the start of data transmission, and evaluation is done using link-level simulation*25. To compare characteristics in environments with varied transmission quality, a range of Signal-to-Noise Ratios (SNR)*26 from –5 dB to 20 dB is specified for the signals being evaluated. Data packet sizes are from 32 to 200 bytes, occurring according to an FTP model.

In addition to the above scenarios, latency and reliability were also verified in high-speed environments of up to 500 km/h on high-speed trains, and in urban transit environments for communication with connected automobiles.

Together with the above evaluation, system level evaluation of the number of URLLC terminals that can be accommodated is also required. Specifically, indices of the number of URLLC terminals able to realize a given level of reliability in indoor hotspot and urban macrocell environments are specified.

It is expected that requirements for URLLC can be achieved using new radio frame*27 structure (Orthogonal Frequency Division Multiplexing (OFDM)*28 subcarrier*29 spacing optimization) and a high-speed ACKnowledgement/Negative ACK (ACK/NACK)*30 feedback design [9].

3.4 Other

Several usage scenarios besides those described above have been proposed. Specific examples include Vehicle to Everything (V2X) communications*31, ultra-high-speed mobility (e.g. 1,000 km/h), and long distance communication such as air to ground*32 and satellite extension to terrestrial*33. These were proposed from various industries (verticals) other than mobile communications, indicating the extent of expectations for 5G.

4. Channel Models

The SI regarding channel models supporting frequency bands at 6 GHz and higher was held between September 2015 and June 2016, and the results are documented in TR 38.900 V1.0.1 [12]. With that, the SI was concluded, but results were integrated with channel models for 6 GHz and below in March 2017, in TR38.901 V14.0.0 [13].

1) 3D and 5G Channel Models for LTE Evaluation

A comparison of the 3D channel model created in TR36.873 for evaluation of LTE and 5G channel models is shown in **Table 6** [14]. The basic channel model design is the same for both, composed of a path-loss model, a line-of-sight probability model*34, and a fast fading model*35, statistically reflecting the levels of received radio waves, the propagation delay, and the arrival angle. Also, TR36.873 only applies to frequencies up to 6 GHz, but TR38.901 applies over the range from 0.5 to 100 GHz, supporting high frequency bands such as millimeter waves (although rural scenarios are an exception). In TR36.873, the delay spread*36 and angle spread*37 used in the fast fading model and the building absorption losses used to calculate path loss between

*25 **Link-level simulation:** Modeling of the transmitter, receiver, and the physical behavior of the radio propagation path between them, applied in experiments on functionality and performance from transmitter to receiver.

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

*27 **Frame:** The period in which an encoder/decoder operates or a data signal of length corresponding to that period.

*28 **OFDM:** A digital modulation method where the information is transmitted over multiple orthogonal carriers and sent in parallel. It allows transmission at high data rates.

*29 **Subcarrier:** In OFDM and other multi-carrier transmission, the individual transport waves are called subcarriers.

*30 **ACK/NACK:** A control signal notifying of whether the data signal was correctly decoded or not.

*31 **V2X communications:** V2X is a generic name for wireless communications systems for communication between vehicles and other vehicles (V2V), vehicles and infrastructure such as traffic signals and road signs (V2I) and between vehicles and pedestrians carrying smartphones (V2P).

outdoor base stations and indoor mobile stations were uniform, regardless of frequency, but in TR38.901, both were made dependent on frequency in order to handle the wider range of frequencies. The building penetration loss model computation results from TR38.901 are shown in **Figure 2**. The figure shows how this model takes into consideration the increasing building penetration losses as frequency increases. There are also high-loss and low-loss models, which consider the building material, such as concrete or glass, so that more-detailed characteristics can be given. TR38.901 also includes additional modeling components to handle other technologies expected to be introduced with 5G.

2) Additional Modeling Components

An overview of additional modeling components is shown in **Table 7**. These models are mainly for more accurate evaluation of technologies such as large-scale array antennas*38 (Massive MIMO), beam tracking*39 (beam forming*40) and Multi-

Table 6 Comparison of channel models for LTE and 5G

	3D channel model for LTE	5G channel model
Document	3GPP TR36.873	3GPP TR38.901
Model type	GSCM	GSCM
Applicable frequency range	Up to 6 GHz	0.5 to 100 GHz
Features	・LSP (delay spread, angle spread, etc.) and building penetration loss are constant, not dependent on frequency.	・LSP and building penetration loss are dependent on frequency. ・Additional modeling components are provided (for handling 5G technologies).

GSCM: Geometry-based Stochastic Channel Model
LSP: Large Scale Parameter

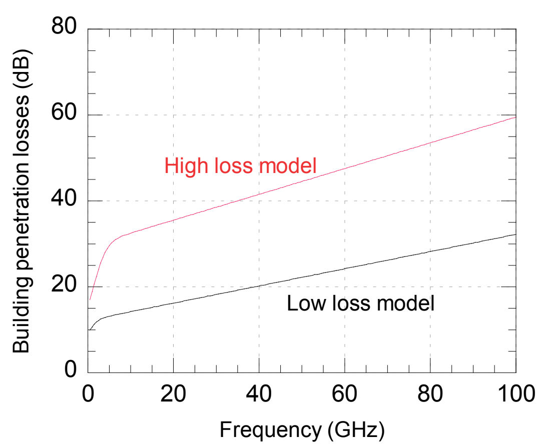

Figure 2 Building penetration losses

*32 Air to ground transmission: Technology for direct communication between aircraft and the ground, without using satellites.

*33 Satellite extension to terrestrial transmission: Satellite communication intended to complement terrestrial communication. This includes Low Earth Orbit (LEO) satellites, Medium Earth Orbit (MEO) satellites, and Geostationary Earth Orbit (GEO) satellites.

*34 Line-of-sight probability model: A model which assigns a probability to whether base station and mobile station have a line-of-sight situation, the main parameter for distance between them.

*35 Fast fading model: A model in which fading occurs with reception level changing over a short period.

*36 Delay spread: For radio propagation in mobile communications, the spread in delay time of signals along all paths due to reflection and diffraction from buildings and other objects. Defined by a standard deviation of delay times of signals arriving on all paths, weighted by received signal power.

*37 Angle spread: For radio propagation, the spread in arrival angle of signals along all paths due to reflection and diffraction from buildings and other objects. Defined by a standard deviation of arrival angles of signals arriving on all paths, weighted by received signal power.

Table 7 Overview of additional modeling components

Model name	Overview
Oxygen attenuation	A model accounting for power attenuation due to oxygen in the 52 to 68 GHz range
Wide band and large-scale array antenna	A model with delay and emission and arrival angles when there is high resolution in the time and space domains through use of wide band and large-scale array antennas
Spatial consistency	A model that continuously changes channels for evaluation of techniques including beam tracking and MU-MIMO
Blockage	A model for cases where the base station or mobile station is obstructed by a static or moving object
A correlation model for simulating multiple frequencies.	A model explaining procedures for simulating multiple frequencies simultaneously
Time-changing Doppler frequency	A model which gives a Doppler frequency, for cases when the mobile station is moving in a straight line, or the arrival angle is changing with time
User terminal rotation	A model which performs computation accounting for rotation of the mobile terminal
Ground reflection	A model that considers ground reflections for LOS environments

LOS: Line Of Sight

User MIMO*41, and to provide simulation as an add-on to the basic model.

5. Conclusion

This article described 5G requirements, scenarios and evaluation conditions defined by the 3GPP, as specification of the 5G radio interface progresses, including progress in technical development as interest in 5G continues to increase around the world. 5G requirements and evaluation conditions are being considered in corresponding working groups for the on-going design and evaluation of the new radio interface for 5G [8] [9]. NTT DOCOMO will continue to fulfill its role consolidating the related discussions, and actively contributing to 5G standardization.

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*38 Array antenna: An antenna consisting of an array of multiple antenna elements.

*39 Beam tracking: A technique for tracking the movement of a mobile station and increasing the antenna gain in that direction; forming a directivity pattern by controlling the signal amplitude and phase among multiple antennas.

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

*41 Multi-user MIMO: A technology that improves spectral efficiency by applying MIMO transmission to simultaneously transmit (multiplex) signals of multiple users.

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Special Articles on 5G Standardization Trends Toward 2020

Status of Investigations on Physical-layer Elemental Technologies and High-frequency-band Utilization

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Aiming to promptly introduce "fifth-generation mobile communications systems" ("5G" for short), as a member of the 3GPP, we have vigorously investigated key technologies for wireless interfaces that satisfy the technical requirements for 5G and completed these basic investigations (on "Study Items", SIs) in March 2017. In this article, the details and results concerning those SIs are presented, and key technologies concerning the physical layer, candidate frequencies, and specifications and performance requirements are discussed in terms of predicted future work on specification development.

1. Introduction

As for fifth-generation mobile communication systems (5G), it is highly anticipated that 5G will support various usage scenarios such as "enhanced Mobile BroadBand" (eMBB), "massive-Machine-Type Communications" (mMTC*1), and "Ultra-Reliable Low-Latency Communications" (URLLC).

In the 3rd Generation Partnership Project (3GPP), a new wireless-communication system without backward compatibility with LTE-Advanced wireless-communication systems, called "New Radio" (NR),

*1 MTC: A general term used in the 3GPP for machine-based communications using no intermediate human operations.

was approved as a "Study Item" (SI)*2, and investigations on that SI began at an assembly held in March 2016. As for the work involved in establishing the specifications for NR, considering the abovementioned utilization scenarios, we assume that the high-frequency band up to 100 GHz—as well as the existing frequency band used by LTE—will be utilized, and we aim to develop specifications that achieve flexible wireless interfaces and that assure wireless performance in that high-frequency band. As for a technical field differing considerably from that of conventional LTE-based wireless interfaces, this article focuses on scalable frame structures compatible with various uses cases and frequency bands, initial-access technology and multi-antenna technology compatible with various frequency bands and base-station designs*3, and channel coding technology for covering a wide range of data sizes and delay requirements. In particular, it overviews the details of investigations on SIs and discusses items forecasted as future works on formulating specifications, i.e., "Work Items" (WIs)*4, namely, key technologies for the physical layer*5, candidate frequencies, and required specifications concerning performance requirements.

2. Elemental Technologies for Physical Layer

2.1 Radio Frame

For NR, radio frame is defined such that Orthogonal Frequency Division Multiplexing (OFDM)*6 with various sub-carrier*7 spacings (namely, at the least, 15, 30, 60, or 120 kHz) are supported. It is well known that narrower sub-carrier spacing is more suitable for wide-area coverage, the low-carrier-frequency band, and severe multipath*8 channel environments; on the other hand, wider sub-carrier spacing is more effective for high-speed movement, the high-carrier-frequency band, and latency reduction. By supporting multiple OFDM sub-carrier spacings in the unified framework of the radio frame, NR can support a wide range of frequencies—namely, from the existing cellular frequency band to the millimeter band—and provide multiple services—ranging from eMBB to URLLC—by a single framework.

In order to realize those features, the NR radio frame is specified as below (**Figure 1**):

- Radio frame is in units of 10 ms (i.e., it does not depend on OFDM sub-carrier spacing used).
- Sub-frames*9 are defined in units of 1 ms (i.e., they do not depend on OFDM sub-carrier spacing used).
- Slots*10 are defined as 14 OFDM symbols*11, and their time interval depends on sub-carrier spacing.

As for OFDM in general, a "Cyclic Prefix" (CP)*12 is attached to each OFDM symbol to assure multipath tolerance. As for NR, it is agreed that the overhead ratio of CPs among OFDM signals with different sub-carrier spacing, is fixed. In other words, in the case that OFDM signals have double the sub-carrier spacing, both OFDM-symbol

*2 SI: Work that involves investigating feasibility and roughly identifying all functions that should be specified.

*3 Base-station design: Scenarios in which requirements of each operator (such as traffic) are considered and base stations are designed and developed.

*4 WI: Work that involves determining all functions needing specifying and formulating detailed specifications for those functions.

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

*6 OFDM: A high-efficiency multi-carrier transmission method that uses orthogonal narrowband sub-carriers. This method has been adopted for LTE because of its high tolerance with multipaths.

*7 Sub-carrier: Individual carrier for transmitting signals with multi-carrier transmission such as OFDM.

*8 Multipath: A phenomenon that results in a radio signal transmitted by a transmitter reaching the receiver by multiple paths due to propagation phenomenon such as reflection, diffraction, etc.

*9 Sub-frame: A unit of radio resources in the time domain consisting of multiple (generally 14) OFDM symbols (see *11).

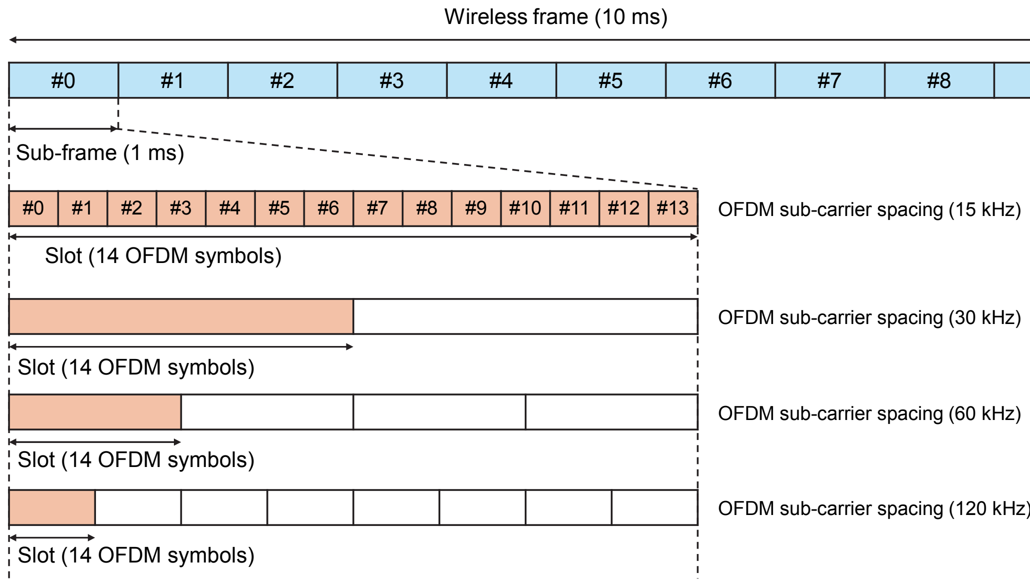

Figure 1 Prescribed configuration of wireless frame (in case of 14 OFDM symbols per slot)

length and CP length are halved.

2.2 Initial Access

As for initial access to an NR cell, the same method as used for general LTE, i.e., detecting synchronization signals*13, acquiring broadcast system information*14, and establishing a connection by random access*15, is used. However, as for the configuration of signals and channels, transmission methods, and so on, NR and LTE are significantly different.

1) NR Synchronization Signals

As in the case of LTE, synchronization signals are composed of two parts, namely, a Primary Synchronization Signal (PSS)*16 and a Secondary Synchronization Signal (SSS)*17. However, in the case of NR, the number of "Physical Cell IDentifiers" (PCIDs)*18 expressed by the synchronous signals is doubled in comparison with that for LTE since a deployment scenario potentially with extremely high density is supposed. In addition, the sequence length of the synchronous signals and the method for generating those sequences are also changed. Since it is preferable that blind detection*19 of OFDM sub-carrier spacing applied for synchronization signals is not required when a mobile terminal makes initial access, a single default OFDM sub-carrier spacing will be defined for each frequency band. In NR, the periodicity and timing of synchronization signals transmission

*10 Slot: A unit for scheduling data consisting of multiple OFDM symbols (see *11).

*11 Symbol: A unit of data for transmission. In OFDM, it comprises multiple sub-carriers. Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK)) map to each sub-carrier.

*12 CP: A guard time (also called "guard interval") inserted between symbols in OFDM signals to minimize interference between prior and subsequent symbols caused by multipath effects. Usually, this part of the signal is copied from the part of the latter-half symbols.

*13 Synchronization signal: A physical signal enabling the mobile terminal to detect cell frequency, reception timing, and cell ID in order to begin communications, e.g., when a mobile terminal powers up.

*14 Broadcast system information: Essential system information (including cell access information required for executing the procedure for connecting mobile terminals to cells, random-access channel information and so on) to be broadcasted within a cell.

*15 Random access: A procedure executed by mobile terminals and base stations for connecting uplink signals and synchronizing their transmission timing.

are configurable by network, and mobile terminals can be notified about them accordingly. Moreover, the default transmission periodicity supposed by a mobile terminal making initial access before the notification is defined as 20 ms, which is longer than the transmission periodicity of synchronization signals in LTE (i.e., 5 ms) so that "always on" signals transmission is reduced as much as possible. Also, to reduce the burden on mobile terminals for NR cell access, a scheme for expanding the frequency raster*20 in comparison with that in LTE and reducing the number of candidate positions is investigated.

2) Beam-sweeping Transmission of Synchronization Signals and Broadcast Channels

In the case of the high-frequency band above 6 GHz, it is considered that beamforming*21 is applied, e.g., to transmission on the base-station side, to assure communication distance between a base station and a mobile terminal and the area covered by the base station. By applying beamforming, on the one hand, it is possible to extend transmission distance (by concentrating transmit signal power in a specified direction); on the other hand, the range of direction in which signals can be received with sufficient signal strength is narrowed due to beamforming. Since Synchronization Signals (SS) and Physical Broadcast CHannel (PBCH)*22 need to reach all mobile terminals within a cell, "beam sweeping" transmission (where a base station transmits signals while switching beam direction sequentially to cover a whole cell area) is supported for multi-beam operation and is applied to transmission of an SS/PBCH block, which is defined as an unit of beam sweeping (i.e., different transmission beams are applied to different SS/PBCH blocks) (**Figure 2** (a)). In addition,

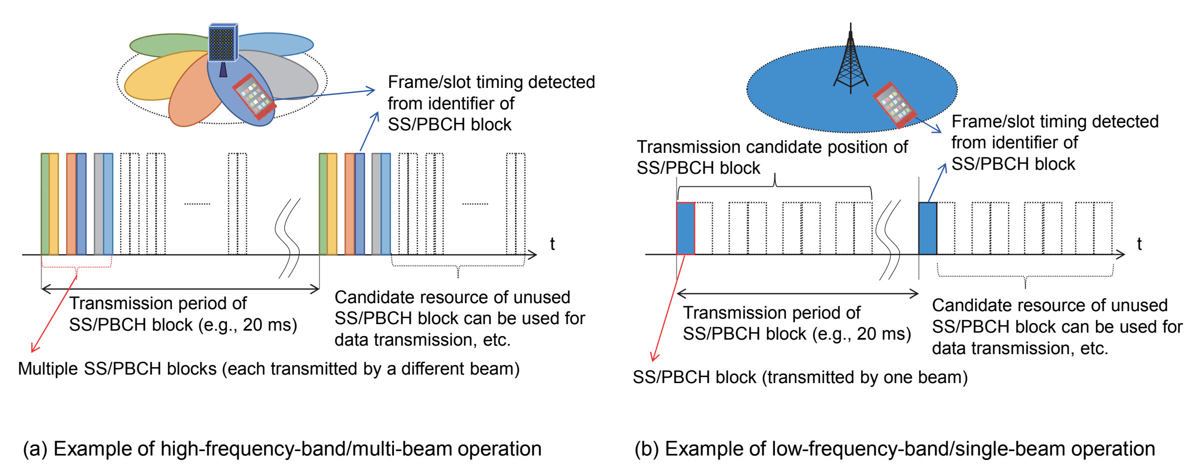

Figure 2 Notification of SS block index when single or multi-beams are used

*16 PSS: A signal used by mobile terminals for achieving time/frequency synchronization with a received symbol of a downlink signal from a base station. One of three different PSS signals is used by a cell as a part of PCID (see *18).

*17 SSS: A signal used by mobile terminals for detecting PCID (see *18) of a base station, and one of 336 signals is used by a cell as a remaining part of PCID.

*18 PCID: An identifier for a physical cell. In case of LTE, 504 PCIDs are available and used, but in case of NR, 1008 PCIDs are used.

*19 Blind detection: A process performed to identify specific signal or parameter from multiple candidates (e.g., based on hypothesis testing).

*20 Raster: A frequency-carrier position used by mobile terminals for finding presence or absence of synchronous signals, e.g., when a mobile terminal powers up.

*21 Beamforming: Technology for generating a directional pattern for transmission and/or reception by using multiple antennas (by means of controlling amplitude and phase of each of multiple antennas) and increasing or decreasing antenna gain in regard to specific directions.

*22 PBCH: A channel for broadcasting essential wireless parameters for receiving control channel and corresponding shared channel (such as system frame number, control channel configuration including sub-carrier spacing and so on).

it is also possible to adopt a configuration in which only one SS/PBCH block is periodically transmitted (i.e., single-beam operation) by a single beam pattern without applying beam sweeping e.g., for the low-frequency band (Fig. 2 (b)). NR will define multiple candidate positions of SS/PBCH blocks within a radio frame and base station can practically transmit SS/PBCH block(s) at one or more candidate position(s) according to the number of beams to be used for transmitting SS/PBCH blocks. However, due to multiple candidate positions of SS/PBCH block within a radio frame, unless a mobile terminal could identify which SS/PBCH block (i.e., position) is actually detected, it is impossible to recognize radio-frame timing and slot timing. Consequently, a mechanism to identify the index of the SS/PBCH block by using the PBCH and reference signal, called "PBCH DeModulation Reference Signal" (PBCH-DMRS), included in the SS/PBCH block is investigated.

3) Random Access after acquisition of Broadcast System Information

After broadcast system information is acquired, mobile terminals use the four-step random access procedure used in LTE (**Figure 3** (a)). For the Physical Random-Access CHannel (PRACH)*23 transmitted as Msg.1, in addition to some formats using the same sequence length and OFDM sub-carrier spacing as LTE PRACH formats, PRACH formats using wide OFDM sub-carrier spacing and shorter sequence length are introduced mainly for the high-frequency band. In the case that transmission beamforming is applied to the SS/PBCH block to extend the cell coverage, it is necessary to apply

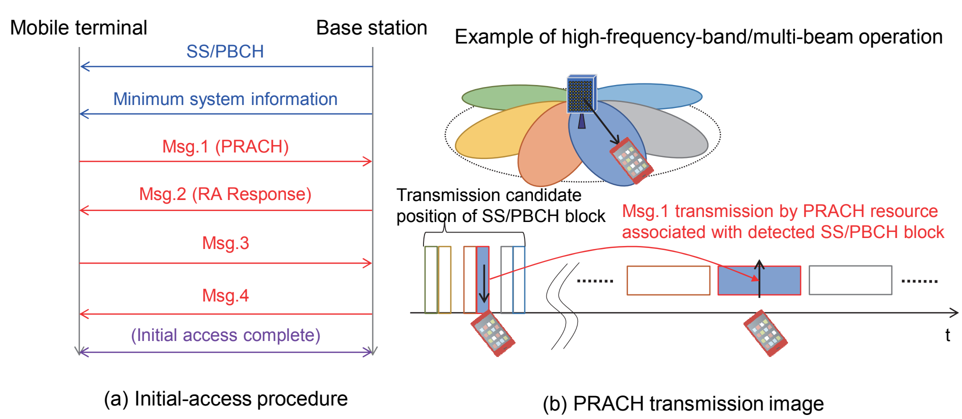

Figure 3 Initial-access procedure and image of PRACH transmission

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

equivalent reception beamforming at base station for receiving the PRACH preamble from the mobile terminal. Consequently, the mobile terminal transmits the PRACH preamble on the resource which is associated with the detected SS/PBCH block so that base station can apply appropriate reception beamforming for receiving PRACH preamble on the resource (Fig. 3 (b)).

4) Cell and Beam-quality Measurements

To measure a reception quality in a cell for, e.g., handover, the reference signals included in the SS/PBCH block (i.e., SSS and PBCH-DMRS) are used. In the case of multi-beam operation applying transmission beamforming for SS/PBCH blocks, mobile terminals can be configured to measure and report the reception quality of each SS/PBCH block as the quality of each base-station beam. It is also possible to configure Channel State Information - Reference Signal (CSI-RS)*24 resources for the measurement so that more flexible measurement, e.g., on each base station and/or each beam, can be performed and reported.

2.3 Multi-antenna Technology

As for NR, the transmission and reception of signals from multiple antennas in the uplink and downlink can be performed by using 3D beam control. Particularly in the case of the high-frequency band, it is vital to create high beam gain with multiple antennas in order to compensate influence of radio attenuation. For example, as for the 30-GHz band, base stations and mobile terminals are equipped with maximums of 256 and 32 antenna elements, respectively. Here, the antenna elements are divided into several groups and digital signal processing is performed with a control unit called "antenna ports."

1) Examples of Equipped Multi-antenna Circuitry and Equipment

Examples of multi-antenna circuitry are shown in **Figure 4**. Digital beamforming is usually applied for the low-frequency band, and multi-antenna technology of LTE is prescribed on the basis of this example. In this example, a transmission-and-reception beam is formed by varying phase and amplitude of a digital signal. In the meantime, as for systems for transmitting broadband signals in the high-frequency band, it is becoming more difficult to achieve beamforming in the digital domain due to influences such as implementation cost. As a result, phase and amplitude of analog signals are varied, and configurations based on analog beamforming and hybrid beamforming are generally applied. As for beamforming in the analog domain, beams cannot be controlled in units of "sub-bands*25" under certain device configurations of analog circuitry; accordingly, beamforming is generally achieved by wideband beam control.

2) Beam Control Regarding Layers 1 and 2

Beam control regarding Layer 1*26 and Layer 2*27 is broadly classified as beam management and Channel-State Information (CSI)*28 acquisition. Beam management is particularly effective at high frequencies, and under the aim of acquiring and maintaining beam pairs for base station and mobile terminals at Layer-1 and Layer-2 levels, it is

*24 **CSI-RS**: A downlink reference signal used by mobile terminals to measure the state of the radio channel.

*25 **Sub-band**: A partial band composed of a part of a system bandwidth.

*26 **Layer 1**: The first layer (physical layer) in the OSI reference model.

*27 **Layer 2**: The second layer (data link layer) in the OSI reference model.

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

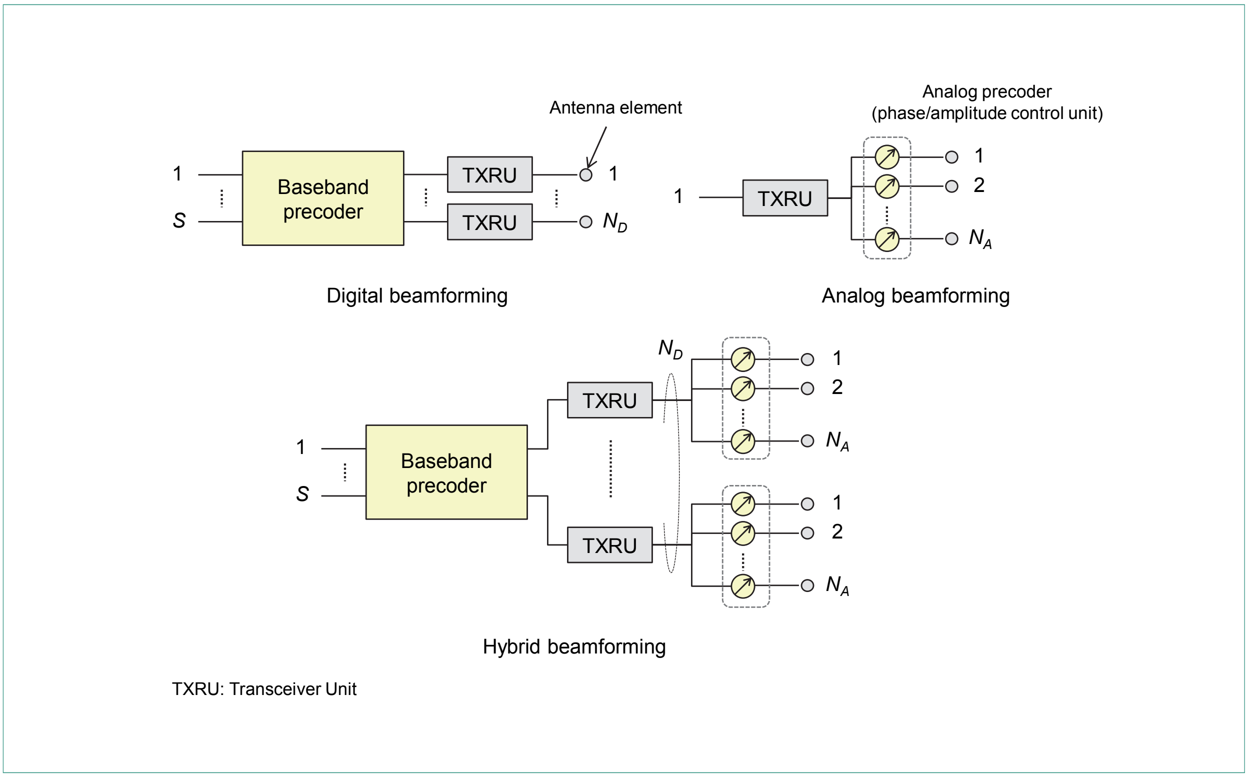

Figure 4 Implementation examples of multi-antenna circuitry for achieving beamforming

supposed that beam post-processing is performed in a longer cycle than that of CSI acquisition on the basis of Reference-Signal Received Power (RSRP)*29. In addition, a technology called "beam failure recovery," which detects mismatching of beam pairs on the terminal side and sending to the base station a request to switch to another beam pair, is supported. Furthermore, CSI acquisition is used for determining the precoder and Modulation and Coding Scheme (MCS)*30 in order to form sharper beams and higher data rate, and it is supposed that the beam is controlled in a relatively short cycle. It is agreed that CSI-RS at least (namely, a downlink reference signal) and a Sounding RS (SRS)*31 (namely, an uplink reference signal) will be used for the techniques described above, and it is planned to formulate technical specifications by applying a simple framework.

3) Data Transmission

As for data transmission, beam control and spatial multiplexing are possible by using the propagation-path information acquired by the above-described techniques. As for NR, it is agreed that single-user Multiple-Input Multiple Output (MIMO)*32 and multi-user MIMO*33 will be supported; in particular, for the downlink, single-user MIMO with a

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

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

*31 SRS: Uplink reference signal for measuring uplink channel quality and reception timing, etc. at a base station.

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

*33 Multi-user MIMO: Technology that uses MIMO transmission at identical temporal frequencies for multiple users.

maximum of eight streams and multi-user MIMO with a twelve streams will be supported, and for the uplink, single-user MIMO with at least four streams will be supported.

2.4 Channel-coding Technology

As for LTE, Tail-Biting Convolutional Coding (TBCC)*34 and turbo coding*35 are applied as error-correction coding. As for NR, in addition to those coding methods, Low-Density Parity-Check (LDPC) coding and polar coding have been investigated. While LDPC coding can shorten delay in decoding processing by using parallel processing, and polar coding can reduce decoding-calculation load in comparison to that in the case of TBCC, together they exhibit an outstanding property in terms of being asymptotic in relation to the Shannon limit*36. Accordingly, LDPC coding was applied to data channels, and polar coding was applied to control channels.

3. High-frequency-band Utilization

As for SIs regarding NR, usage of frequency bands, specification of wireless characteristics for each frequency band, and test methods have been investigated as part of investigations related to frequency.

3.1 Frequency Band Used for NR

As one step towards achieving eMBB (namely, one use case of 5G), in regard to NR, technologies that utilize more-continuous frequencies than those used for LTE for broadband communication have been investigated. Although the first SIs started with investigations targeting frequencies up to 100 GHz, in consideration of the necessity of promptly formulating specifications, candidate frequencies in each region were investigated. The results of that investigation revealed that, as shown in **Figure 5**, in the millimeter range, frequencies from around 30 to around 40 GHz are expected to be mainly utilized.

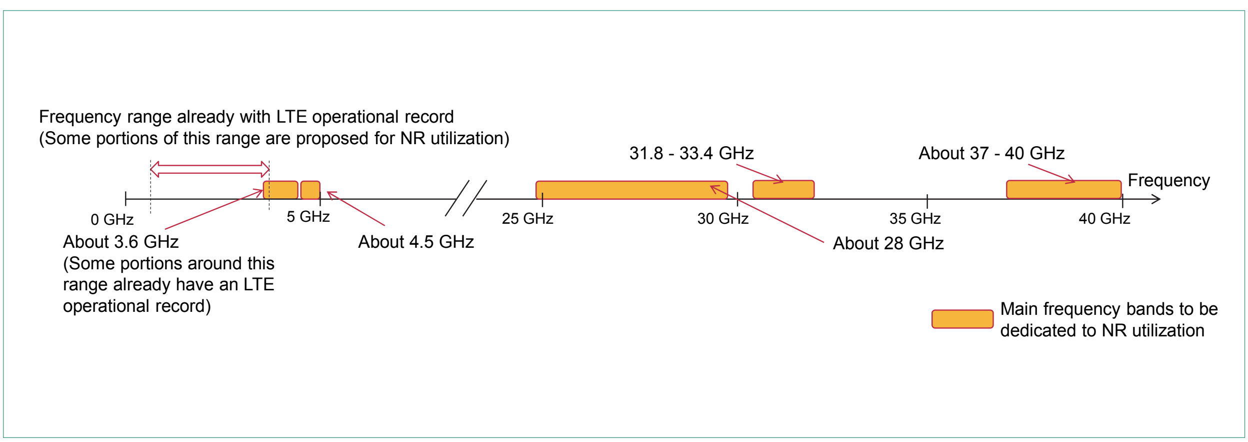

Figure 5　Candidate frequencies expected to be mainly utilized for NR in each region

*34 TBCC: A type of error-correcting code; namely, a coding scheme that generates codewords by using convolution calculation. TBCC has already been practically applied in 3G mobile-communications systems.

*35 Turbo coding: A type of error-correcting code proposed by Berrou et al. in 1993. Together with Low-Density Parity-Check (LDPC) code, it is known to produce characteristics that are closest to the Shannon limit (see *36), and it has already been implemented in systems (including 3G mobile communications).

*36 Shannon limit (also known as "Shannon communication-channel capacity"): Theoretically derived from bandwidth and Signal-to-Noise (SN) ratio, the maximum amount of information that can be transmitted.

The frequencies that have been conventionally specified for LTE range up to a maximum of about 6 GHz. Radio-characteristics specifications in regard to the millimeter band (including frequencies from 30 to 40 GHz) have not been investigated by the 3GPP. In addition, since utilization success in regard to the mobile telephony in the millimeter band has not been reported, it is necessary to newly investigate such utilization from the viewpoint of manufacturing technology. Accordingly, from that viewpoint, investigations focused on the millimeter band in particular have been performed.

3.2 Radio-characteristics Specification

As a matter that should be considered when investigating specifications for the millimeter band, the viewpoint under which specifications presuppose transmission and reception by beamforming, utilization of the frequencies continuing over a width of several hundred megahertz, and necessity of specification based on measurement by Over-The-Air technology (OTA)*37 (described in Section 3.3) is cited.

1) Coexistence Investigations Presupposing Transmission and Reception by Beamforming

In the 3GPP, in the case that Adjacent Channel Leakage Ratio (ACLR)*38 (i.e., a basic parameter concerning wireless characteristics) and Adjacent Channel Selectivity (ACS)*39 are discussed, interference effects between mobile terminals or wireless base-station equipment using adjacent frequencies are investigated by simulation (namely, "coexistence investigations") with the consideration of requirements in terms of system performance.

Although similar coexistence investigations are performed in regard to the millimeter band, in the case a frequency channel used by the current cell is beamformed, the influence on adjacent frequencies is a key point to be considered. In concrete terms, it is necessary to consider points such as base-station expansion supposing the millimeter band depends greatly on beamforming gain, and the extent of the interference effect between adjacent frequencies depends on beamforming gain at the above-mentioned frequencies and surrounding frequencies. In consideration of such points, investigations on base-station expansion supposing the millimeter band and evaluations of mobile terminals wireless equipment that presuppose transmission and reception by beamforming have begun in the 3GPP. Moreover, when those evaluations are performed, new radiowave-propagation characteristic models corresponding to the millimeter band are used. On top of that, in regard to setting required values for definitive ACLR/ACS, in addition to evaluation results of the coexistence investigations from the above-mentioned viewpoint of system performance, implementation verification from the viewpoint of fabrication technology was considered, when initial results of investigations as SIs were summarized. Moreover, basic parameters concerning wireless characteristics such as transmission power, spectrum mask*40, and spurious emission*41 were investigated, and the results of those investigations were reported, alongside those on ACLR/ACS, at the International Telecommunication

*37 OTA: A method for setting specified points and measurement points in a radiowave-propagation space, specifying wireless performance (including antenna emission and reception characteristics), and measuring those parameters.

*38 ACLR: In modulated signal transmission, the ratio between the transmitted signal band power and undesired power generated in the adjacent channels.

*39 ACS: The ability to correctly select and receive (i.e., filtering) the desired wave even under the condition that signal-power ratios of the desired wave and an interfering wave adjacent to the desired wave are prescribed.

*40 Spectrum mask: An unwanted wave (excluding spurious emission*41) emitted in the frequency range adjacent to the primary signal when that signal is transmitted.

*41 Spurious emission: An unwanted wave emitted at a wavelength outside the channel bandwidth of the main signal when that signal is transmitted.

Union - Radio Communication Sector (ITU-R).

2) Feasibility from the Viewpoint of Implementing Equipment for Broadband Transmission

Aiming to make it possible to utilize a continuous frequency band spanning a width of several hundred megahertz, in addition to discussions on conditions required from the viewpoint of system performance, investigations considering implementation of equipment from the aspects of BaseBand (BB)*42 components and Radio-Frequency (RF)*43 components of base station and mobile terminals were performed. For example, from the viewpoint of implementation of the BB, in the case that a certain OFDM sub-carrier spacing is used, as the frequency bandwidth used for communication gets wider, information-bit number theoretically usable for transmission and reception by one slot increases in proportion to channel bandwidth; even so, it is necessary to implement Fast Fourier Transform (FFT) functional units*44 with even higher processing power. Moreover, from the viewpoint of RF, as the frequency band used gets higher, the effect of phase noise*45 gets more prominent, and communication using a multi-value modulation scheme and a multiple number of streams becomes difficult. As for solving that problem, it is necessary to implement high-accuracy RF devices with, for example, Phase-Locked-Loop (PLL)*46 circuits, and it is also necessary to apply even bigger OFDM sub-carrier spacing. In either case, it is necessary to consider costs and feasibility.

Conclusions drawn from the results of investigation on SIs concerning maximum channel bandwidth, OFDM sub-carrier spacing, and FFT processing capacity are listed in **Table 1**. As for WIs, on the basis of demands such as each specified band, it is planned to discuss optimum maximum channel bandwidth and size of OFDM sub-carrier spacing.

3.3 Specification Presupposing OTA and Related Issues

1) Necessity of Specifications Presupposing OTA

As for wireless-characteristics specifications for LTE, except in the case of some specifications*, as shown in **Figure 6**, physical connectors of the

Table 1 Conclusions of SIs about maximum channel bandwidth, sub-carrier spacing, and FFT size

	LTE	NR	
		Less than 6 GHz	Greater than 6 GHz
Maximum channel bandwidth	20 MHz*1	100 – 200 MHz*2	100 MHz – 1 GHz*2
Sub-carrier spacing	15 kHz	15 kHz, 30 kHz, 60 kHz	60 kHz, 120 kHz, 240 kHz, (480 kHz)
FFT size	2,048	4,096, (8,192)	

*1 In the case Carrier Aggregation is used, radio characteristics up to 100 MHz have been specified.

*2 Whether accomplished by 1 CC (carrier component) is undetermined.

*42 BB: The circuits or functional blocks that perform digital signal processing.

*43 RF: The radio frequency circuit.

*44 FFT functional unit: A functional unit for executing a fast FFT (or an Inverse FFT (IFFT)) required by the transmission and receival process.

*45 Phase noise: Random phase modulation due to a noise source modulating a transmitter.

*46 PLL: A circuit that synchronizes the output signal frequency with a standard frequency.

* In the case of LTE as well as NR, Release15 WI—called “enhancements of Base Station RF and EMC requirements for Active Antenna System” (eAAS)—has been prescribed as a specification based on OTA; however, target frequency band is below 6 GHz, and from the viewpoint that a specification stipulating wired connection is also possible, investigations on SIs regarding NR differ from those regarding LTE.

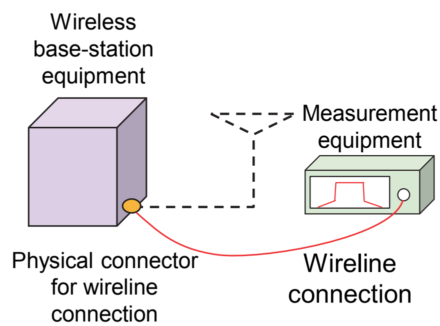

Figure 6 Example of wireline-connection specification based on physical connector

antennas of mobile terminals and wireless base stations are used as reference points for specifying and measuring requirements (wired-connection provision). On the contrary, in the case of a high-frequency band like that of millimeter waves, power attenuation within circuits becomes significant; consequently, devices such as amplifiers, filters, and antennas become more integrated (for achieving low loss), and physical connectors themselves cannot be installed. Furthermore, in the case that use of multiple amplifiers and antennas (such as massive MIMO*47) is supposed, even when frequencies below the 6-GHz band are used, measuring each physical connector is a point of demerit from the viewpoint of man-hours spent for testing. In consideration of those circumstances, as for SIs, the necessity and importance of OTA specifications for executing prescription and measurement under wireless-characteristics specifications for a certain propagation space were discussed. As a result of those discussions, as specifications to be discussed as future WIs, on the one hand, as for frequencies under 6 GHz, specifications presupposing wireline connection or OTA were targeted; on the other hand, as for millimeter waves, only specifications presupposing OTA were targeted.

2) Challenges Concerning Specification Presupposing OTA

In the case that tests using OTA are performed, in general, the scale of test facilities increases, and while time is required for measuring radio characteristics at spatial axis in addition to conventional frequency axis, inaccuracy of the measurements tends to become worse in comparison to that of wireline tests. As for formulating specifications, from the viewpoint of running tests and their costs, it is therefore extremely important to formulate specifications properly in consideration of spatial characteristics (since directional characteristics of power radiated from mobile terminals and wireless

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

base-station equipment are generally not uniform). For example, at a certain measurement frequency, spurious emission is defined in terms of the sum of all energies emitted in a certain space. When spurious emission is measured, the space is divided up into several regions, and spatial measurements are performed for each region. In that case, if the divided regions are made smaller (or the number of divisions is increased), in general, measurement accuracy improves. However, that means that the number of points in space that must be measured increases, and it becomes a risk that all the points cannot be measured in a reasonable time. Accordingly, during the discussions on future WIs, it is important to formulate each wireless specification in consideration of the trade-off between measurement time and accuracy described above.

4. Conclusion

In this article, the contents of technical investigations (completed in March 2017) by 3GPP RAN on SIs were explained. In the phase of 5G WIs, key technologies and candidate frequencies studied as SIs, as well as wireless-performance requirement specifications and their effects, are being continually investigated. From now onwards, it is expected that the results of those investigations will be implemented as commercial products. NTT DOCOMO will push ahead with investigations on essential key technologies for implementing commercial 5G products.

Technology Reports | 5G | LTE-NR DC | Front-haul Open Interface

Special Articles on 5G Standardization Trends Toward 2020

5G Radio Access Network Standardization Trends

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

1. Introduction

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

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

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

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

2. LTE-NR DC

2.1 Overview

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

2.2 Functional Extensions of Radio Protocol

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

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

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

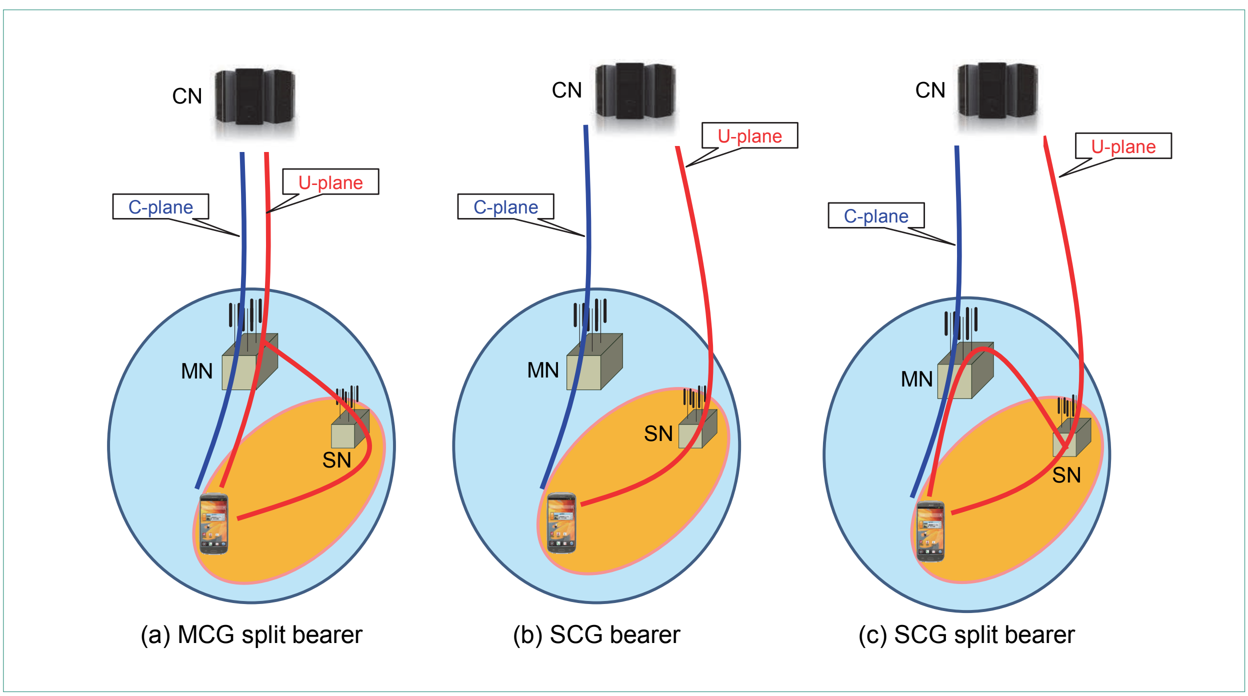

Figure 1　U-plane bearer type in LTE-NR DC

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

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

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

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

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

and then transferred by an SN carrier.

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

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

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

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

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

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

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

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

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

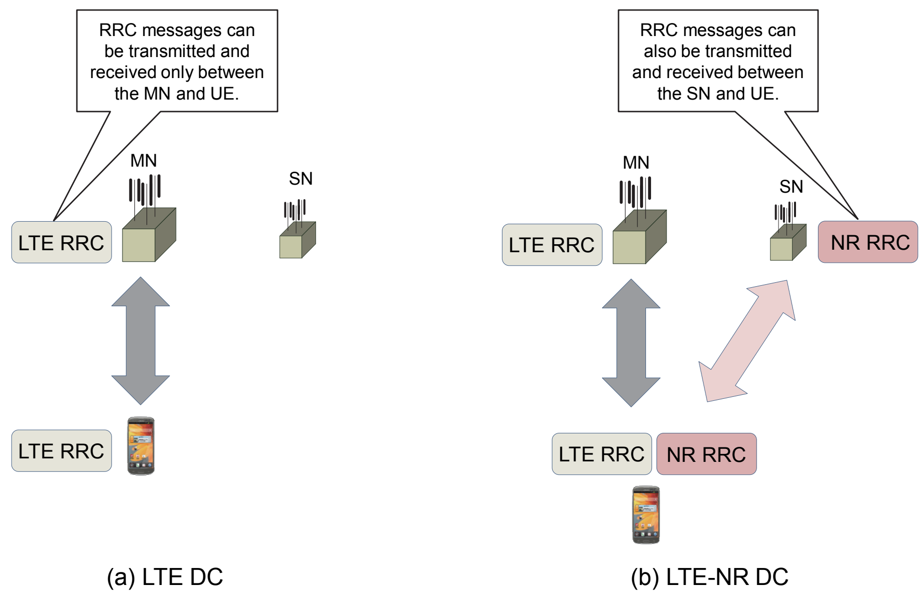

Figure 2 Independent control of LTE-NR RRC in DC

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

3. CU-DU Functional Split and Open Interface

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

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

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

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

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

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

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

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

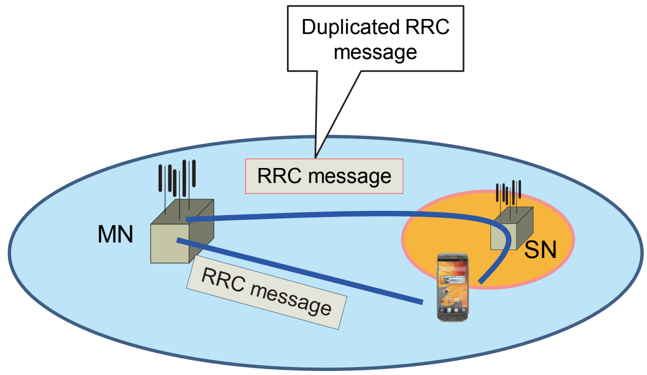

Figure 3 Transmit diversity of C-plane signal

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

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

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

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

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

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

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

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

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

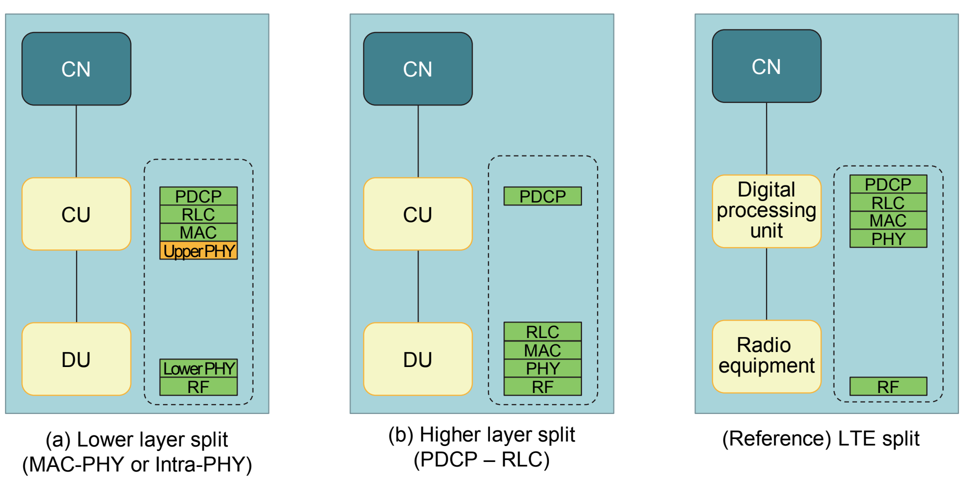

Figure 4 Examples of CU-DU functional split configurations

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

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

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

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

4. 5G Radio Access Network

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

4.1 RAN Configuration

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

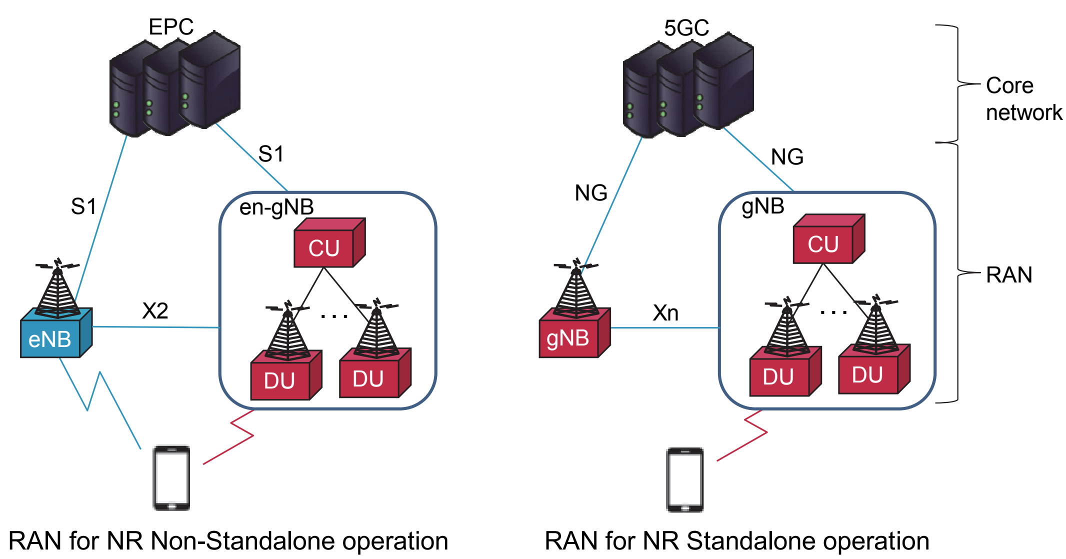

Figure 5　5G RAN configurations

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

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

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

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

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

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

4.2 U-plane Radio Protocol

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

1) Main Extensions for NR U-plane

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

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

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

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

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

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

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

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

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

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

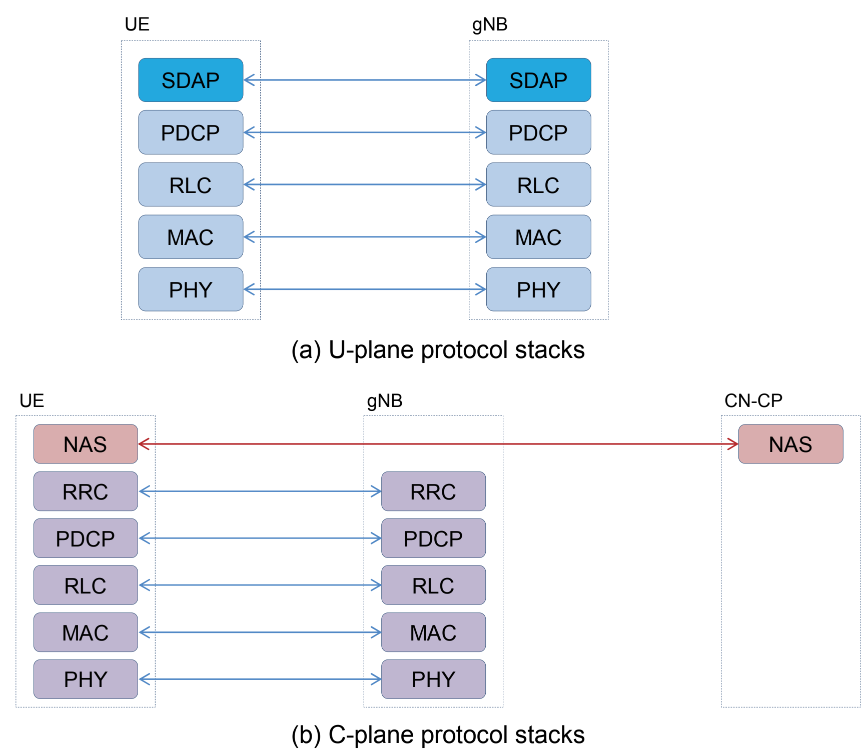

Figure 6 NR radio-interface protocol stacks

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

2) Extensions for Achieving High-reliability Communications

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

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

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

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

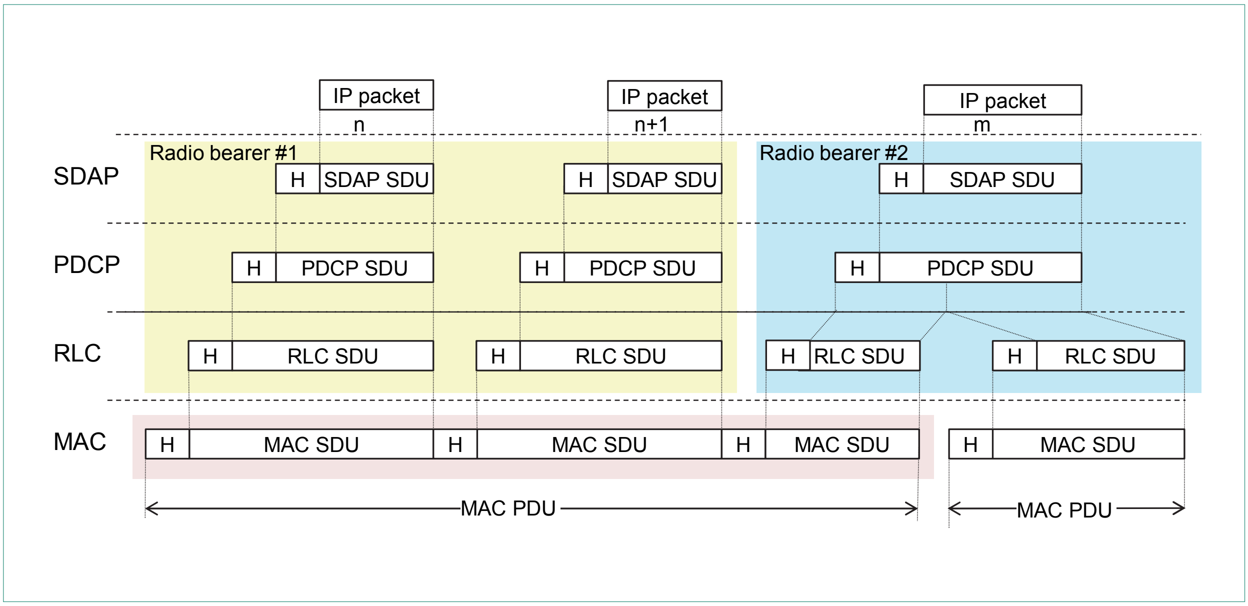

Figure 7 U-plane data frame configuration

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

4.3 C-plane Radio Protocol

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

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

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

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

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

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

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

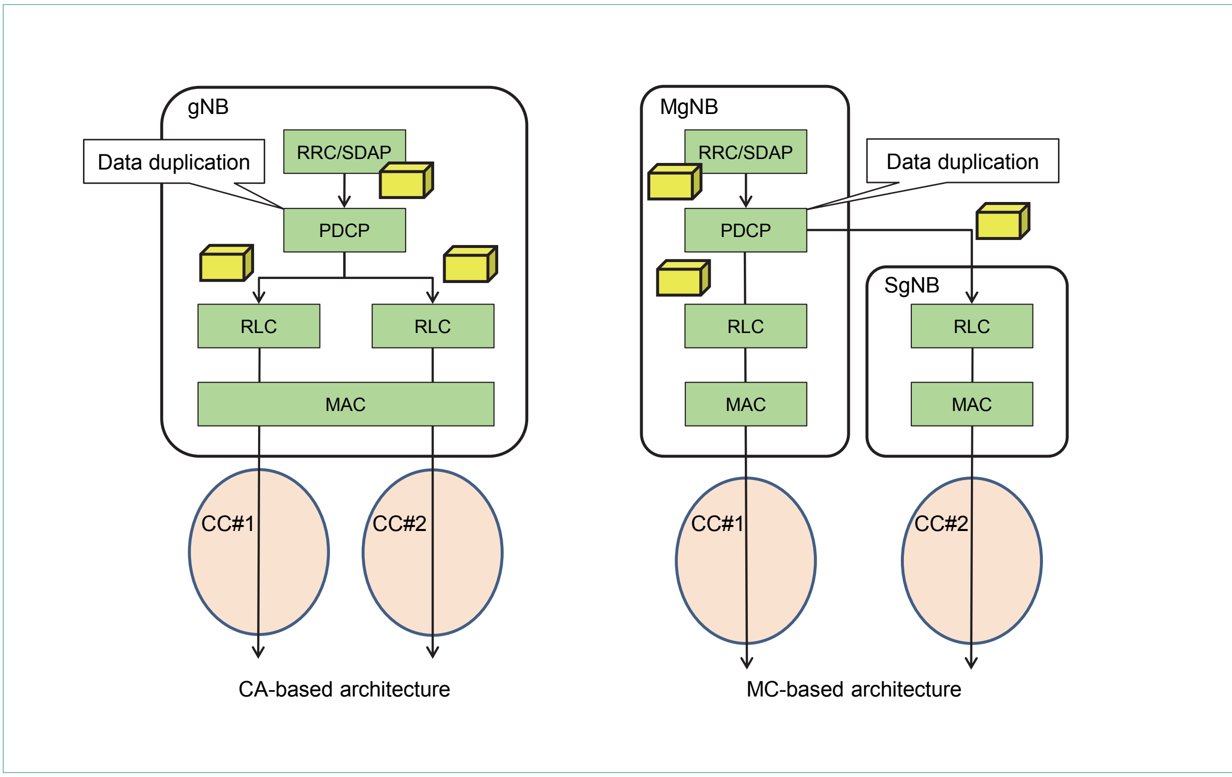

Figure 8 Layer 2 data flow in PDCP duplicate transmission

manner only when needed.

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

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

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

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

5. Conclusion

This article described main component technologies

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

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

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

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

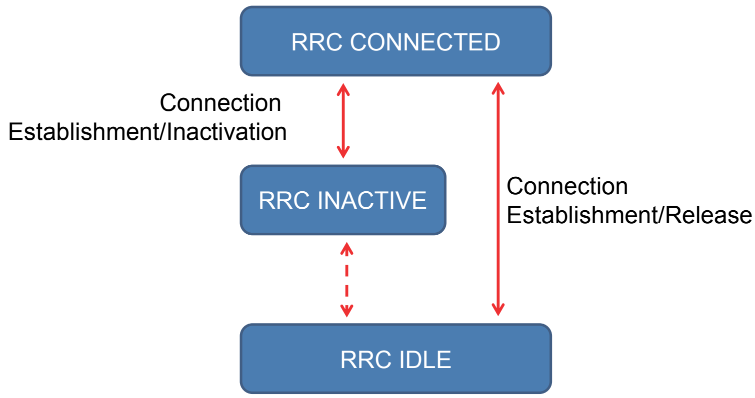

Figure 9 NR RRC states

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

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Technology Reports

5G | Core Network | Network Slicing

Special Articles on 5G Standardization Trends Toward 2020

5G Core Network Standardization Trends

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Aiming for an early deployment of the fifth-generation mobile communications system (5G), component technologies of a core network satisfying 5G requirements are being actively studied in 3GPP SA. A basic study was completed in December 2016 and the normative work based on the results of that study was begun in January 2017 toward actual specifications. This article describes the component technologies of the 5G core network targeted for standardization.

1. Introduction

To meet the service requirements of the fifth-generation mobile communications system (5G), the plan at the 3rd Generation Partnership Project (3GPP) is to formulate specifications for the new core network*1 (hereinafter referred to as "5G core network") as 3GPP Release 15 by June 2018 through studies conducted in 3GPP Service and System Aspects (SA)*2. In this article, we describe the main component technologies of the 5G core network overviewed in the opening article of this issue's Special Articles [1].

2. 5G Core Network Technology Overview

2.1 Division of Functions among Terminal, RAN, and Core Network

In 5G, the system configuration divided into

† Currently Mirai Translate, Inc.

*1 Core network: A network consisting of switches and subscriber-information management equipment. Mobile terminals communicate with the core network via the radio access network.

*2 SA: A 3GPP group that formulates specifications in relation to service requirements, architecture, security, coding, and network management.

terminal, Radio Access Network (RAN)*3 and core network and the division of functions among those components are the same as before, but the node configuration within the core network has changed. The core network architecture in 5G is shown in **Figure 1**.

To begin with, the U-plane*4 function, or User Plane Function (UPF), is clearly separated from the C-plane*5 function group. This scheme reflects the concept of C/U separation studied under the item name of Control and User Plane Separation (CUPS) as an enhancement of Evolved Packet Core (EPC)*6.

1) Features of UPF

The UPF in the 5G core network provides functions specific to U-plane processing the same as Serving GateWay (S-GW)-U*7 and Packet data network GateWay (P-GW)-U*8 in CUPS.

2) Features of C-plane Function Group

(1) AMF and SMF separation

The C-plane function group reorganizes the division of functions among the Mobility Management Entity (MME)*9, S-GW-C*10, and P-GW-C*11 in EPC and clearly divides the Access and Mobility management Function (AMF) and Session Management Function (SMF), which, as the names imply, govern mobility management and session*12 management, respectively. In the 5G core network, the idea is to perform terminal-related

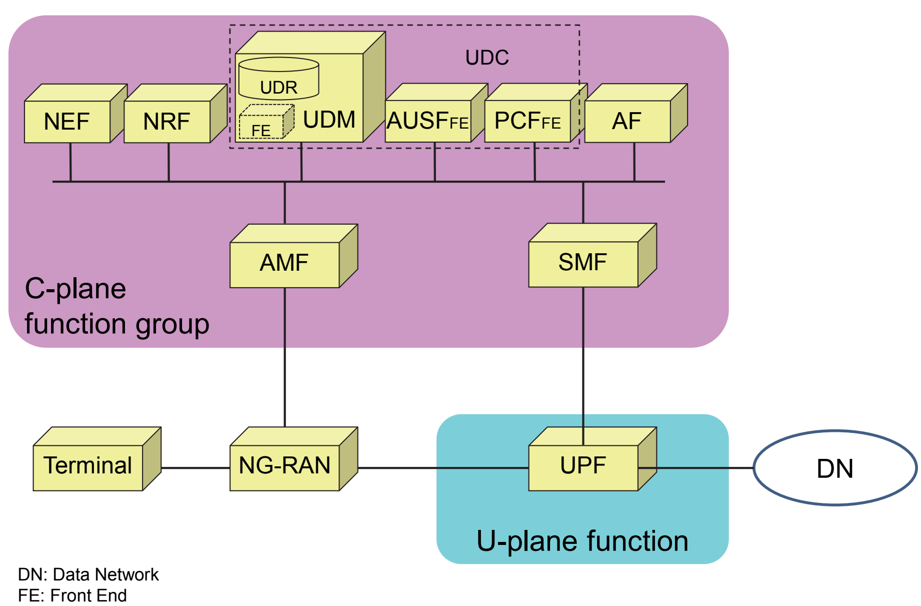

Figure 1　Core network architecture in 5G

*3 RAN: The network consisting of radio base stations and radio-circuit control equipment situated between the core network and mobile terminals.

*4 U-plane: User plane. Refers to transmission and reception of user data.

*5 C-plane: Control plane. Refers to the series of control processes and exchanges involved in establishing communication and other tasks.

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

*7 S-GW-U: An area packet gateway accommodating the 3GPP access system providing functions specific to U-plane processing.

*8 P-GW-U: A gateway acting as a connection point to a PDN (see *25); it allocates IP addresses and transports packets to the S-GW providing functions specific to U-plane processing.

*9 MME: A logical node accommodating a base station (eNodeB) and providing mobility management and other functions.

management at one location and to handle traffic on multiple network slices*13. As a consequence, having a node that performs some session management in addition to mobility management as in MME in conventional EPC is inconvenient. These functions have therefore been reallocated in AMF and SMF so that mobility management can be performed in a centralized manner and session management can be located in each network slice.

(2) Specification of new nodes

Unified Data Management (UDM), which is analogous to the Home Subscriber Server (HSS)*14 in EPC architecture, introduces the concept of User Data Convergence (UDC) that separates the User Data Repository (UDR) storing and managing subscriber information from the front end processing subscriber information. The front-end section also includes new specifications for an Authentication Server Function (AUSF) dedicated to authentication processing and a Policy Control Function (PCF) corresponding to the Policy and Charging Rule control Function (PCRF)*15 in EPC. A Network Exposure Function (NEF) having a function similar to the Service Capability Exposure Function (SCEF)*16 in EPC and an Application Function (AF) fulfilling the role of an application server have also been specified.

Furthermore, while not shown in the above figure, consideration is being given to providing connection to an Access Network (AN) other than Next Generation (NG)-RAN*17 with the aim of accommodating diverse forms of access.

2.2 Service-based Architecture

In 5G core network architecture, service-based architecture is adopted as a method for achieving 5G when the focus is on inter-node linking (**Figure 2**). This architecture defines Network Functions (NFs) as functions required by the network in the manner of AMF and SMF described above. Connections among these NFs are made via a uniform interface called a service-based interface. In addition, an individual NF consists of smaller unit functions called NF services, and an NF service in a certain NF can directly access an NF service in another NF without having to pass through another node. A Network Repository Function (NRF) providing a discovery function for NF services is also specified in service-based architecture.

Specific protocols for the service-based interface are now under study, but discussions are being held on using HyperText Transfer Protocol (HTTP)*18-based RESTful*19 and JavaScript Object Notation (JSON)*20 above that. The plan is to unify the linking of network functions through a common protocol. It also appears that the General Packet Radio Service Tunneling Protocol (GTP)-C*21 used as the C-plane protocol in EPC will not be adopted.

2.3 Enhanced Support for Virtualization

The 5G core network assumes the use of virtualization, the purpose of which is to separate hard-

*10 S-GW-C: An area packet gateway accommodating the 3GPP access system providing functions specific to C-plane processing.

*11 P-GW-C: A gateway acting as a connection point to a PDN; it allocates IP addresses and transports packets to the S-GW providing functions specific to C-plane processing.

*12 Session: A virtual communication path for transmitting data or the transmission of data itself.

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

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

*15 PCRF: A logical node for controlling user data QoS and charging.

*16 SCEF: A logical node installed in a 3GPP mobile network having a standard interface for providing a number of 3GPP services to third-party application providers.

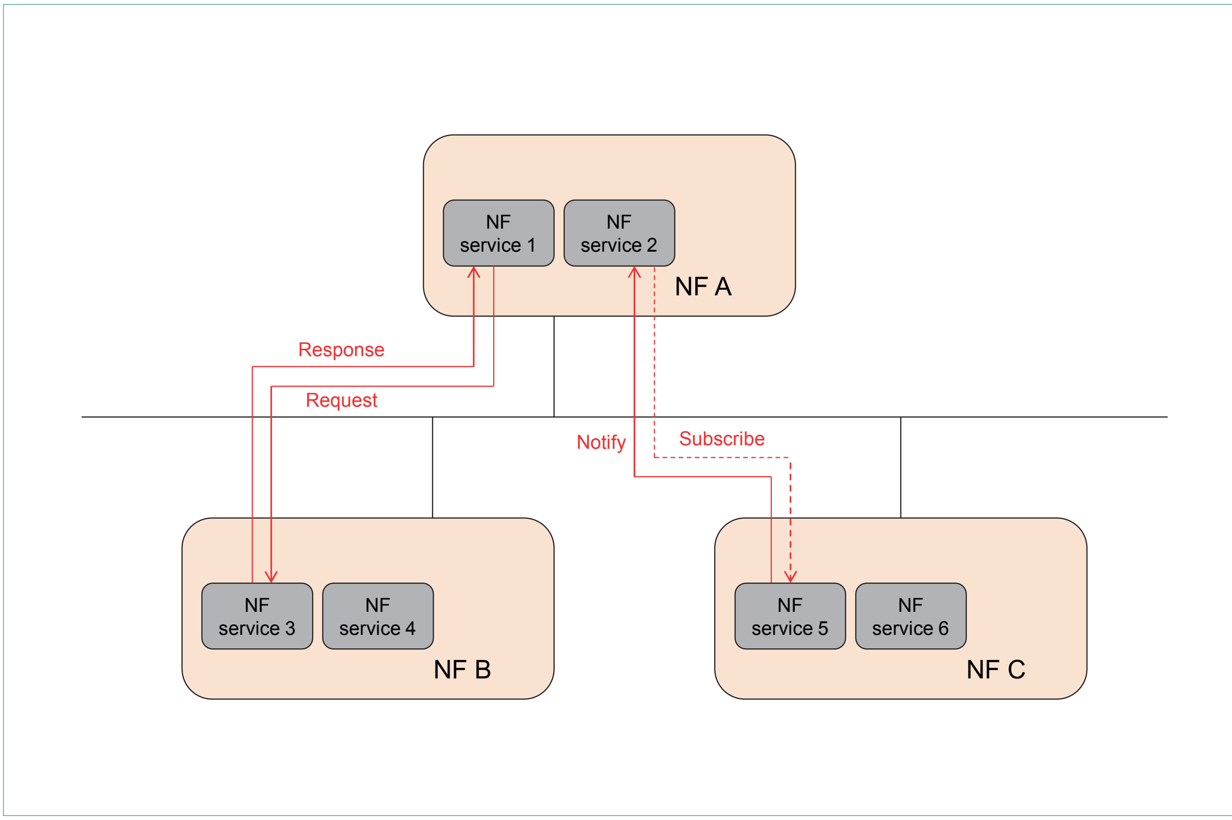

Figure 2 Service-based architecture

ware and software. The various types of identifiers used in 5G architecture take on a configuration that presumes virtualization. In addition, each function such as AMF can separate terminal context information and call processing.

2.4 Network Slices and Simultaneous Connection to Session-related Nodes

In EPC, a single terminal connects to only one S-GW, but in 5G, a single terminal can simultaneously connect to multiple sets of SMF/UPF. In more detail, UPFs are divided among different types of services to efficiently accommodate traffic having different performance requirements. **Figure 3** shows the case of a terminal simultaneously connecting to a network slice accommodating ordinary voice and packet services and a network slice accommodating low-latency services. In this configuration, multiple sets of SMF/UPF each belong to a different network slice while NG-RAN and functions like AMF are shared in common. The network slice for low-latency services places the UPF at a location geographically near radio access. In this case, multiple SMFs are not necessarily needed, but taking as an example the case of providing a low-latency service to a specific enterprise, it

*17 NG-RAN: A RAN connecting to the 5G core network using NR or E-UTRA as radio access technology.

*18 HTTP: A communications protocol used between Web browsers and Web servers to send and receive HyperText Markup Language (HTML) and other content.

*19 RESTful: The idea of obtaining/providing information by directly pointing to the information to be provided in a stateless manner.

*20 JSON: A data description language based on object notation in JavaScript®. Oracle and Java are registered trademarks of Oracle Corporation and its subsidiaries and affiliates in the United States and other countries.

*21 GTP-C: A communication protocol that establishes communication paths within the core network for transferring user data.

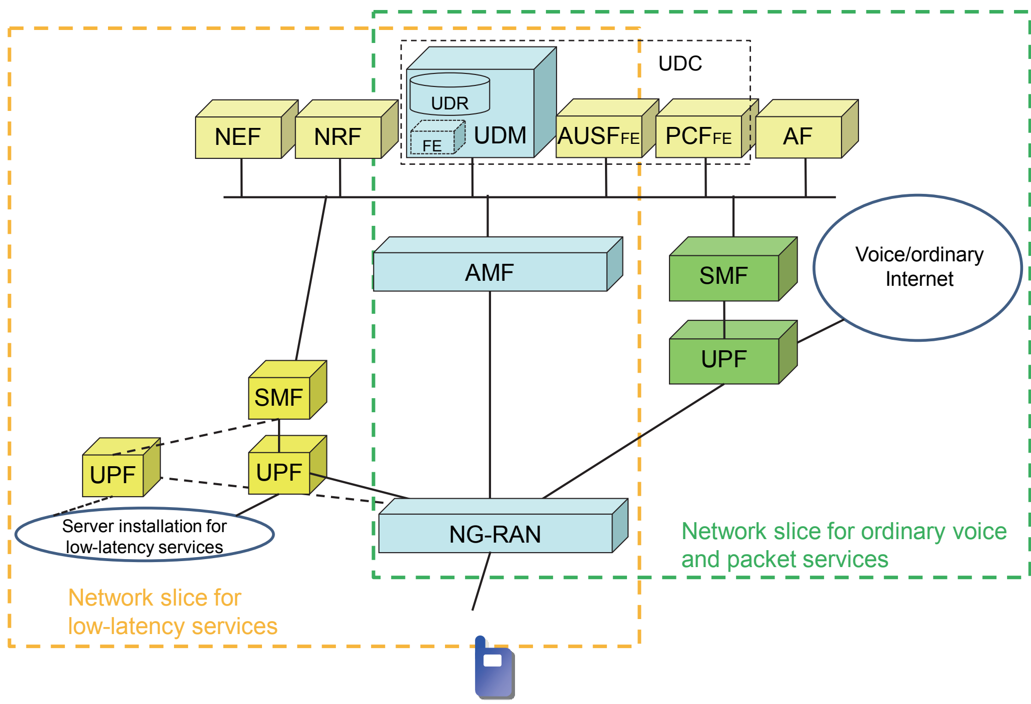

Figure 3 Simultaneous connection to session-related nodes

would be desirable to use a separate SMF to avoid outside effects such as congestion in other services. It may also be desirable to separate SMFs for geographical reasons associated with the distributed arrangement of UPFs.

2.5 Mobile Management and Session Control Procedures

A variety of processing procedures have been reassessed for the 5G core network. The following describes some of these procedures focusing on mobility management and session management.

(1) The attach*22 procedure without session management adopted in Cellular IoT (CIoT) technology in EPC has also been adopted in the 5G core network. Labeled as a registration management procedure, it is also used for periodic location registration and location registration due to movement.

(2) With the aim of accommodating diverse forms of access, session management excludes the concept of a bearer*23 unique to the mobile

*22 Attach: The process of registering a mobile terminal to a network when the terminal's power is turned on, etc.

*23 Bearer: A logical user-data packet transmission path established among P-GW, S-GW, eNodeB, and UE.

communications network in the interface between RAN and the core network and within the core network. The SMF, together with the terminal and NG-RAN, controls the setting/releasing of a Protocol Data Unit (PDU)*24 session corresponding to a Packet Data Network (PDN)*25 connection in EPC.

(3) The AMF and SMF functions operate in a coordinated manner with respect to the handover*26 procedure. For example, switching of the tunnel termination point between NG-RAN and UPF is performed between the NG-RAN and SMF while the provision of handover restrictions to NG-RAN for each RAT is performed by the AMF. At the time of a handover, NG-RAN sends a signal to AMF to switch the communications route.

(4) In EPC, MME obtains all subscriber information from HSS, but in the 5G core, AMF or SMF obtains subscriber information from UDM depending on the type of information needed. Specifically, AMF and SMF obtain information related to mobility management and session management, respectively, from UDM.

(5) As described above, a single terminal can simultaneously connect to multiple sets of SMF/UPF. In this regard, the procedure for returning the connection between the NG-RAN and UPF from a preservation*27 state can do so only for a PDU session that desires that return. Handover can also be performed for each PDU session.

(6) Taking into account the deployment of UPFs corresponding to P-GW-Us in EPC at the network edge, a procedure for switching connections between UPFs by the make before break*28 technique has been provided.

3. Conclusion

This article described the main component technologies of the 5G core network. With the aim of standardizing these component technologies in Release 15 specifications, 3GPP SA and 3GPP Core network and Terminals (CT)*29, which performs detailed protocol studies, are preparing the Technical Reports (TRs) and Technical Specifications (TSs) listed in **Table 1**. As an active promoter of 5G core network standardization at 3GPP, NTT DOCOMO

Table 1 List of architecture/protocol-related documents

	Document name	Completion period
Architecture technical report	TR 23.799	Completed December 2016
Architecture specifications	TS 23.501	September 2017
	TS 23.502	December 2017
Protocol technical report	TR 24.890, TR 29.890, TR 29.891, TR 31.890	December 2017
Protocol specifications	(To be prepared later)	June 2018 target

*24 PDU: A unit of data processed by a protocol layer/sublayer.
*25 PDN: An external network to which the EPC is connected.
*26 Handover: A technology for switching base stations without interrupting a call in progress when a terminal straddles two base stations while moving.
*27 Preservation: The state in which the bearer is preserved between the P-GW and S-GW but released between the S-GW and eNodeB.
*28 Make before break: A method of switching paths by establishing a new path before deleting the old path.
*29 CT: A 3GPP group that specifies protocols for use within the core network or between mobile terminals and the core network.

plans to contribute to the further development of the 5G core network going forward.

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

Standardization

ITU-R IMT-2020 5G

Special Articles on 5G Standardization Trends Toward 2020

IMT-2020 Radio Interface Standardization Trends in ITU-R

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With international standardization of fifth-generation mobile communications systems (5G) in mind, ITU-R has set a new standard name called "IMT-2020," and begun work on IMT-2020 radio interface standardization. This article describes discussions leading up to this work and future plans.

1. Introduction

As shown in **Table 1**, The International Telecommunication Union-Radiocommunication sector (ITU-R)*1 has realized international radio interface standards (ITU-R Recommendations) in partnership with external organizations such as 3rd Generation Partnership Project (3GPP) for the International Mobile Telecommunications-2000 (IMT-2000), the 3rd generation mobile communications system,

Table 1 Mobile communications system standardization in ITU-R

Name	Positioning	Recommendation no., typical radio interfaces
IMT-2000	3rd generation mobile communications systems	Recommendation ITU-R M.1457 W-CDMA, HSPA, LTE, cdma2000, WiMAX etc.
IMT-Advanced	IMT-2000 successor systems	Recommendation ITU-R M.2012 LTE-Advanced, Wireless MAN-Advanced
IMT-2020	IMT-Advanced successor systems	(Recommendations will be formulated in 2020 with fifth-generation mobile communications systems (5G) standardization in mind)

*1 ITU-R: The Radiocommunication Sector of the ITU, which is an international organization in the telecommunications field. It conducts studies required to revise international regulations for radio communications and conducts research on radio communications technologies and operations.

and the IMT-Advanced system, the successor system of IMT-2000. In light of the rising global interest in fifth-generation mobile communications systems (5G) and advances in technical developments, ITU-R has defined IMT-2020*1 as a new standard name for the successor system for IMT-Advanced [1] and has begun work on international standardization of its radio interface. This article describes discussions to date and future plans in ITU-R Working Party 5D (WP 5D) overseeing detailed studies of this work.

2. Formulation of Vision Recommendation

Because 5G research and development has become active, ITU-R discussed a vision for mobile communications systems for 2020 and beyond. The results of these discussions are summarized in Recommendation ITU-R M.2083 published in September 2015 [2]. As shown in **Figure 1**, as typical usage scenarios for the IMT-2020 system, this recommendation summarizes (1) further mobile broadband advances (enhanced Mobile BroadBand (eMBB)), (2) machine-type communications enabling simultaneous multiple connections (massive Machine Type Communications (mMTC)), and (3) high-reliability, low-latency communications (Ultra-Reliable and Low Latency Communications (URLLC)). In addition, as shown in **Figure 2**, the key capabilities that IMT-2020 should have to enable these usage scenarios are shown as comparative improvements on IMT-Advanced. The key capabilities shown in this figure, such as the maximum data transmission rate (20 Gbps), multiple simultaneous connections (1,000,000 devices/km^2) and low latency (1 ms) are described in the IMT-2020 vision.

3. Schedule for IMT-2020 Radio Interface Standardization

With the completion of Recommendation ITU-R M.2083, ITU-R has developed a schedule for the

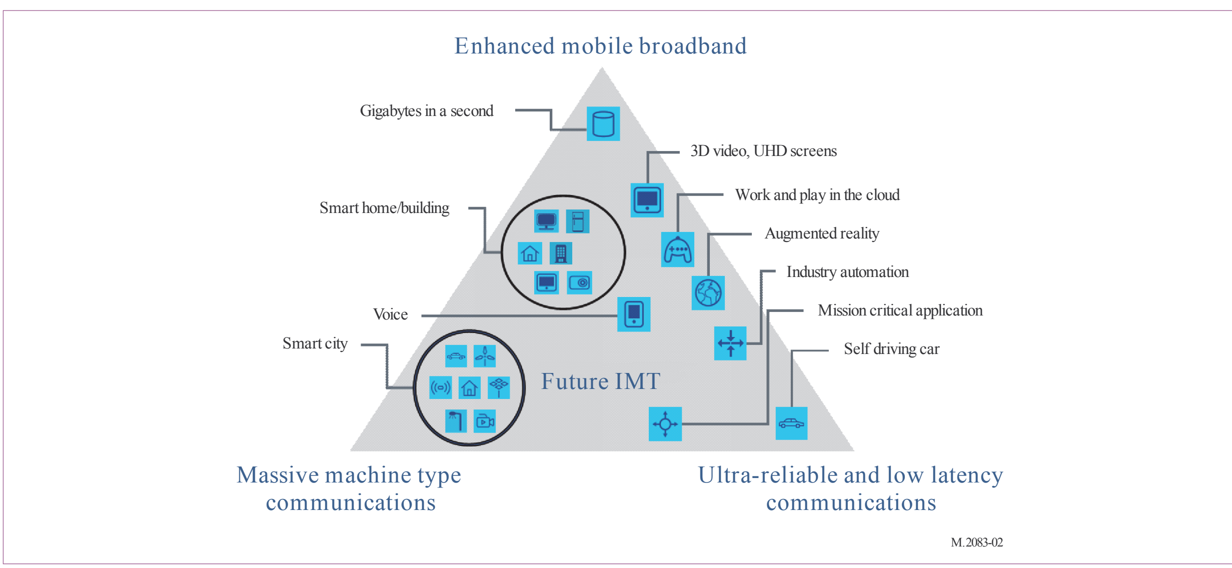

Figure 1　IMT-2020 typical usage scenarios (from Recommendation ITU-R M.2083, Figure 2)

*1　After discussions on IMT-Advanced, ITU-R has been avoiding the use of the name "Nth generation mobile communication system." However, ITU-R is working on the standardization of IMT-2020 radio interface with 5G international standardization in mind.

formulation of ITU-R Recommendations on the IMT-2020 radio interface to achieve the vision in M.2083, as shown in **Figure 3**. To formulate ITU-R Recommendations, it is agreed that studies should proceed in the following steps, as has been done in the past for the IMT-Advanced development.

(1) ITU-R to set requirements for the IMT-2020 radio interface, and solicit proposals from

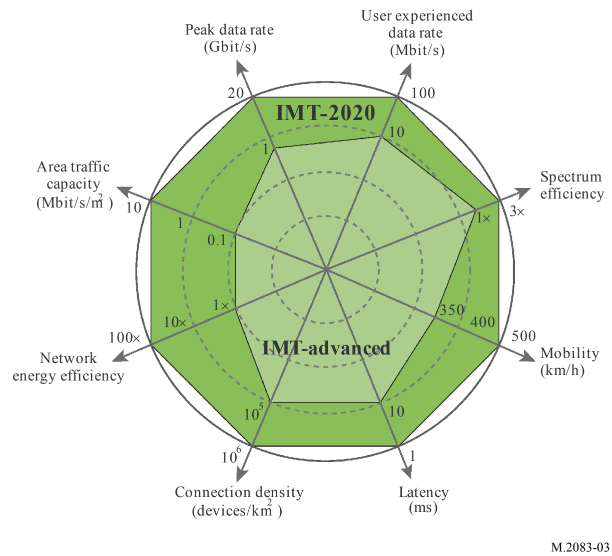

Figure 2 Capabilities that IMT-2020 should have (from Recommendation ITU-R M.2083, Figure 3)

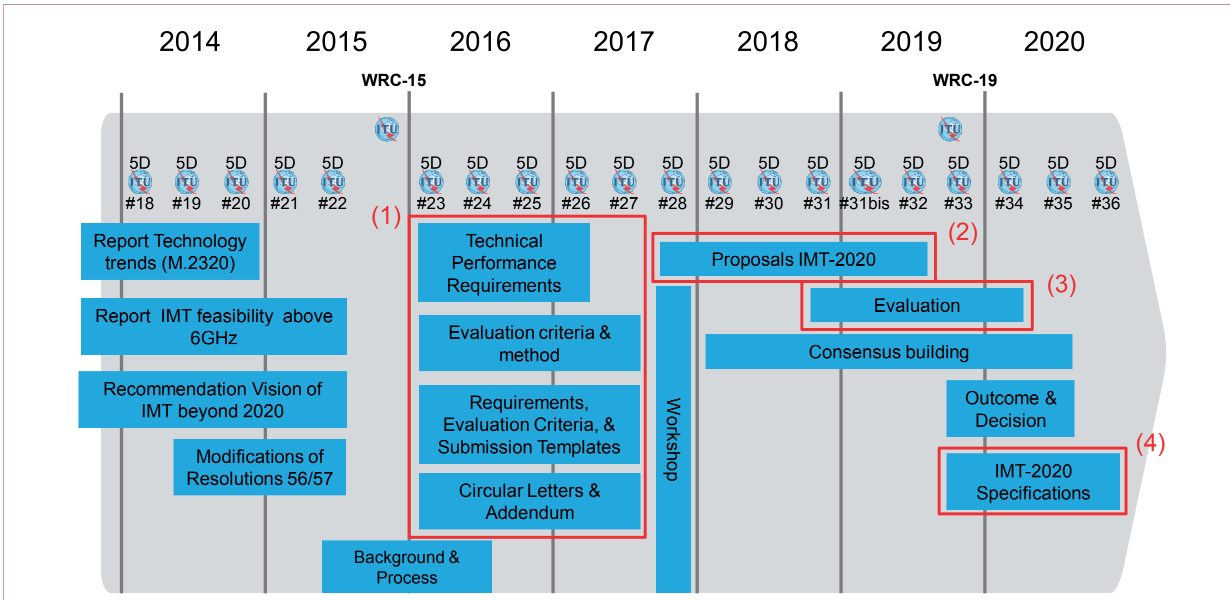

Figure 3 Work schedule for IMT-2020 radio interface developments (from ITU-R WP 5D Web site)

external organizations etc. (2016 to first half of 2017).

(2) External organizations etc. to make radio interface proposals to ITU-R. Proponents to submit self-evaluated results indicating that the details of their proposals satisfy the ITU-R requirements (second half of 2017 to first half of 2019).

(3) Based on proposal details and self-evaluated results information, external evaluation bodies registered in ITU-R are to conduct evaluations of whether the proposals satisfy the ITU-R requirements (second half of 2018 to first half of 2020).

(4) Agreement to be reached on recommendations for the radio interface in ITU-R in view of the evaluation results conducted by external evaluation bodies etc., and specific recommendation documents to be created (second half of 2019 to second half of 2020).

Accordingly, ITU-R plans to accept proposals from external organizations from October 2017 to June 2019. ITU-R Recommendations will be completed in the second half of 2020.

4. Documentation for IMT-2020 Radio Interface Standardization

ITU-R WP 5D has created three new ITU-R reports prescribing IMT-2020 radio interface requirements*2. External organizations and so forth making proposals to ITU-R must make their proposals in accordance with the contents of these ITU-R reports. In addition, documentation prescribing the details of the IMT-2020 radio interface proposal and the evaluation process has also been created.

4.1 Report ITU-R M. [IMT-2020. SUBMISSION]

This ITU-R report prescribes requirements for IMT-2020 radio interface proposals and templates for submitting proposals [3].

Firstly, multiple supports for the usage scenarios (eMBB, mMTC and URLLC) indicated in Recommendation ITU-R M.2083 are required as service requirements.

Also, as spectrum requirements, (1) usage of at least one frequency band identified for IMT in the ITU Radio Regulations must be supported, and (2) usage of frequency bands at or above 24.25 GHz must be supported. The latter of these requirements was formulated in view of the characteristics newly introduced in 5G.

In addition, technical performance requirements have also been prescribed, the details of which will be available by referring to Report ITU-R M. [IMT-2020. TECH PERF REQ] described in the next section.

4.2 Report ITU-R M. [IMT-2020. TECH PERF REQ]

This ITU-R report defines 13 items of technical performance requirements for the IMT-2020 radio interface and prescribes their required values [4]. Details are shown in **Table 2**. For example, with eMBB, the IMT-2020 spectral efficiency*2 requirement is approximately three times the required value for IMT-Advanced. In addition, for mMTC and URLLC, requirements are set for connection density, latency and reliability. Also, for a number

*2 These new reports were approved by Study Group 5 in November 2017, and will be published soon.

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

Table 2 IMT-2020 radio interface technical performance requirements, required values and evaluation methodology

	Requirement \ Test environment		Indoor Hotspot-eMBB	Dense Urban-eMBB	Rural-eMBB	Urban Macro-mMTC	Urban Macro-URLLC	Evaluation methodology
1	Peak data rate		Downlink: 20 Gbps, Uplink: 10 Gbps			–	–	Analytical
2	Peak spectral efficiency		Downlink: 30 bps/Hz, Uplink: 15 bps/Hz			–	–	Analytical
3	User experienced data rate		–	Downlink: 100 Mbps Uplink: 50 Mbps	–	–	–	Analytical for single band and single layer cell layout Simulation for multi-layer cell layout
4	5^{th} percentile user spectral efficiency		Downlink: 0.3 bps/Hz Uplink: 0.21 bps/Hz	Downlink: 0.225 bps/Hz Uplink: 0.15 bps/Hz	Downlink: 0.12 bps/Hz Uplink: 0.445 bps/Hz	–	–	Simulation
5	Average spectral efficiency		Downlink: 9 bps/Hz Uplink: 6.75 bps/Hz	Downlink: 7.8 bps/Hz Uplink: 5.4 bps/Hz	Downlink: 3.3 bps/Hz Uplink: 1.6 bps/Hz	–	–	Simulation
6	Area traffic capacity		10 Mbps/m^2	–	–	–	–	Analytical
7	Latency	User plane	4 ms			–	1 ms	Analytical
		Control plane	20 ms			–	20 ms	Analytical
8	Connection density		–	–	–	1,000,000 device/km^2	–	Simulation
9	Energy efficiency		Shall have the capability to support a high sleep ratio and long sleep duration.			–	–	Inspection
10	Reliability		–	–	–	–	$1-10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms	Simulation
11	Mobility		Normalized traffic channel link data rates of 1.5 bps/Hz at 10 km/h in the uplink	Normalized traffic channel link data rates of 1.12 bps/Hz at 30 km/h in the uplink	Normalized traffic channel link data rates of 0.8 and 0.45 bps/Hz at 120 and 500 km/h, respectively, in the uplink	–	–	Simulation
12	Mobility interruption time		0 ms			–	0 ms	Analytical
13	Bandwidth		At least 100 MHz Shall support bandwidths up to 1 GHz for operation in higher frequency bands (e.g. above 6 GHz).					Inspection

of technical performance requirements, requirements and required values have been set for test environments (described later), as shown in the table.

3GPP have also defined requirements and target values prior to their studies on 5G radio interface specifications. Technical performance requirements defined by ITU-R are similar to their equivalent 3GPP requirements. However, ITU-R technical performance requirements [5] include items not in the 3GPP requirements (e.g., bandwidth to be supported).

4.3 Report ITU-R M. [IMT-2020. EVAL]

This ITU-R report prescribes details of evaluation methodology, test environments, and evaluation configurations, and the configurations of channel models used for evaluation for IMT-2020 radio interface requirements [6].

1) Evaluation Methodology, Test Environment and Evaluation Configurations

As shown in the right column of Table 2, there are three methods defined for evaluation methodologies for each requirement - inspection, analytical, and simulation. Also, to evaluate specified requirements, the following five test environments have been defined in consideration of the three typical usage scenarios (eMBB, mMTC, URLLC) described in Recommendation ITU-R M.2083.

- Indoor Hotspot-eMBB: Indoor environments assumed for eMBB usage scenarios
- Dense Urban-eMBB: Dense urban environments assumed for eMBB usage scenarios
- Rural-eMBB: Rural environments assumed for eMBB usage scenarios
- Urban Macro-mMTC: Urban environments assumed for mMTC usage scenarios
- Urban Macro-URLLC: Urban environments assumed for URLLC usage scenarios

Furthermore, one or more evaluation configurations, in other words, sets of evaluation parameters are defined for each of these test environments, as shown in **Tables 3** and **4**. For a proposed radio interface to be judged as having satisfied

Table 3 Evaluation configurations for eMBB test environments

Parameters	Indoor Hotspot-eMBB			Dense Urban-eMBB			Rural-eMBB		
	Spectral efficiency, mobility and area traffic capacity evaluations			Spectral efficiency and mobility evaluations		User experienced data rate evaluation	Spectral efficiency and mobility evaluations		Average spectral efficiency evaluation
	A	B	C	A	B	C	A	B	C
Carrier frequency for evaluation	4 GHz	30 GHz	70 GHz	4 GHz (Macro layer only)	30 GHz (Macro layer only)	4 GHz & 30 GHz (Macro + Micro layers)	700 MHz	4 GHz	700 MHz
Base station (BS) antenna height	3 m	3 m	3 m	25 m	25 m	25 m for Macro BSs and 10 m for Micro BSs	35 m	35 m	35 m
Inter-BS distance	20 m	20 m	20 m	200 m	200 m	200 m (Macro layer)	1,732 m	1,732 m	6,000 m
Number of antenna elements at BS	Up to 256 Tx/Rx	Up to 256 Tx/Rx	Up to 1024 Tx/Rx	Up to 256 Tx/Rx	Up to 256 Tx/Rx	Up to 256 Tx/Rx	Up to 64 Tx/Rx	Up to 256 Tx/Rx	Up to 64 Tx/Rx
Number of antenna elements at user terminal	Up to 8 Tx/Rx	Up to 32 Tx/Rx	Up to 64 Tx/Rx	Up to 8 Tx/Rx	Up to 32 Tx/Rx	4 GHz: Up to 8 Tx/Rx 30 GHz: Up to 32 Tx/Rx	Up to 4 Tx/Rx	Up to 8 Tx/Rx	Up to 4 Tx/Rx
User deployment	100% indoor 3 km/h	100% indoor 3 km/h	100% indoor 3 km/h	80% indoor 3 km/h, 20% outdoor (in-car) 30 km/h	80% indoor 3 km/h, 20% outdoor (in-car) 30 km/h	80% indoor 3 km/h, 20% outdoor (in-car) 30 km/h	50% indoor 3 km/h, 50% outdoor (in-car) 120 km/h, 500 km/h for mobility evaluation	50% indoor 3 km/h, 50% outdoor (in-car) 120 km/h, 500 km/h for mobility evaluation	40% indoor 3 km/h, 40% outdoor 3 km/h, 20% outdoor (in-car) 30 km/h

requirements for a particular test environment, requirements must be satisfied in at least one evaluation configuration under that test environment. The definition of multiple evaluation configurations under each test environment is due to the various frequency bands, deployment scenarios and usage scenes to be supported in IMT-2020, and is the result of the wide range of views submitted to ITU-R WP 5D.

2) Overview of Channel Models*3

Figure 4 describes channel model configurations used for a simulation-based evaluation method. The

Table 4 Evaluation configurations for mMTC and URLLC test environments

Parameters	Urban Macro-mMTC		Urban Macro-URLLC	
	Connection density evaluation		Reliability evaluation	
	A	B	A	B
Carrier frequency for evaluation	700 MHz	700 MHz	700 MHz	4 GHz
Base station (BS) antenna height	25 m	25 m	25 m	25 m
Inter-BS distance	500 m	1,732 m	500 m	500 m
Number of antenna elements at BS	Up to 64 Tx/Rx	Up to 64 Tx/Rx	Up to 64 Tx/Rx	Up to 256 Tx/Rx
Number of antenna elements at user terminal	Up to 2 Tx/Rx	Up to 2 Tx/Rx	Up to 4 Tx/Rx	Up to 8 Tx/Rx
User deployment	80% indoor 3 km/h, 20% outdoor 3 km/h	80% indoor 3 km/h, 20% outdoor 3 km/h	20% indoor 3 km/h, 80% outdoor 30 km/h	20% indoor 3 km/h, 80% outdoor 30 km/h

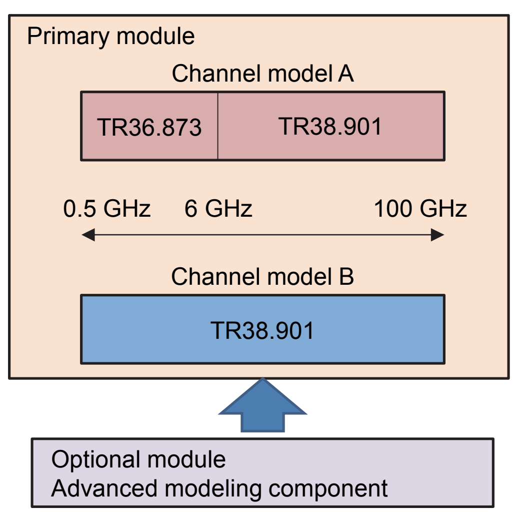

Figure 4 Channel model configurations

*3 **Channel model**: A model simulating the behavior of radio waves, used for evaluating the performance of radio communications systems.

basic system simulation model is called the "primary module," and consists of a path loss model, (Line Of Sight) LOS probability model and fast fading model. The unification of the primary module in one model was vigorously discussed in ITU-R WP 5D, although finally two models, channel model A and B, were prescribed. For channel A, the 0.5 to 6 GHz model described in 3GPP TR36.873 [7] and the 6 to 100 GHz model described in TR38.901 [8] newly prescribed by 3GPP for evaluating 5G have been adopted. For channel B, the model described in TR38.901 was adopted for the entire 0.5 to 100 GHz frequency range. Both channels A and B have models defined for indoor hotspots*4 (InH_x), urban macrocells*5 (UMa_x), urban microcells*6 (UMi_x) and rural macrocells (RMa_x), and enable evaluation in the aforementioned test environments. When proponents of radio interfaces perform self-evaluation with simulations, they have to perform the evaluation by selecting the same channel model, A or B, for all their evaluated test environments.

Additionally, a range of new technologies are anticipated for application with IMT-2020 such as Massive Multiple Input Multiple Output (Massive MIMO)*7, Multiuser MIMO*8, and to evaluate these technologies, an optional model called "advanced modeling component" has been prescribed. This has been created based on the additional modeling component prescribed in TR38.901.

4.4 Document IMT-2020/2 (Rev.1)

This documentation prescribes details of the IMT-2020 radio interface proposal and evaluation process [9].

The document assumes two cases – the case when proposals are received and finally included in recommendations as single Radio Interface Technologies (RIT) and the case when proposals are received and finally included in recommendations as combined Sets of Radio Interface Technologies (SRIT).

Moreover, this document prescribes specific requirements that must be satisfied in all of the aforementioned five test environments as requirements for recommendations as IMT-2020 radio interface technologies.

5. Conclusion

This article has described standardization trends for IMT-2020 radio interfaces ongoing in ITU-R in view of the rising global interest in 5G, and advances in related technical developments. To date, requirements and so forth necessary for IMT-2020 have been agreed upon, and ITU-R has moved to a stage of acceptance of specific proposals from external organizations going forward.

As a member of the Japan delegation, proactively contributing to the activities of ITU-R WP 5D, NTT DOCOMO intends to continue to be active in ITU-R while coordinating with 3GPP studies.

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[1] Resolution ITU-R 56-2: "Naming for International Mobile Telecommunications," Nov. 2015.

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[3] Draft new report ITU-R M. [IMT-2020.SUBMISSION]: "Requirements, evaluation criteria and submission templates for the development of IMT-2020," Jun. 2017.

[4] Draft new report ITU-R M. [IMT-2020.TECH PERF REQ]: "Minimum requirements related to technical performance for IMT-2020 radio interface(s)," Feb. 2017.

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

*5 Macrocell: In mobile communications systems, a cell is an area covered by a single base station antenna. A macrocell is a relatively large area with radius of 500 m or more.

*6 Microcell: A communications area of radius from several tens to several hundreds of meters, covered by a single base station.

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[7] 3GPP TR36.873 V12.4.0: "Study on 3D channel model for LTE (Release 12)," Mar. 2017.

[8] 3GPP TR38.901 V14.0.0: "Study on channel model for frequencies from 0.5 to 100 GHz (Release 14)," Mar. 2017.

[9] Document ITU-R IMT-2020/2 (Rev.1): "Submission, evaluation process and consensus building for IMT-2020," Feb. 2017.

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

*8 Multiuser MIMO: A technology that improves spectral efficiency by using MIMO technologies to simultaneously transmit (multiplex) signals for multiple users.

Technology Reports 3GPP Release 14 High-speed Moving Mobile Environment SFN Scenario

Performance Enhancement Technologies in High-speed Moving Mobile Environment in LTE-Advanced Release 14

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As demands have grown for mobile communications quality improvements in high-speed moving environments such as high-speed rail, basic studies on performance enhancements in high-speed moving environments were discussed in 3GPP Release 13 and technical specifications for these performance enhancements have been specified in Release 14. This article describes the technologies newly specified in Release 14 for improving mobile communications quality in high-speed moving environments.

1. Introduction

In recent years, the demands for broadband mobile communications in high-speed moving environments such as high-speed rail have been increasing. In addition, high frequency bands can be used for mobile communications. In general, in high-speed moving mobile environments, the higher the frequency, the greater the Doppler frequency shift*1 effects, which results in major technical issues to ensure mobile communications quality. In addition, as deployment planning*2 on commercial networks becomes more diversified, technical issues with deployment planning in high-speed moving mobile environments have been emerging, which were not sufficiently considered in early 3GPP specifications.

Due to this situation, mobile communications quality improvements in high-speed moving mobile environments were discussed as a Study Item (SI)*3 in 3GPP Release 13. Based on the results of this SI, new specifications were defined in Release

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

*2 Deployment planning: The design of base station positioning and parameters to fulfill area and quality requirements.

*3 SI: Work to “consider achievability, and generally defined functions that should be specified.”

14 to improve the communications quality of new deployment planning, and improved Random Access CHannel (RACH)*4 detection characteristics. This article describes these Release 14 specifications.

2. Issues in High-speed Moving Mobile Environments

2.1 Improving Communications Quality in High-speed Movement in SFN Scenarios

1) SFN Scenario Overview

An example of a Single Frequency Network (SFN)*5 scenario is shown in **Figure 1**. Essentially, SFN refers to a network on which the same radio frequency is used with master and relay stations. Here, the SFN scenario refers to a deployment planning in which same signals are sent and received with the same frequencies through multiple Remote Radio Heads (RRH)*6 installations covering the area. This scenario is suitable for high-speed moving mobile environments such as areas in high-speed rail tunnels because there is no interference from adjacent RRH signals, and hand over*7 does not occur when mobile terminals move from RRH1 area to RRH2 area because the cell does not change, as shown in Fig. 1.

2) The Doppler Frequency Shift Issue with High-speed Movement in SFN Scenarios

In the SFN scenario, the same signals are sent from each RRH. Signals arriving from the RRH in front of the mobile terminal and signals arriving from the RRH behind the mobile terminal are affected by positive Doppler frequency shift and negative Doppler frequency shift, respectively. An example of this phenomenon is shown in **Figure 2**. When the mobile terminal passes through RRH1 and RRH2, the signal arriving from RRH1 has a negative Doppler frequency shift effect, while the signal arriving from RRH2 has a positive Doppler frequency shift effect. Because the Doppler frequency shift with high-speed movement is significant, at the timing for switching the RRHs connected to the high-speed moving mobile terminal, i.e., in the halfway area between the two RRHs, signals affected by positive and negative Doppler frequency shift with significant absolute values arrive at the high-speed moving terminal with almost

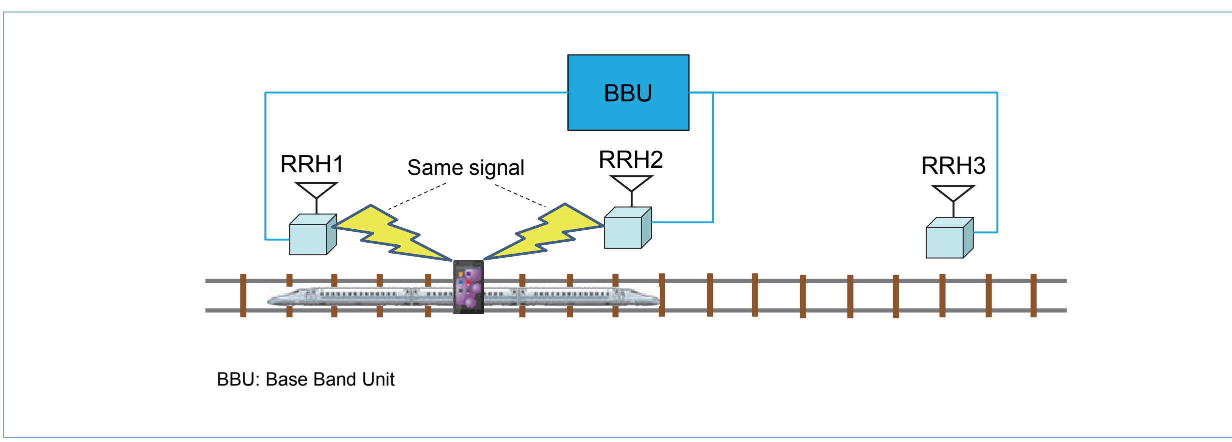

Figure 1 SFN scenario

*4 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.

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

*6 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.

*7 Hand over: 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.

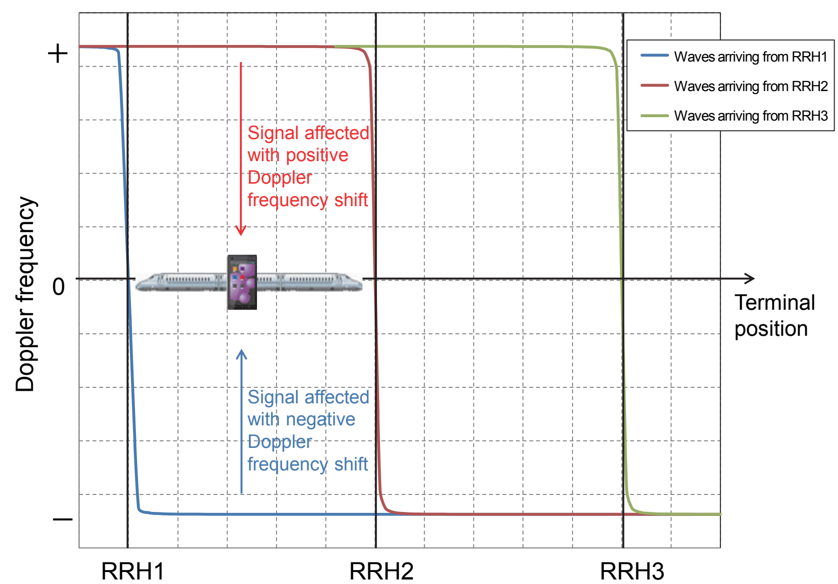

Figure 2 Doppler frequency effects

the same timing. Since the high-speed moving mobile terminal must switch RRHs while receiving these two signals simultaneously, it is difficult for the terminal to track the sudden Doppler frequency shift change from negative to positive, which results in degraded communications quality.

2.2 RACH Detection Performance Improvement in High-speed Moving Mobile Environments

1) Restricted Set of Cyclic Shifts in Release 8 LTE

When a base station receives an uplink signal from a high-speed moving mobile terminal, in addition to the Doppler frequency shift of the transmitted uplink signal, it's necessary to consider the larger Doppler frequency shift compared to that in case of a downlink signal reception at the mobile terminal, as transmitting mobile terminals synchronize with downlink signals that have been Doppler frequency shifted. This issue is not limited to SFN scenarios, but also occurs in general deployment scenarios. Considering the above, the Physical Random Access CHannel (PRACH)*8 in Release 8 LTE was designed so that base stations can detect PRACH with Doppler frequency shift up to +/– 1.25 kHz in high-speed moving mobile environments. This enables sufficient PRACH detection performance at 2 GHz up to 350 km/h.

(a) PRACH CS detection in normal scenario

The PRACH transmission sequence is generated by applying Cyclic Shift (CS)*9 to Zadoff-Chu (ZC) sequence*10. The CS value applied is selected by the mobile terminal from candidate values according to the base

*8 PRACH: Physical channel for transmitting the random access preamble.

*9 CS: Cyclic shift processing of the relationship between time indexes and elements for sequence etc.

*10 ZC sequence: A Constant Amplitude Zero Auto Correlation (CAZAC) sequence, in which the amplitude is kept constant for the time index, and is characterized by a delta function as the autocorrelation function.

station settings. In cells that don't assume high-speed moving mobile terminals, the integral multiple values of N_{CS}, which is the PRACH reception timing window length, are set as the CS candidate values (**Figure 3** (a)). At the base station, by detecting the CS value that generates a correlation*11 peak between the received PRACH sequence and the ZC sequence template, it's possible to recognize the transmission sequence selected by the mobile terminal and the timing error in the N_{CS} range.

(b) Restricted set of PRACH CS for high-speed movement scenarios

In high-speed movement scenarios, multiple correlation peaks between the received PRACH sequence and the ZC sequence template are observed at the base station due to Doppler frequency shift effects. To prevent degradation of PRACH detection performance due to the shift of the maximum correlation peak position, restricted set of PRACH CS was introduced in Release 8 LTE. By preparing three timing detection windows for a CS, $+d_u$ and $-d_u$ for the CS at the base station where d_u is the CS corresponding to the reciprocal of the PRACH preamble*12 sequence time length, correlation peaks observed at each detection window are used in combination so that the base station can recognize the PRACH transmission sequence selected by the mobile terminal and timing errors in the N_{CS} range even with certain level of Doppler frequency shift (Fig. 3 (b)). Hence, to prevent recognition errors in the PRACH transmission sequence, CSs that can

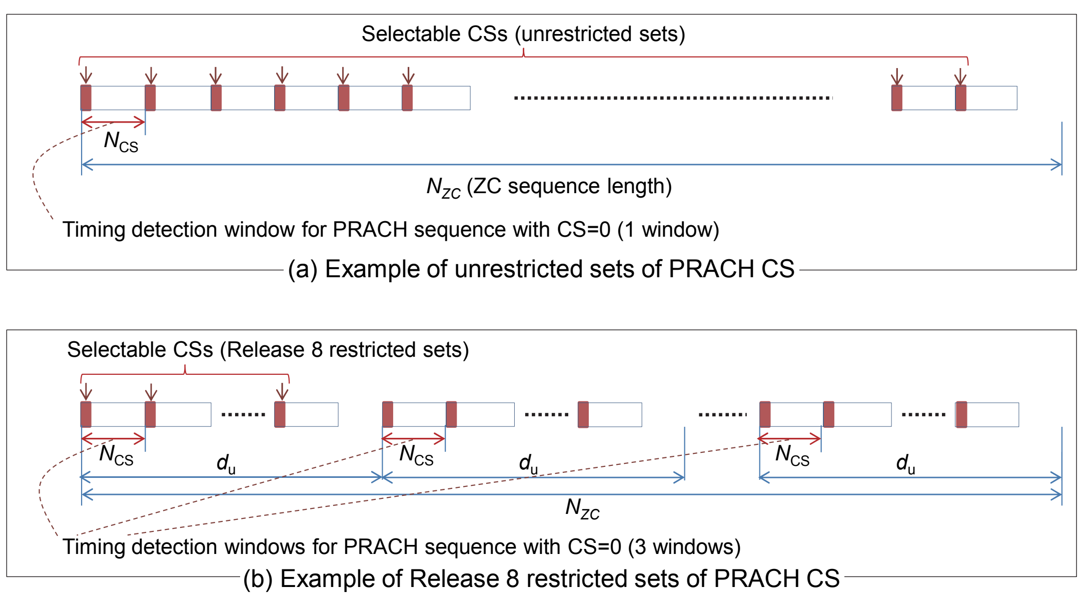

Figure 3 Conventional CS selection and detection methods for PRACH sequence

*11 Correlation: An index expressing similarity between different signals. Expressed as a complex number, its absolute value ranges from 0 to 1. Similarity is higher for a value closer to 1.

*12 Preamble: A signal with a fixed pattern positioned at the beginning of packets. Receivers use these to detect packets, control gain, and synchronize frames and frequencies etc. as preparation to receive the data portion.

be selected by the mobile terminal are restricted so that no candidate CS overlaps with other candidate CSs, $+d_u$, and $-d_u$ positions of other candidate CSs.

2) Issues of PRACH Detection in High-speed Moving Mobile Environments

As described above, PRACH in Release 8 LTE was designed to handle Doppler frequency shift in high-speed moving mobile environments with up to +/− 1.25 kHz. However, there is increasing necessity for advanced PRACH detection performance with higher frequencies or in environments such as SFN scenarios where Doppler frequency shift effects are emerging. Also, when the Doppler frequency shift is large, the maximum correlation peaks are observed at the $+2d_u$ and $-2d_u$ positions. In such cases, the restricted set in Release 8 has the issue of recognition errors in the PRACH transmission sequence.

3. New Requirements and Their Performance

3.1 New Requirements for Downlink Reception Performance with High-speed Movement in SFN Scenarios

To solve the issues described in Section 2.1, new high-speed moving mobile environment model simulating an SFN scenario similar to that in Fig. 1 was defined in Release 14, and throughput performance requirements for using this model were added. When these new throughput performance requirements were discussed, the following mobile terminal receiver functions were considered as standard studies.

- The terminal tracks all signals affected by positive and negative Doppler frequency shift with significant absolute values arriving at the high-speed moving terminal at the same time, estimates the Doppler frequency shift and modifies the center frequency shift.
- Advanced propagation path estimation to improve interpolation accuracy especially in the time domain*13.

An evaluation result example is shown in **Figure 4** [1]. The horizontal axis shows the Signal-to-Noise Ratio (SNR)*14 while the vertical axis shows the throughput. Comparing conventional receivers (red in Fig. 4) and receivers designed for the above standards (green in Fig. 4), it can be seen that the throughput is greatly improved when moving at 350 km/h.

However, as the behaviors of these receivers are specialized for SFN scenarios, operating these receivers in low-speed or high-speed moving environments outside SFN scenarios can lead to degraded performance and increased power consumption. For this reason, control signaling (network assisted signaling) was introduced to enable receiver functions to be switched ON/OFF. **Figure 5** describes an overview of these receiver functions including the ON/OFF function. This control signal is included in the System Information Block (SIB)*15 sent from the base stations in SFN scenarios, so that when a high-speed moving mobile terminal receives the signal, the defined receiver function starts.

3.2 PRACH Enhancement for High Doppler Frequency Shift Environments

To solve the issues described in Section 2.2, new restricted sets of PRACH CS that can handle

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*13 Time domain: In signal analysis, this domain is used to show the temporal makeup of a signal's components. A time-domain signal can be converted to a frequency-domain signal by a Fourier transform.

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

*15 SIB: 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.

up to +/− 2.5 kHz Doppler frequency shift in high-speed movement scenarios were introduced in Release 14. With the new restricted sets, selectable CSs at the mobile terminal are further restricted so that no candidate CS overlaps with other candidate CSs, $+d_u$, $-d_u$, $+2d_u$ and $-2d_u$ positions of other candidate CSs. Base stations are equipped with N_{CS} range timing detection windows at the above five positions used for detection by combining the correlation peaks observed in each detection window (**Figure 6**). This improves PRACH detection performance in high-speed moving mobile environments e.g., above 350 km/h at 2 GHz with up to +/− 2.5 kHz Doppler frequency shift.

4. Conclusion

This article has described characteristic functions

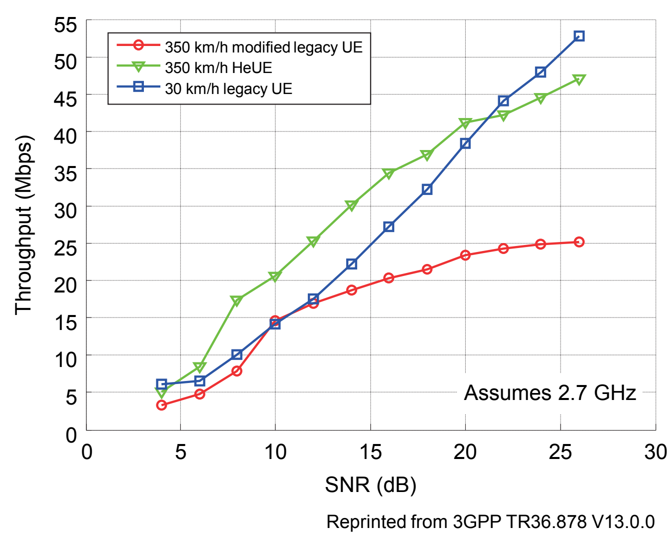

Figure 4　Example of SFN scenario evaluation results

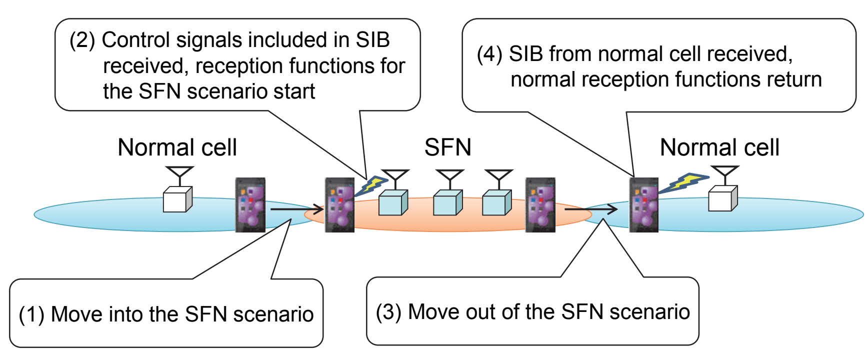

Figure 5　Overview of reception functions specialized for SFN scenarios

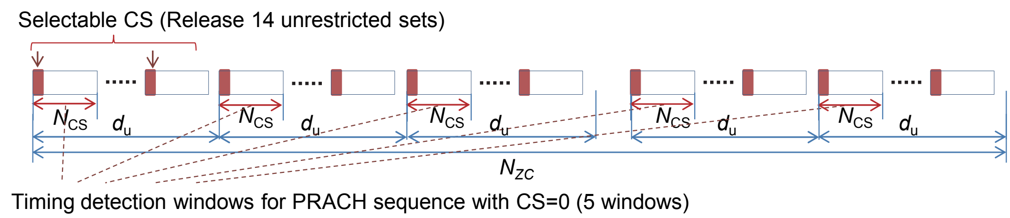

Figure 6　Example of Release 14 restricted sets of PRACH CS

and basic behaviors for performance enhancements in high-speed moving mobile environments in 3GPP Release 14, specifically reception requirements for new deployment planning, and the specifications to improve PRACH performance. These functions enable further improvements to communications quality in high-speed moving mobile environments such as high-speed rail.

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Technology Reports | Wearable Device | Motion Recognition | Meal Content Estimation

Meal Content Estimation Technology Focusing on Forearm Motion —Toward Simplified Meal Management—

Research Laboratories Takato Saito Satoshi Kawasaki† Daizo Ikeda Masaji Katagiri

Recent years have seen the social issues of lifestyle-related diseases caused by overeating and unbalanced diets emerge. While there are a number of balanced diet management services available, these require the user to constantly record information on their diet without any omissions, which takes time and is an impediment to receiving the appropriate support from the service. In this article, we propose a meal content estimation methodology that focuses on the forearm motion associated with eating. This technology uses sensor data from a wearable device on the user's dominant hand to enable recognition of meal content without the hassle of user input.

1. Introduction

It has often been said in recent years that dietary issues such as unbalanced eating habits or overeating can cause lifestyle-related illnesses manifesting as social issues. With the diversification of lifestyles and the expansion of meal choices, opportunities to eat out and consume processed foods have been increasing. These foods tend to have high salt and fat content and continued consumption of these foods raises concerns about increases of the number of people likely to get lifestyle-related illnesses. Therefore, it is important to consider a balanced diet in case of daily eating-out and consumption of processed foods.

As an initiative to promote the health of citizens, the Ministry of Agriculture, Forest and Fisheries has formulated dietary guidelines [1], and advocates review of eating habits. Also, the Ministry of Health, Labor and Welfare has formulated a balanced food

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guide [2] to tie specific actions to these dietary guidelines. In spite of these initiatives, a survey by the Cabinet Office indicates that one in two people do not have an appropriate diet [3], the most prevalent reasons for which are (1) they don't exactly know what they should do regarding diet, or (2) they are too busy and don't have time to consider diet [4].

These circumstances have led to a wide range of companies and organizations providing services to support management of dietary balance. These services take many forms, and include a wide variety of smartphone-based dietary support services [5]. However, to receive proper assistance using these services, users should continuously record meal information every day without omissions. Therefore, many of the existing services require manual user entry of feeding details such as the time and content of meals, which takes time and hence can discourage continued use.

Technology for recognizing wrist action to record the time of meals with high precision has been developed [6], and wearable devices with these functions [7] are available for practical use. In addition, to record meal content, recognition methods using images of food captured with the camera [8] and methods of recognizing the upper limb movements associated with feeding*1 [9] etc. have been researched. The former has issues with users forgetting to capture images and privacy protection, while regular use of the latter is seriously hindered because multiple devices must be attached to the body in a number of locations.

Hence, NTT DOCOMO has developed technology to estimate meal content using only forearm motion with the aim of being able to continually and automatically grasp the details of meal content without any of these hindrances. This article describes the method of recognizing meal content details from sensor data acquired from a generic wristband-type wearable device worn on the forearm of the user's dominant hand.

2. Related Research

2.1 Amft, et al.'s Method

As the method for estimating meal content, Amft, et al. proposed a method using accelerometers*2 and gyro sensors*3 placed in four locations on both upper arms and forearms to collect upper limb motion data, as well as a throat microphone*4 and microphone earbuds*5 to collect data [9] [10]. Their method estimates meal content through detection via sensors picking up the sequence of actions that occur with eating, which include preparatory motions to cut food, motions to bring the food to the mouth, and chewing and swallowing. Hence, they showed the effectiveness of using data sources other than imaging. This research suggests the importance of a temporal sequence of motions for estimating meal content. However, this method requires wearing multiple devices for accurate detection using a state transition model*6 and thus presents a major impediment to regular use.

2.2 Zhang, et al.'s Method

In technological research to recognize human motion such as walking and running, Zhang, et al. proposed a high accuracy method of recognizing human motion that focuses on the frequency of states rather than the transition of states [11]. In

*1 Feeding: The act of carrying food to the mouth and consuming it.

*2 Accelerometer: A sensor that measures changes in speed. Equipping a mobile terminal with an accelerometer enables it to sense changing movement. Sensors fixed mutually and orthogonally to each other to measure acceleration in 3 directions are also referred to as "3-axis accelerometers."

*3 Gyro sensor: A sensor that measures rotational speed.

*4 Throat microphone: A microphone attached to the throat to capture low-level vocalizations or swallowing sounds etc.

*5 Microphone earbud: A microphone inserted into the inner ear to capture the sounds associated with chewing that travel through the jaw.

this method, actions such as walking and running are interpreted as collections of multiple characteristic primitive motions, where a Bag-of-Words (BoW) representation*7 is applied to distinguish actions. As this research shows, we believe the BoW representation is an effective way to focus on human motion, even for recognizing forearm motions associated with eating. Hence, we employ a method that includes BoW representations to recognize forearm motion as combinations of characteristic primitive motions.

3. The Proposed Method

3.1 Overview

Figure 1 shows an overview of our proposed method. This study focuses on differences in forearm motions when eating to estimate meal content. For example, when eating a hamburger, motions to carry the food to the mouth and motions to change the chewing location occur. In contrast, when eating ramen noodles, motions to lift up the noodles, motions to cool the noodles and motions to slurp the noodles occur in a time sequence. Meal content estimation is made possible by recognition based on the time sequence of these motions, because they are different depending on meal contents. This proposed method entails wearing a device on forearm of the dominant hand and acquiring sensor data accompanying forearm motion when eating (hereinafter referred to as “forearm motion data”). Features*8 are extracted from this

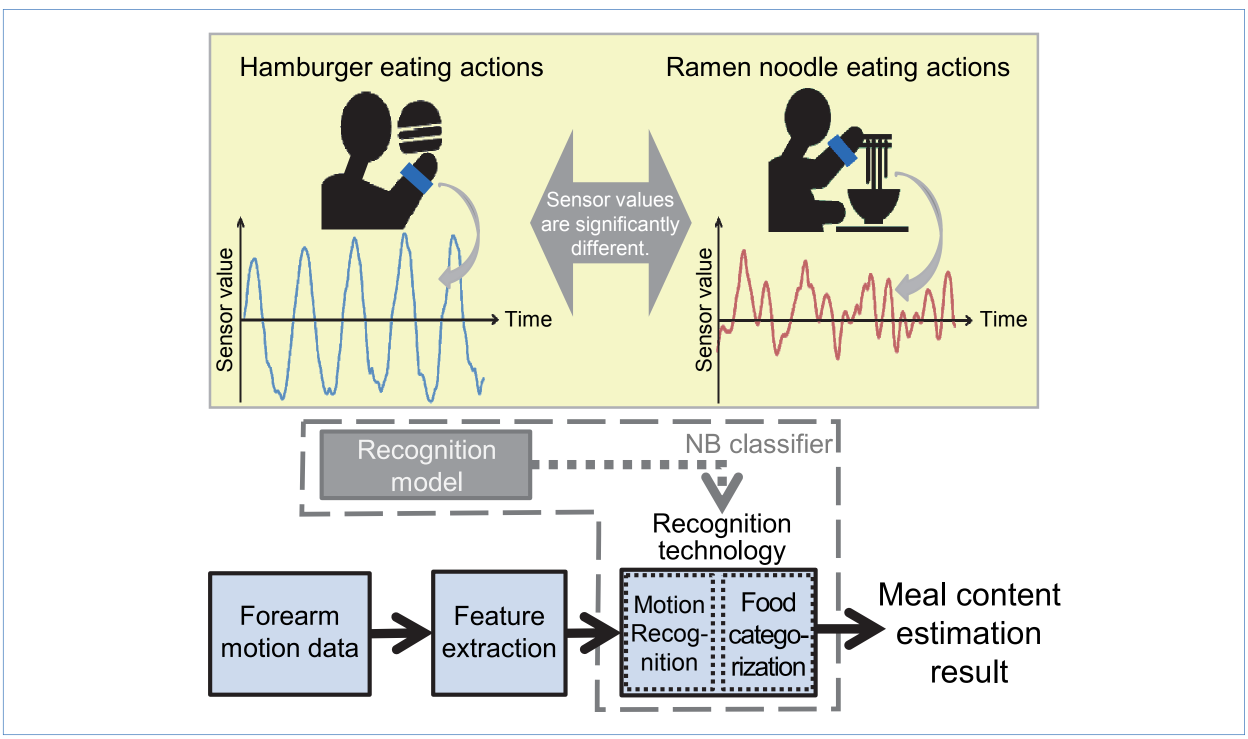


Figure 1 Overview of the proposed method

*6 State transition model: A model that expresses the flow of a procedure as transitions of states beginning with an initial state, and finishing with a final state. For example, in the process of eating, the initial state describes preparatory actions, followed by repeated transitions between carrying food to the mouth and chewing, with swallowing as the final state.

*7 BoW representation: Used with document categorization, a method of expressing a document in terms of the frequency that words appear in it.

*8 Feature: Values, or collections of values arbitrarily calculated to compare data. Calculating the features from source data is called “feature extraction.” With data consisting of multiple columns such as that from a 3-axis accelerometer, or if multiple calculation methods are selected, features can also consist of multiple columns. In such cases, the number of columns that make up the feature is called the “dimension.”

forearm motion data, and a Naive Bayes classifier*9 (hereinafter referred to as "NB classifier") recognizes motions to estimate meal content.

As previous methods to recognize meal content required multiple wearable devices, achieving a similar method with one device has been problematic. In this proposed method, we use BoW representations to recognize eating movements as combinations of characteristic primitive motions. Then, through an approach extending to N-gram*10 to describe time series information based on the order that motions occur, we have achieved meal content estimation with fewer wearable devices, which was problematic with the aforementioned conventional methods.

We have achieved a simpler method for continually and automatically recognizing meal content without hindering user participation, using only one commercially available wristband-type device worn on the dominant hand.

3.2 Flow of Estimation

Data from a 3-axis accelerometer is used as the forearm motion data, and the feature is extracted from this sensor data in fixed width moving windows*11 after the data has been filtered to reduce noise. If the dimensions of the feature are increased unnecessarily, the performance of the classifier will degrade, hence in this study we use a 12 dimension statistical value of the accelerometer for features, as shown in **Table 1**. With forearm motion when eating, a recognition method based on the order that motions occur is effective. Hence, firstly a BoW representation is applied to the 12 dimension feature, and expressed as a combination of elemental characteristic movements (hereinafter referred to as "primitive motions") (**Figure 2** (1)). Then, considering the order that the primitive motions occur and summarizing them into collections (hereinafter referred to as "primitive motion sequence") (Fig. 2 (2)), so that forearm movement data can be expressed as the frequency of occurrence of primitive motion sequences (Fig. 2 (3)) which is then applied to the NB classifier to estimate meal content. As shown in Fig. 2, it's possible to represent a set of primitive motion sequences by extending to N-gram after expressing forearm motion data as a set of primitive motions. Here, the primitive motions are expressed as "words," hence, movements such as slurping noodles or eating a donburi (rice bowl with topping) can be expressed as primitive motion sequences. For instance, the case of slurping noodles consists of movement to grab the noodles, movement to lift them up, and movement to carry them to the mouth. These movements can be expressed as primitive motions on a time axis. However, since eating actions such as carrying food to the mouth or chewing in which the forearm does not move occur with every meal, these words are not effective for estimating meal content. This means lowering importance placed on frequent words for various common eating actions,

Table 1 Extracted features and their dimensions

Features	Number of dimensions
Average value	3
Standard deviation	3
Variance	3
Median	3

*9 Naive Bayes classifier: A classifier based on a probability theory called "Bayesian probability."

*10 N-gram: A method of viewing N number of words in a series, among the words included in a document, as a new word.

*11 Moving window: In processing sensor data, the range of the target data is referred to as a "window." One of these windows moved according to certain rules is referred to as a "moving window."

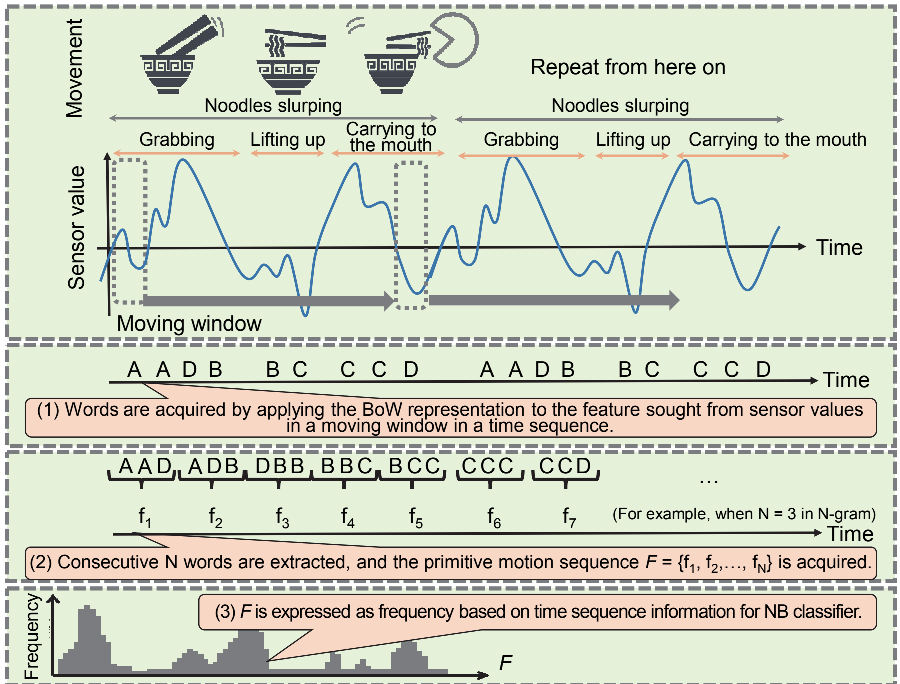


Figure 2　BoW representation using N-gram

while magnifying the importance of words for unique eating actions for specific meal content to raise the accuracy of meal content estimation.

When eating, primitive motions are repeated or performed alternately. In contrast to the aforementioned method of Amft, et al., research based on the continuity of all state transitions included in a single meal, this method can capture local continuity because it focuses on the frequency of actions using an NB classifier. For this reason, our method holds the promise of better meal content estimation accuracy compared to conventional methods, even with sudden noise or changes in the order of eating due to meal contents.

4. Experiments and Evaluations

4.1 Forearm Motion Data Collection and Experimental Conditions

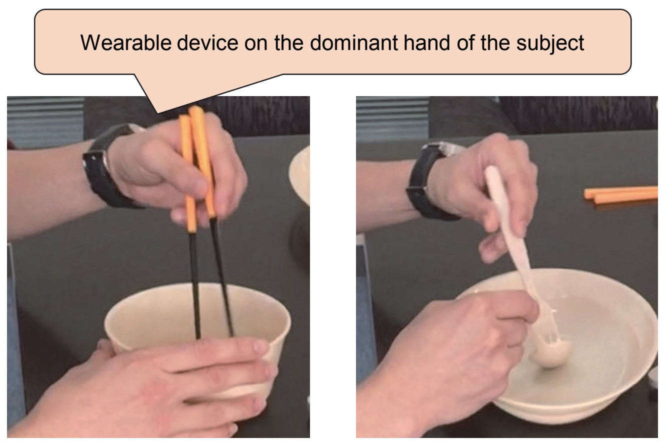
1) Experimental Conditions

We chose five items for meal content recognition as shown in **Table 2**, and also tabulated utensils used by experimental subjects at mealtimes, and the number of data collected. Forearm data was collected using an Android Wear™*12 -based wristband-type device (HUAWEI WATCH W1®*13) to collect forearm motion data. As shown in **Figure 3**, subjects ate with utensils in their dominant hand, and forearm movement data was collected. Forearm motion data covers approximately seven minutes

*12 Android Wear™: A trademark of Google Inc.
*13 HUAWEI WATCH W1®: A registered trademark of HUAWEI Technologies Co.

Table 2　Breakdown of meal contents, utensils and number of data

Meal content	Utensils	Requirements
Donburi, (with beef, pork cutlet, chicken and egg, tempura (fritter) or seafood topping)	Chopsticks	29
Curry and rice	Spoon	32
Breads (pasties, sandwiches, pizza and burgers)	Bare hands	26
Pasta (spaghetti)	Fork	27
Noodles (ramen)	Chopsticks	33



(a) Grabbing noodles with chopsticks

(b) Coiling pasta with a fork

* Data collected while actually eating meals

Figure 3　Forearm motion data collection experiments

per meal. Of the nine subjects, whose ages ranged from 20 to 40 (seven males and two females), one male was left-handed, while the remainder were right-handed. Referring to the number of data used in research done by Amft, et al. [9], we collected forearm motion data for approximately 30 meals per meal content item. However, because forearm motion data for the meal contents we chose for this research was collected during the subjects' daily lives, there were differences in the amount of forearm motion data collected depending on the subjects and the content of the meals they ate. In addition, the forearm motion data was collected in company canteens, residences and restaurants etc., and hence was not exactly the same, even for the same meal contents.

2) Collection of Experimental Data

It is said that in general, 99% of bodily movement takes place at or below 15 Hz [12]. For this reason, recognizing actions such as walking or running with accelerometers often entails measuring frequencies approximately 100 Hz to provide a margin [11]. Also, it has been shown that frequencies of eating actions obtained from wearable devices worn on the wrist in real life are between 0.2 and 0.6 Hz [13]. Since it is preferable to perform sampling at least twice the frequency of the motion to be sampled, features were extracted in this research using forearm motion data acquired at 20.0 Hz, which leaves plenty of margin for the 0.6 Hz maximum frequency of eating movements.

3) Applying the BoW Representation

A codebook*14 is created to record the primitive motions (words) from the extracted features. The total amount of words in the codebook is referred to as a "Vocabulary". When applying a BoW representation to motion recognition, a Vocabulary with comparatively low values is effective [11]. Hence, we applied a Vocabulary = 20 BoW representation to the feature extracted from the forearm motion data.

4) Application of N-gram

After creating the BoW representation, by applying the N-gram focusing on N words that occurred, we attempted to express actions such as slurping noodles or coiling pasta with a fork, which make sense with time width. Because the combinations of words increases explosively with the application of N-gram, we adopted the N=3 Trigram*15 for this research. This value was set based on the duration of actions such as slurping noodles or coiling pasta with a fork, and used to express a 2 second sample by moving a 1 second moving window in 0.5 second increments for the forearm motion data subsampled*16 at 20.0 Hz.

4.2 Evaluations

In this experiment, the NB classifier learned from the collected forearm motion data and the estimation performance was measured. We used the Leave-One-Out Cross Validation (LOOCV)*17 method for evaluating estimation performance. With this method, the forearm motion data collected for one meal is used for evaluation, while the remaining data is used for classifier learning. Evaluation indicators are a general f1 measure*18, the harmonic mean value between Recall*19 and Precision*20, and Accuracy, the ratio of the total number of true positives*21 and true negatives*22 for each meal content to the total number of forearm motion data.

Figure 4 shows a confusion matrix of LOOCV. In this table, the true values of meal contents to which forearm motion data belong are shown in the vertical direction, while the results of classifier estimation are shown in the horizontal direction. The closer the background color is to black, the higher the percentage of estimated result accuracy. It can be seen from the confusion matrix that the results of estimation for noodles are higher than other meal contents. In contrast, there were a significant number of cases of curry rice mistakenly estimated to be pasta or noodles, because in this experiment, we did not use a gyro sensor that could directly measure rotation of the wrist so it was difficult to reflect wrist rotation. Specifically, the action of eating curry rice entails gathering the rice and curry roux and then carrying it to the mouth. With the features adopted in Table 1, the actions of gathering the curry roux and rice and carrying them to the mouth seem to be seen as the same action, which means distinguishing those

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*14 Codebook: An index of all words used for BoW representations. Also called a "dictionary."

*15 Trigram: The name given to an N-gram where N=3. N-grams with N=2 and N=1 are called bigrams and unigrams, respectively.

*16 Subsampling: Extracting certain portions of sensor data according to certain rules.

*17 LOOCV: A method of splitting data used for classifier evaluation. Because all the data is used for evaluation, this method is often used when the total amount of data is small.

*18 f1 measure: A combination index derived by finding the harmonic mean of both the Recall and Precision indexes. While classifiers with both high Recall and Precision are ideal, there is a trade-off between the indexes. For this reason, the f1 measure is often used because it enables combined evaluation rather than evaluation using the individual indexes.

actions from other meal contents can be problematic, hence there were many estimates mistaken for noodles, which prior probability*23 is the highest.

As meal content estimation results, **Figure 5** shows f1 measures, and **Figure 6** shows Accuracy. The average f1 measure for meal contents is 63%, and the average Accuracy is 72%. Since Recall and Precision are remarkably low for curry rice, both the f1 measure and Accuracy have the lowest estimation performance. Other meal contents have f1 measures of 65% or more, and Accuracy of 70%

		Estimation result				
		Donburi	Curry	Breads	Pasta	Noodles
True value	Donburi	0.55	0.00	0.00	0.17	0.28
	Curry	0.16	0.09	0.00	0.34	0.41
	Breads	0.04	0.04	0.68	0.12	0.16
	Pasta	0.19	0.04	0.04	0.62	0.08
	Noodles	0.03	0.00	0.00	0.06	0.91

Figure 4　Meal content estimation: Confusion matrix

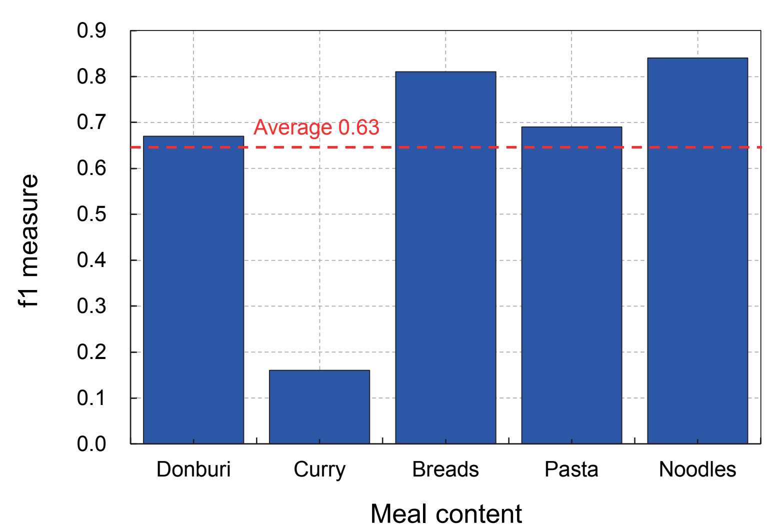

Figure 5　Meal content estimation results (f1 measure)

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*19　**Recall:** Expresses comprehensiveness as a lack of leakage with estimation results, but cannot express precision of estimation results.

*20　**Precision:** An index that can express the accuracy of estimation results, but cannot express the comprehensiveness of estimation results.

*21　**True positive:** Estimation results that match actual actions taken, from among the estimation results matching true values. For example, when actually eating ramen noodles, the number of events that are estimated to be ramen noodle events.

*22　**True negative:** Estimation results that match actual actions not taken, from among the estimation matching true values. For example, if meal content is not ramen noodles, the number of events that are estimated not to be ramen noodles.

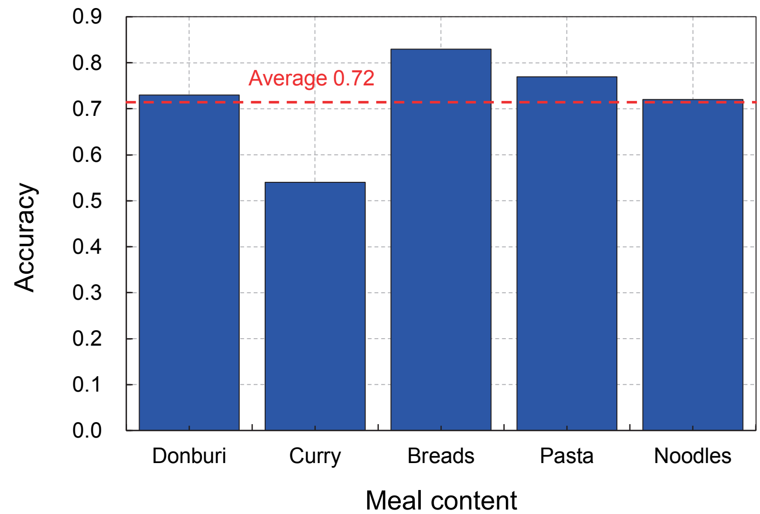

Figure 6 Meal content estimation results (Accuracy)

or more, which indicates that it's possible to estimate meal contents from forearm motion data in situations where food items are limited to some degree.

5. Conclusion

Aiming to produce technology that can automatically and continually grasp meal content without any hassle to the user, we have studied a meal content estimation method that focuses on forearm motion. In experimental conditions, the recognition performance of this proposed method achieved an average f1 measure of 63%, and an average Accuracy of 72%. These results indicate that it's possible to estimate meal content in situations where food items are relatively limited such as workplace canteens. We intend to work towards commercializing services with this technology by improving its recognition accuracy so that it can be used with a wider range of food items such as those in restaurants or at home. Features need to be added that can express forearm motion in more detail, because, with the general statistics we adopted for features, the estimation accuracy was low for some meal contents. We also believe formulating recognition models and adjusting features for individuals will be effective as we found differences in the forearm motions of experimental subjects even with the same meal contents.

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*23 Prior probability: In Bayesian probability, a theory of probability that an event will occur based on changes in the amount of knowledge related to that event. Before acquiring the knowledge, the assumed probability that an event will occur is called prior probability, while the probability after knowledge is acquired is called posterior probability.

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NTT DOCOMO
Technical Journal Vol.19 No.3

Editorship and Publication
NTT DOCOMO Technical Journal is a quarterly journal edited by NTT DOCOMO, INC. and published by The Telecommunications Association.

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