NTT DOCOMO

Technical Journal

Vol.22 No.2 | Oct. 2020

DOCOMO Today

- Real Issues and Future Vision of 5G

Technology Reports (Special Articles)

Special Articles on 5G (1) —NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

- History of 5G Initiatives
- NTT DOCOMO Contributions to 5G Standardization
- 5G Network

Technology Reports (Special Articles)

Special Articles on Lifestyle-enriching AI Technology

- Health Risk Prediction from Health Examination Data
- Music Recommendation Technology that Considers the Time Series of Singing History

Technology Reports

- Improving Maintenance Efficiency through Resource Assurance System Implementation

NTT docomo

Real Issues and Future Vision of 5G

General Manager of 6G Laboratories
Takehiro Nakamura

The commercial service of NTT DOCOMO's fifth-generation mobile communications system (5G) was launched on March 25, 2020. As someone who has been involved in 5G from the beginning of its research and development, I can say "Finally, this day has come," but in a sense, we have just arrived at the starting line of 5G.

Studies toward 5G began just after the commercial launch of LTE services in 2010. Up to now, a new generation of mobile communications has come to be launched in a roughly 10-year cycle, so 2020 was targeted as the 5G launch period from the very start. We began with studies of basic 5G concepts, and based on those studies, we exchanged opinions with key world players in a step-by-step manner to form a worldwide consensus. By 2014, a global view had been achieved on main requirements, such as transmission speeds in excess of 10 Gbps and low latency on the order of milliseconds, and on elemental technologies. Wireless transmission experiments began in earnest in 2014 to demonstrate the technical feasibility of these requirements, and transmission speeds exceeding 10 Gbps and low latency on the millisecond level were achieved. In addition, given the rising expectations in other industries toward 5G and the need to formulate 5G use cases from an early stage to explore business opportunities for NTT DOCOMO as well, we began in 2017 to hold many use-case trials and exhibitions showcasing 5G features in collaboration with players from diverse industries. Then, in 2018, the DOCOMO 5G Open Partner Program was launched to expand activities toward the creation of new usage scenarios together with an even broader group of partners. These activities were taken up in many press releases and articles thereby spreading the word throughout Japan on the potential of 5G to solve pressing social problems and bring innovative changes to many industries.

In truth, however, this coverage in the media gave the false impression that high performance reflected by 5G requirements and the many use cases targeted by trials would soon become a reality throughout the country. At present, there are no 5G commercial systems anywhere in the world that are operating at transmission speeds of 10 Gbps with low latency on the millisecond level, and areas with 5G coverage are limited. This is the same pattern followed in past generations, namely, that several years would be needed to ramp up performance and that use cases even for business would be created gradually. On the other hand, 5G differs from past generations in a number of ways. For example, many studies and experiments have been conducted and reported both inside and outside Japan toward the creation of new services, and diverse industries and local governments have been expressing great expectations of 5G even prior to the launch of the commercial service. Thus, with today's 5G issues in mind, we feel that it is extremely important to pursue research and development that can drive the evolution of 5G into the future. We need to understand real performance in today's real environment and plan the creation of new services and business opportunities in a steady manner. At the same time, we need to adequately grasp the gap with real market needs and plan for future 5G enhancements. Additionally, to meet the expectations of a broad range of industries, enhancements to the public mobile communications network will not be sufficient. We need to meet special requirements for private use in a variety of industrial scenarios such as factories, construction sites, and farmland. There will also be a need to promote short-term and medium-term initiatives toward solving social problems and achieving a social transformation as described in Sustainable Development Goals (SDGs)*1 and Society 5.0*2.

Today, with 5G commercial services coming to be launched around the world, 6G studies have commenced on a global basis as a future long-term mobile communications system toward a 2030 launch. NTT DOCOMO has already published white papers and promoted discussions on 5G evolution and 6G. As a member of the NTT DOCOMO R&D team, I am committed to making the 5G system and business opportunities expected by general users and diverse industries a reality at an early stage and to continue with my R&D efforts toward a long-term mobile communications system of the future.

*1 SDGs: A set of global goals adopted by United Nations General Assembly in 2015 for the period from 2016 to 2030. They consist of 17 goals and 169 targets with the aim of achieving a sustainable society.

*2 Society 5.0: A new economic society advocated by the Japanese 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.

NTT DOCOMO
Technical Journal
Vol.22 No.2 Oct. 2020

[Contents]

DOCOMO Today

Special Articles on 5G (1) —NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

Technology Reports (Special Articles)

(P.23)

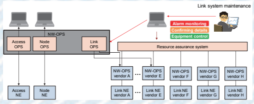
(P.40)

Special Articles on Lifestyle-enriching AI Technology

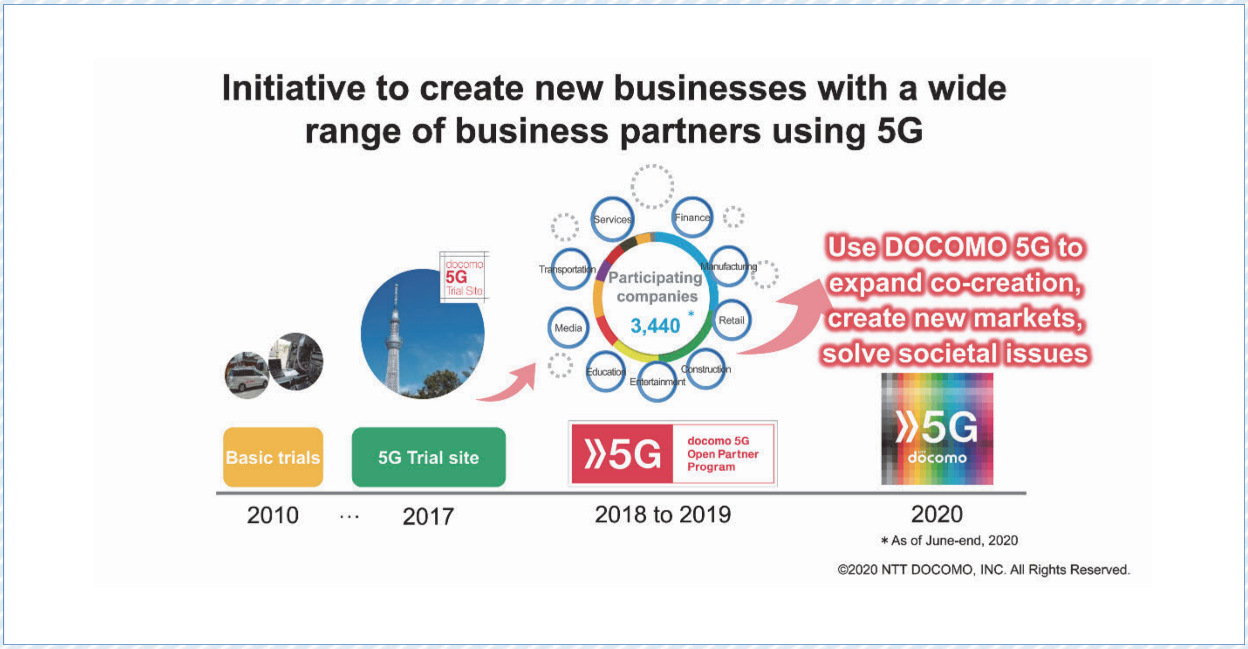
Technology Reports (Special Articles)

(P.47)

Technology Reports



(P.54)



Technology Reports (Special Articles) History of 5G Initiatives (P.4)
NTT DOCOMO 5G Open Partner program

Technology Reports (Special Articles) 5G Concepts 5G Trials 5G Use Cases

Special Articles on 5G (1)—NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

History of 5G Initiatives

6G Laboratories Yoshihisa Kishiyama Satoshi Suyama

In March 2020, NTT DOCOMO began providing commercial 5G communications services, which we have been studying since about 2010. Since then, we have steadily released products supporting 5G, including six smartphone models and one data communications device (a Wi-Fi router), and have introduced seven services utilizing the high speed and high capacity of 5G, such as "Shintaikan Live CONNECT," which enables multi-angle (multi-viewpoint) and VR live viewing.

This article describes the history of NTT DOCOMO's development work and co-creation with partner companies and organizations in realizing 5G, from when we started studying 5G through to provision of these services.

1. Introduction

In 2010, when NTT DOCOMO began our LTE services, we started investigating fifth-generation mobile communication systems (5G) with the goal of implementing them within ten years. We studied the basic concepts and radio access technologies for 5G, prototyped 5G simulators, and in 2014, we published a 5G white paper [1]. That same year, we also began 5G trials in collaboration with individual hardware vendors from around the world, and evaluation of 5G frequencies and radio access technologies. We also expanded collaboration in 5G trials with various partner enterprises around the world and developed many use cases for features of 5G through joint trials with these partners. In February 2018, we started the "NTT DOCOMO 5G Open Partner Program," to promote co-creation of solutions with partner organizations. This article reviews these initiatives at NTT DOCOMO, from proposing basic 5G concepts to co-creation of solutions through trial activities.

2. Preparing for Publication of the 5G White Paper (2010 to 2014)

The history of 5G concepts arising in external presentations is outlined in **Figure 1**. In about 2010, looking forward to 2020, mobile communication traffic was expected to increase rapidly, by a factor of 1,000 in ten years, so to realize such requirements, we proposed a "cube" concept (improve spectral efficiency*1 × expand frequency bandwidth × increase network density) as a direction for technical advancement [2]. In around 2011, we proposed specific technical candidates for implementing this cube concept, such as a radio access technology combining the existing low-frequency bands with high-frequency bands of 6 GHz or greater [3]. Then, around 2012, requirements that are now features of 5G in addition to high speed and capacity came to light, including low latency and many-terminal connectivity, and the current definition of 5G combining extensions to LTE and a New Radio Access

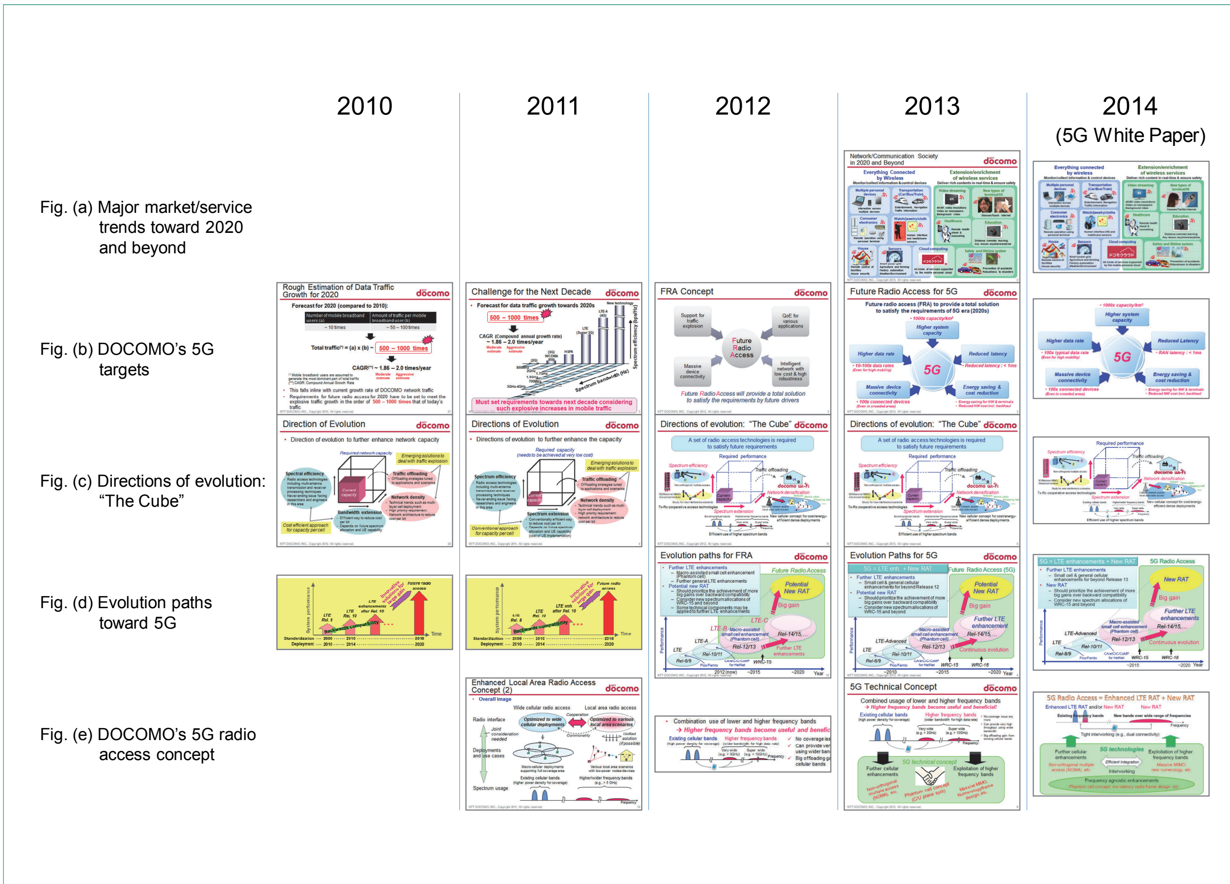


Figure 1 History of 5G concepts in external presentations

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

Technology (New RAT)*2 was proposed [4]. By about 2013, the technical concepts described in the 5G white paper published in 2014 were largely complete, including services and applications anticipated for the 5G era [5]. In this way, the basic concepts and radio access technologies for 5G advanced, building consensus with major companies around the world, and also including proposals from other companies that shared requirements and other concepts, such as exploiting higher frequency bands [6] [7].

Initially, NTT DOCOMO used the name "Future Radio Access" externally, but the name "5G" was first used in October 2013 at CEATEC. At this first exhibit of 5G, a demonstration was given using a simulator to visualize the basic 5G concepts and radio access technologies, which received the "Minister for Internal Affairs and Communications CEATEC Award 2013" [8]. As shown in **Figure 2**, development of the 5G simulator continued after that, with updates such as the stadium model. Around the time when the "5G" was first used, the focus for the 5G radio access technology was on using high-frequency bands efficiently, with Massive Multiple-Input Multiple Output (Massive MIMO)*3, in 5G research projects such as "Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)*4 in Europe. NTT DOCOMO participated in METIS, leading proposals for technologies such as Phantom cells*5 (C/U separation) [9] and Non-Orthogonal Multiple Access (NOMA)*6 [10]. These radio technologies

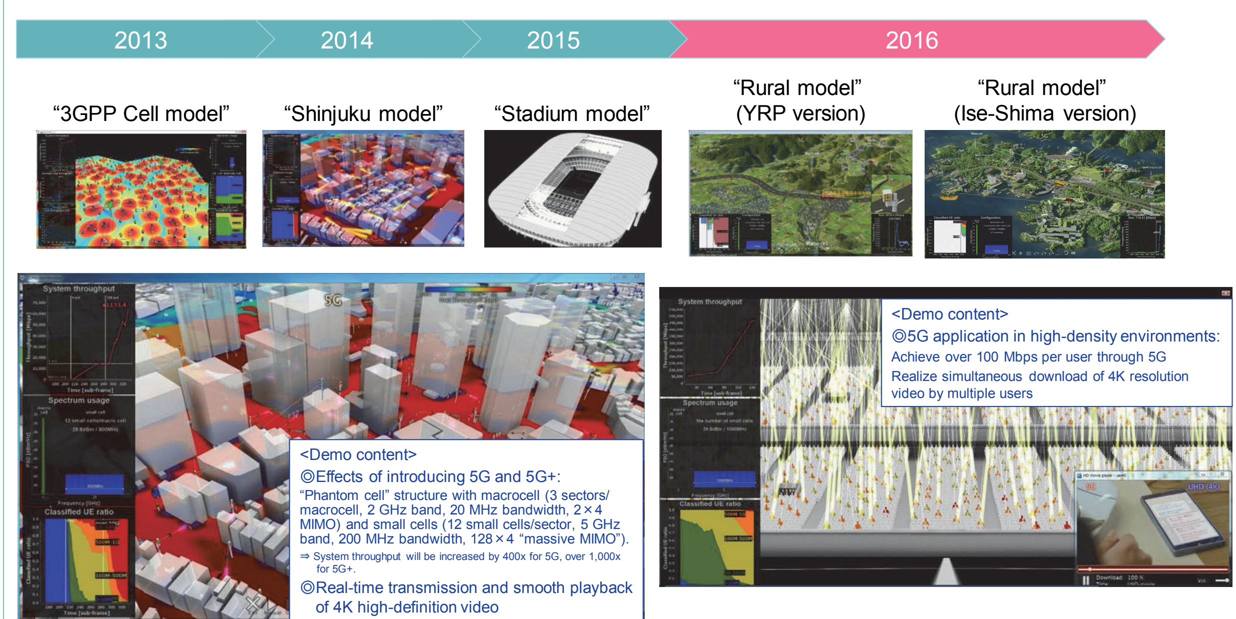


Figure 2　History of 5G Simulator

*2　New RAT: A new radio interface standard that is not backward compatible with 4G LTE. Also referred to as 5G New Radio (NR).

*3　Massive MIMO: Large-scale MIMO using a very large number of antenna elements. Massive MIMO is expected to be useful for 5G because antenna elements can be miniaturized when using high-frequency bands, and many elements can be placed within the same area.

*4　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.

and simulator prototyping were also published in the "DOCOMO 5G White Paper," as the latest work at the time [1].

3. 5G Trials and Development of Use Cases (2014 to 2020)

3.1 NTT DOCOMO Initiatives with Partner Enterprises

To verify 5G frequencies and key radio access technologies, NTT DOCOMO conducted 5G trials collaborating individually with major global vendors. In May 2014, we announced joint testing with six companies [11], and in July 2015, we expanded this to 13 companies [12]. Through joint testing with each of these companies, we verified 5G radio access technologies such as Massive MIMO in frequency bands up to the 70 GHz band, and in February 2016, we successfully conducted the world's first multi-user 5G communication tests, achieving total throughput exceeding 20 Gbps in an outdoor environment (**Figure 3**). Results of other major 5G trials published in press releases are shown in **Table 1**. By March 2018, we had given 170 conference presentations based on these 5G trials [13].

Starting around 2016, we have developed various use cases utilizing features of 5G in collaboration with partner enterprises in various industries [14]. To date, we have conducted 430 service trials (as of June 2020), such as building 5G trial sites as 5G test environments in the Tokyo Rinkai Fukutoshin district (Odaiba/Aomi areas) and the Tokyo Skytree Town neighborhood.

3.2 MIC 5G Field Trial Initiatives (2017 to 2019)

Over three years starting in FY2017, the Ministry of Internal Affairs and Communications (MIC) has conducted "5G Field Trials," toward creation of new markets and new services and applications, with participants from various application fields [15]. The

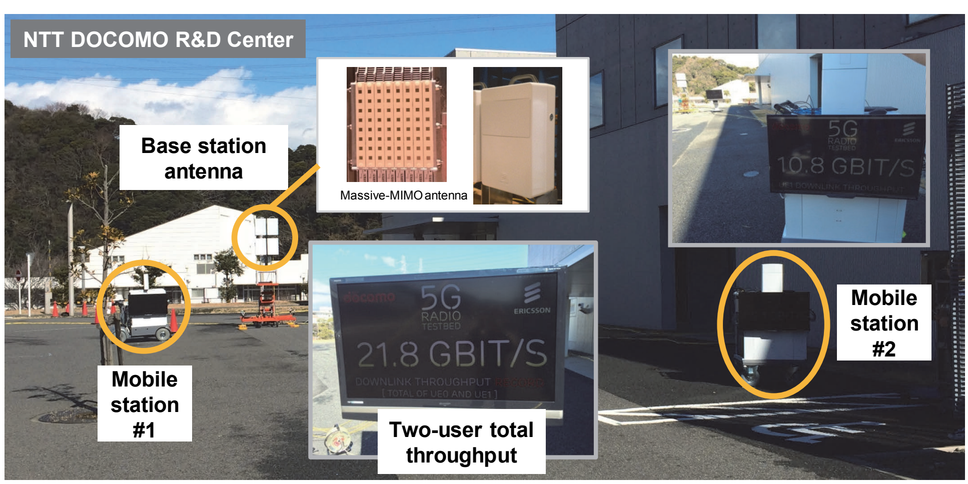


Figure 3　20 Gbps field trial

*5　Phantom cell: The name of the advanced small-cell system proposed by NTT DOCOMO, with the basic concept of C/U separation. Reflected under "Dual Connectivity" in 5G standardization.

*6　NOMA: A method for improving efficiency of multiple access by permitting resources to overlap among users when allocating resources such as time, frequencies, or codes to multiple users.

Table 1 Major results in 5G radio technology trials (press releases)

Press release date	Test results	Trial partner
2015/3/3	Successful reception of data at over 4.5 Gbps using the 15 GHz band	Ericsson
2015/3/3	Successful reception of data at over 2 Gbps using the 70 GHz band	Nokia
2015/11/26	Successful communication tests at over 2 Gbps in real environments with commercial equipment using the 70 GHz band	Nokia
2015/11/26	Successful data communication receiving over 2.5 Gbps in a high-speed mobile environment traveling at approximately 60 km/h using the 28 GHz band	Samsung
2016/2/22	Successful multi-user 5G communication trial achieving capacity over 20 Gbps in an outdoor environment using the 15 GHz band	Ericsson
2016/5/24	Successful real-time 5G transmission of 8K video using the 70 GHz band	Nokia
2016/11/16	Successful 5G wireless data transmission at 2.5 Gbps while moving at high-speeds of 150 km/h using the 28 GHz band	Samsung
2016/11/16	High-speed, high-capacity communication achieved between 23 terminals distributed in an outdoor environment, totaling 11.29 Gbps, using the 4.5 GHz band	Huawei
2017/11/2	Successful field trial of 5G Ultra-Reliable, Low-Latency Communication (URLLC) using the 4.5 GHz band	Huawei
2017/11/2	Successful trial increasing spectral efficiency using the world's first smartphone-sized NOMA chip set	MediaTek
2017/11/6	Successful 5G trials for implementing connected cars in the Odaiba area using the 28 GHz band	Toyota, Ericsson, Intel
2018/4/23	Successful 5G wireless communication trials in an ultra-high-speed environment of 300 km/h using the 28 GHz band	NEC
2018/5/23	Successful 5G wireless communication with multiple mobile terminals, reducing interference using cooperative beamforming among 4.5 GHz base stations	NEC
2018/7/25	Successful 5G communication for connected cars using "vehicle glass mounted antenna" and using the 28 GHz band	AGC, Ericsson
2018/11/22	Successful field trial of 27 Gbps communication using the 28 GHz band	Mitsubishi Electric
2019/5/29	Successful communication using a glass antenna for 5G terminals using the 28 GHz band	AGC, Ericsson

content of 5G field trials conducted by NTT DOCOMO throughout Japan with collaboration partners over the three years is shown in **Table 2**. Trial group GI conducted field trials in low-speed mobile environments, while trial group GII conducted field trials in high-speed mobile environments (60 km/h and greater). In 5G field trials in FY2017, GI conducted trials of 10 Gbps ultra-high-speed communication in densely populated areas and service and application trials using 4.5 GHz and 28 GHz bands in the application fields of entertainment, smart city and medicine [16]. NTT DOCOMO also participated in 2 Gbps high-speed communication trials while moving at high speed (GII), which were conducted

Table 2 Location and details of 5G field trials conducted, 2017 to 2019

Trial group	Application field	Use case	Location	Fiscal year 2017	Fiscal year 2018	Fiscal year 2019
GI	Entertainment	(1) Live music VR experience using 5G	Sumida Ward, Tokyo	○		
		(2) MR communication using 5G	Sumida Ward, Tokyo	○		
		(3) 8K video multichannel MMT transmission using 5G	Sumida Ward, Tokyo	○		
		(4) 4K Low-power digital signage using 5G	Sumida Ward, Tokyo	○		
		(5) High-definition video transmission in a shopping-mall environment	Sumida Ward, Tokyo	○		
		(6) Live viewing of a sports event using 5G	Yokohama City, Kanagawa Prefecture	○		
		(7) Ultra-high-definition video transmission to steam locomotive "SL Taiju" using 5G	Nikko City, Tochigi Prefecture		○	
		(8) Tourism promotion using 5G and 8K video	Kyoto City, Kyoto Prefecture		○	
		(9) Live video distribution for wheelchair basketball using 5G	Kamakura City, Kanagawa Prefecture		○	
		(10) Remote museum visits using 5G and VR technology	Katsuyama City, Fukui Prefecture		○	
		(11) Live viewing of tourism events using 5G	Aizuwakamatsu City, Fukushima Prefecture		○	
		(12) Remote live support for sporting events using 5G	Kawasaki City, Kanagawa Prefecture		○	
		(13) Promoting tourism in Okinawa Prefecture with 5G and Body Sharing technology	Nago City Region, Okinawa Prefecture			○
		(14) Real-time cloud editing/relay solution using 5G	Sendai City, Miyagi Prefecture			○
	Smart city	(1) Facilities monitoring using 5G	Koto Ward, Tokyo	○		
		(2) Wide area surveillance using elevated cameras and 5G	Sumida Ward, Tokyo	○		
		(3) Car security using 5G	Kamiyama Town, Tokushima Prefecture		○	
		(4) Rural monitoring services using 5G	Aizuwakamatsu City, Fukushima Prefecture		○	
	Medicine	(1) Remote medical examination and treatment using 5G	Wakayama City, Wakayama Prefecture Hidakagawa Town, Wakayama Prefecture	○	○	○
		(2) Advanced urgent conveyance solutions using 5G	Maebashi City, Gunma Prefecture		○	○
		(3) Monitoring and behavior understanding using highly accurate face recognition authentication, sensors, and 5G	Hiroshima City, Hiroshima Prefecture			○
	Workplace	(1) Mobile satellite offices using 5G	Kamiyama Town, Tokushima Prefecture		○	
		(2) Ensuring work safety for highly skilled workers using 5G	Imabari City, Ehime Prefecture			○
	Smart life	(1) Transmission of traditional arts using 5G (remote education)	Nakatsugawa City, Gifu Prefecture			○
		(2) Lifestyle support through visualization of sound using 5G	Nakatsugawa City, Gifu Prefecture			○
GII	Entertainment	(1) Transmission of high-definition video to high-speed moving objects using 5G	Tochigi, Kanuma Cities, Tochigi Prefecture; Kasukabe City, Saitama Prefecture	○	○	
		(2) Guidance at a golf course using 5G	Nagano City, Nagano Prefecture			○
	Transportation	(1) Monitoring for safe operation of high-speed trains using 5G	Takatsuki City, Osaka Prefecture		○	
		(2) Driving assistance during heavy fog using 5G	Oita City Region, Oita Prefecture			○
		(3) Support ensuring subway safety using 5G	Osaka City, Osaka Prefecture			○
	Smart city	(1) Protection against snow damage using 5G (improving efficiency of snow removal)	Eiheiji Town, Fukui Prefecture			○

mainly by NTT Communications, with entertainment field trials communicating using the 28 GHz band while traveling at the high speed of 90 km/h [16].

In 5G field trials in FY2018, we conducted trials at ultra-high-speeds (GI) averaging 4 to 8 Gbps in an outdoor environment, to verify both maximum and average 5G performance, and in office/workplace environments in addition to the three application fields tested in FY2017 [17]. We also conducted trials of high-speed communication averaging 1 Gbps for fast-moving objects traveling at 60 to 120 km/h (GII), and in the field of transportation in addition to entertainment [17].

In January 2019, MIC held the "5G Utilization Ideas Contest," with the objective of uncovering unique ideas that can resolve various issues that arise in outlying areas [18]. 5G field trials in FY2019 emphasized user models that use 5G to solve regional issues or contribute to regional revitalization, encompassing results from the idea contest described above, and from earlier technology trials. This involved trials with various new collaboration partners in various application fields [19].

4. Creating Solutions with Partners

To expand initiatives for creating new user scenarios with a wide range of partners, NTT DOCOMO started the "DOCOMO 5G Open Partner Program" in February 2018 (**Figure 4**). This program provided information regarding 5G technologies and specifications to partner enterprises and organizations, and 5G Partner Workshops as a place for them to exchange ideas with each other. As of the end of June 2020, there were 3,440 partners participating.

NTT DOCOMO also operates the "DOCOMO 5G Open Lab" as a permanent 5G technology test bed, providing partners with test equipment free

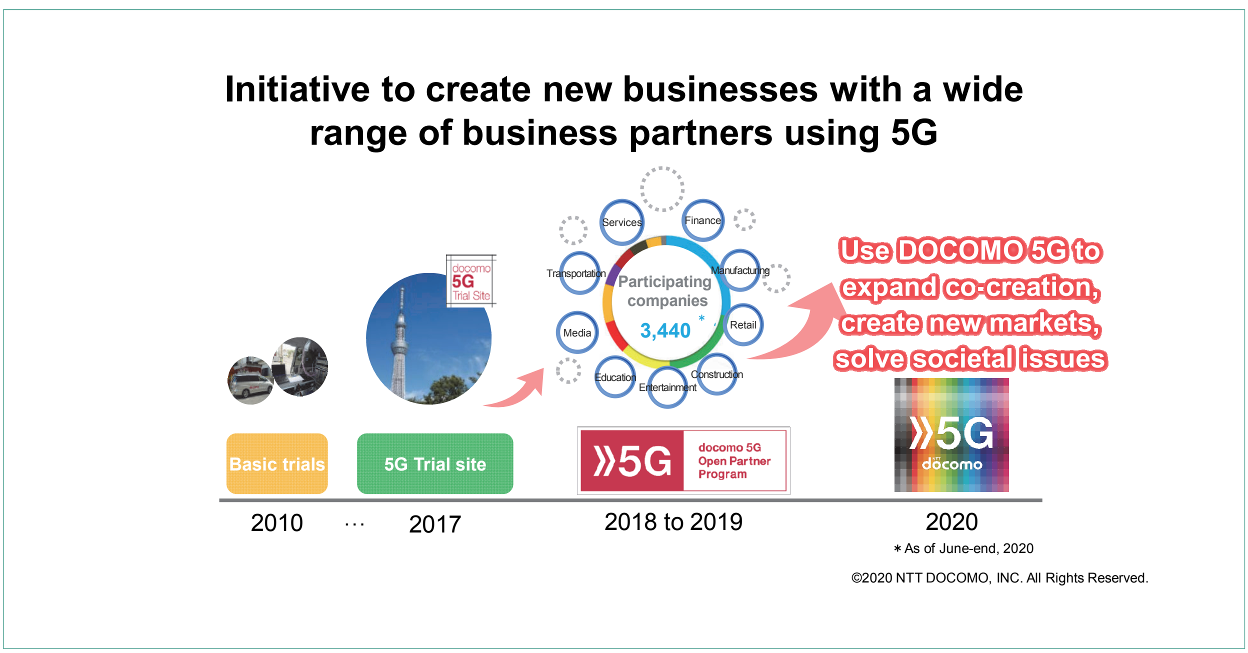


Figure 4　NTT DOCOMO 5G Open Partner program

of charge, such as 5G test base stations and video transmitters connected to mobile test stations. By participating in this program, partner enterprises and organizations can build and test services using 5G early, before commercial services begin, improving the quality of their own services and creating new services using the features of 5G, which are high speed, high capacity, low latency, and multi-terminal connectivity. As of the end of June 2020, DOCOMO 5G Open Lab had 11 locations in Japan and internationally. DOCOMO 5G Open Lab is also providing the "DOCOMO Open Innovation Cloud" trial environment connected directly to cloud computing infrastructure and is conducting technology verification.

NTT DOCOMO also began the "5G pre-commercial service" in September 2019. It uses the same network equipment and frequency bands as 5G commercial services, and represents the start of services substantially the same as connecting to a 5G commercial service, enabling business creation to begin in earnest, and allowing users to experience an environment equivalent to a 5G commercial service. The 5G pre-commercial service is for the over-3,000 partners participating in the DOCOMO 5G Open Partner Program, and by lending out terminals that support the 5G pre-commercial service together with provision of 5G Open Lab, over 200 of field trials have been conducted throughout Japan, toward creating industries using 5G and solving social issues. From these, seven services and 22 solutions produced through co-creation with all of our partners, such as Shintaikan Live CONNECT, were announced at the start of 5G services, focused on solving social issues such as "advancing industry," "reform work practices." In the future, we intend to provide new kinds of value related to work practices, utilizing the 5G features of high speed, high capacity, and low latency, and focusing on areas such as remote work support and high-definition video transmission.

5. Conclusion

In this article, we have described the path leading to the start of 5G services by NTT DOCOMO. In the future, NTT DOCOMO will continue to study technologies and conduct R&D, with the goal of further advancing 5G.

REFERENCES

[1] NTT DOCOMO: "NTT DOCOMO 5G White Paper," Sep. 2014.
[2] Y. Kishiyama: "LTE enhancements and future radio access," APCC2010 Seminar on Future Wireless Technologies, Nov. 2010.
[3] Y. Kishiyama: "LTE enhancements and future radio access towards next decade," 1st NGMN Innovation Day, Stockholm, Sweden, Sep. 2011.
[4] Y. Kishiyama: "Future radio access challenges," WWRF Wireless World 2020 Workshop, Berlin, Germany, Oct. 2012.
[5] NTT DOCOMO: "Future radio access for 5G," ARIB 2020 and Beyond Workshop, Tokyo, Japan, Nov. 2013.
[6] Ericsson: "White paper - 5G radio access," Jun. 2013.
[7] Nokia Solutions and Networks: "White paper – Looking ahead to 5G," Dec. 2013.
[8] NTT DOCOMO Press Release: "'Next-generation Mobile communications system (5G)' receives Minister for Internal Affairs and Communications Award at the CEATEC AWARDS 2013," Oct. 2013.
[9] H. Ishii, Y. Kishiyama, and H. Takahashi: "A novel architecture for LTE-B: C-plane/U-plane split and Phantom cell concept," IEEE Globecom, Dec. 2012.
[10] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi: "Non-orthogonal multiple access (NOMA) for cellular future radio access," IEEE VTC

Spring, Jun. 2013.
[11] NTT DOCOMO Press Release: "DOCOMO to Conduct 5G Experimental Trials with World-leading Mobile Technology Vendors," May 2014.
[12] NTT DOCOMO Press Release: "DOCOMO Expands 5G Trials Collaborating with World-leading Vendors," Jul. 2015.
[13] NTT DOCOMO: "Overview of 5G Trials in Collaboration with World-leading Vendors,"
https://www.nttdocomo.co.jp/corporate/technology/rd/tech/5g/5g_trial/
[14] T. Nakamura: "Views of the Future Pioneered by 5G —A World Converging the Strengths of Partners—," NTT DOCOMO Technical Journal 25th Anniversary, pp. 53–59, Dec. 2018.
[15] MIC Press Release: "5G Integration Trials Begin," May 2017.
https://www.soumu.go.jp/menu_news/s-news/01kiban14_02000297.html
[16] NTT DOCOMO Press Release: "Results of FY2017 Ministry of Internal Affairs and Communication "5G comprehensive demonstration test"," Mar. 2018 (In Japanese).
https://www.nttdocomo.co.jp/binary/pdf/corporate/technology/rd/topics/2017/topics_180326_03.pdf
[17] NTT DOCOMO Press Release: "FY2018 MIC "5G Integration Testing" Results: Verification of various 5G use cases contributing to regional revitalization and Japan's first application of 5G for emergency medical treatment," Mar. 2019.
https://www.nttdocomo.co.jp/binary/pdf/info/news_release/topics_190319_01.pdf
[18] MIC Press Release materials: "Holding the '5G utilization idea contest'," Dec. 2018.
https://www.soumu.go.jp/menu_news/s-news/01kiban14_02000362.html
[19] NTT DOCOMO Press Release: "FY2019 MIC '5G Integration Testing' Results: Verification of 12 5G use cases contributing to regional revitalization," Mar. 2020.
https://www.nttdocomo.co.jp/binary/pdf/info/news_release/topics_200316_00.pdf

Technology Reports (Special Articles) 3GPP 5G Standard O-RAN

Special Articles on 5G (1)—NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

NTT DOCOMO Contributions to 5G Standardization

6G Laboratories Satoshi Nagata
Core Network Development Department Atsushi Minokuchi
Radio Access Network Development Department Anil Umesh
Communication Device Development Department Yuta Oguma
R&D Strategy Department Shinji Takeda†

At the 3rd Generation Partnership Project (3GPP), the initial version of the 5G standard was completed in June 2018, and at the O-RAN Alliance, specifications for achieving a 5G open radio access network were released in March 2019. NTT DOCOMO is an active contributor to standardization efforts at 3GPP and O-RAN and the commercial 5G service that it launched in March 2020 conforms to 3GPP and O-RAN specifications. This article provides an overview of NTT DOCOMO's contributions to the formulation of these specifications.

1. Introduction

At the 3GPP Technical Specification Group (TSG) #84 plenary meeting*1 held in June 2018, 3GPP Release 15 specifications were declared frozen marking the completion of the initial 5G standard. The 5G standard is a new radio access specification called New Radio (NR). It features a new core network*2

† Currently, Communication Device Development Department

*1 Plenary meeting: The highest level of 3GPP TSG meetings. It draws up schedules for formulating specifications in WGs under the TSG and approves the specifications formulated in WGs.

*2 Core network: A network consisting of packet transfer equipment, subscriber information management equipment, etc. Mobile terminals communicate with the core network via the radio access network.

called the 5G Core network (5GC) and includes functions for linking with the existing Long Term Evolution (LTE)/Evolved Packet Core (EPC)*3 system.

At 3GPP, 5G standardization envisioned the following three usage scenarios based on the ITU-RM.2083 vision recommendation issued by the International Telecommunication Union-Radio Communication Sector (ITU-R)*4 in September 2015: (1) enhanced Mobile BroadBand (eMBB), (2) massive Machine Type Communications (mMTC), and (3) Ultra-Reliable and Low-Latency Communications (URLLC). Studies for Release 14 commenced in March 2016 with a Study Item (SI) established on requirements and elemental technologies. This was followed by studies for Release 15 from March 2017 with a Work Item (WI) established on detailed specifications.

NTT DOCOMO proactively contributed to the formulation of 5G specifications at 3GPP over the two-year, three-month period from the beginning of Release 14 to the completion of Release 15. This contribution included technical proposals, compilation of specifications, and Chairman and Vice Chairman roles at meetings. During this time, the number of contributions to 5G specifications submitted by NTT DOCOMO came to approximately 3,700 items, which ranked ninth among worldwide companies and first as a mobile operator※1. NTT DOCOMO was also evaluated as first among mobile operators in terms of the number of 5G candidate essential-patent*5 applications※2.

In parallel with these 3GPP standardization activities, NTT DOCOMO established the O-RAN Alliance with AT&T, China Mobile, Deutsche Telekom, and Orange in February 2018. Aiming to construct a highly extendible, open, and intelligent next-generation Radio Access Network*6 as typified by 5G, the O-RAN Alliance has been working to (1) promote open interfaces with high interoperability, (2) apply virtualization and white box*7 schemes to radio network equipment, and (3) leverage Artificial Intelligence (AI) and big data.

As a result of these efforts, 3GPP Release 15 specifications were completed in June 2018 and O-RAN fronthaul*8 specifications were completed in March 2019 thereby opening the door to development for 5G commercial services.

This article describes the activities involved in the formulation of 5G specifications and NTT DOCOMO's contributions to this effort.

2. Activities toward Early Formulation of 5G Specifications at 3GPP and Contributions

In the formulation of 5G specifications at 3GPP, studies on NR, the new radio access system, proceeded with the aim of standardizing specifications targeting use cases for achieving parts of eMBB and URLLC in Release 15 and standardizing remaining specifications including URLLC and mMTC in the next stage consisting of Release 16 and beyond. Here, it was decided to formulate specifications in a systematic manner through stepwise standardization of 5G that encompasses a wide array of requirements and use cases. For example, standardization activities would first tackle specifications

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

*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.

※1 Source: "Application trend of ETSI standard essential patent (5G-SEP) candidates contributing to realization of 5G and proposal trend of contributions for standards," Cyber Creative Institute Co. Ltd.

※2 Source: "Application trend of 5G-SEP candidates and 5G-SEP declarations contributing to realization of 5G and proposal trend of contributions for standards," Cyber Creative Institute Co. Ltd.

*5 Essential patent: A patent for which infringement cannot be avoided without a license when manufacturing a product conforming to a particular standard.

*6 Radio Access Network: The network situated between the core network and mobile terminals consisting of base stations and other equipment for controlling the radio layer.

for the case of combining and operating 4G base stations and the 4G core network with 5G base stations in a scheme called Non-Standalone operation and then take up all specifications in the next stage including Standalone operation that enables operation with only 5G base stations and the 5G core network.

NTT DOCOMO made major contributions not only to promoting 5G standardization overall but also to early formulation of 5G specifications. Specifically, while guaranteeing the standardization of Non-Standalone operation and Standalone operation in the same release (Release 15) by June 2018 as originally scheduled, NTT DOCOMO and 47 other companies jointly submitted to 3GPP a document stating that specifications for Non-Standalone operation would be completed by December 2017 thereby contributing to early formulation. This early completion of specifications helped to accelerate the worldwide deployment of commercial 5G.

3. Activities and Contributions in 3GPP TSG SA/CT

At 3GPP, TSGs carry out technical studies under the Project Coordination Group (PCG) that oversees all projects. These TSGs consist of three groups: TSG Service and System Aspects (SA), TSG Core Network and Terminals (CT), and TSG Radio Access Network (RAN). The first of these, TSG SA, studies use cases and derives system requirements, decides on architecture and derives requirements for individual functions, and decides on the flow of information between functional units and the operation of individual functions. It also prescribes specifications for each of the above items. TSG CT, meanwhile, prescribes protocols between terminals and the core network and between functional units within the core network plus detailed specifications for an external Application Programming Interface (API)*9 for third-party users and for a Universal Subscriber Identity Module (USIM)*10. Among its work in prescribing 5G specifications, NTT DOCOMO has held Vice Chairman posts in TSG CT and SA Working Group 3 (SA-WG3) and has contributed greatly to establishing overall policies on prescribing specifications, drawing up schedules, and promoting technical studies.

In prescribing 5G specifications, TSG SA/CT expanded functions for accommodating NR as a Non-Standalone system in EPC and studied 5GC as new core-network specifications. Thinking that a suitable amount of time would be needed to expand the 5G coverage area, NTT DOCOMO emphasized the launching of 5G services in a Non-Standalone system within SI studies for Release 14. However, at the beginning of these studies, it was the opinion of both vendors and mobile communications operators that studies on a new core network should be unified, so no approval for our proposal could be obtained. However, thanks to repeated explanations and progress in TSG RAN technical studies (described below), approval was gradually obtained, and later, priority was placed on drafting specifications for a Non-Standalone system as 5G at the RAN/SA #72 plenary meeting. Despite this

*7 White box: Hardware whose internal configuration and processing are open in contrast to black box hardware.

*8 Fronthaul: The circuit between radio equipment and the baseband processor of base-station equipment achieved by optical fiber, etc.

*9 API: An interface that enables a function provided by an enabler to be used by other equipment.

*10 USIM: An IC card used to store information for identifying a subscriber having a contract with a mobile phone company.

drawn-out chain of events, many operators around the world have since adopted this Non-Standalone system as the main network configuration in the initial period of 5G deployment.

In addition, specifications for a new core-network concept were established as 5GC for application to the 5G service rollout period.

NTT DOCOMO contributed to advancing specifications for both accommodating NR in EPC (Non-Standalone system) and for 5GC.

1) SA-WG1

SA-WG1, whose responsibilities are to study use cases and derive system requirements, studied only 5GC without relation to the Non-Standalone system. Here, NTT DOCOMO hypothesized that customer needs and desires would be varied with a long-tail*11 distribution that would require not a uniform network but rather a divided network (the network slice*12 concept), which it promoted. NTT DOCOMO also took up issues fundamental to operators and took the lead, in particular, in drawing up specifications for access control.

2) SA-WG2

SA-WG2 is responsible for determining architecture, deriving requirements for each functional unit, and deciding the flow of information between functional units and the operation of individual functions. This WG studied both the Non-Standalone system and 5GC.

Some European communications operators treated the Non-Standalone system as part of the flow toward higher LTE radio speeds. With this being the case, policies were established on operating this system without any changes to the core network so that many operators could deploy it and on inserting functions enabling advanced control for operators willing to make changes to the core network. Additionally, for individual technical items, policies were established on studies regarding encryption and Serving GateWay (S-GW)*13 selection in SA-WG3 and CT-WG described below.

In 5GC, several companies declared their candidacy for the position of Rapporteur*14 thereby delaying the drafting of the Work Item Description (WID), but NTT DOCOMO took on the role of Editor*15 at the request of WG members and got the WID completed. After that, NTT DOCOMO also contributed to studies on network slicing and EPC-5GC interoperability.

3) SA-WG3

SA-WG3 has the responsibility of making comprehensive studies on security issues from use cases to protocol. In this WG, studies were made on both of the systems described above. NTT DOCOMO served as Vice Chairman and led technical studies. In the Non-Standalone system, it was decided that security applied to the Secondary Radio Access Technology (Secondary RAT)*16 radio interval would operate by reading LTE security capabilities into NR security capabilities without having to make changes to the Mobility Management Entity (MME)*17. NTT DOCOMO led the drafting of specifications for this scheme. In 5GC studies, NTT DOCOMO served as Rapporteur of main specifications documents for 5GC overall and led improvements to encryption and authentication in the radio portion.

*11 Long tail: Here, a state in which a distribution appears to have a long tail when plotting the number of customers desiring each kind of service in descending order. In other words, a state having not a small demand for each of a variety of services.

*12 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.

*13 S-GW: The area packet gateway accommodating the 3GPP access system.

*14 Rapporteur: A position whose role includes managing progress, summarizing discussion, and editing technical reports that capture results of discussion for Work Items.

*15 Editor: The role of coordinating the drafting and revising of specifications.

*16 Secondary RAT: Radio access technologies such as NR, LTE, 3G, GSM, and Wi-Fi used by SN.

*17 MME: A logical node that accommodates a base station (eNodeB) and provides mobility management and other functions.

4) CT-WG1

CT-WG1 is responsible for specifying protocol in detail between terminals and the core network and of studying certain basic functions in terms of architecture. In relation to 5GC, NTT DOCOMO promoted the drafting of specifications for Earthquake and Tsunami Warning System (ETWS)*18, Steering Of Roaming (SOR)*19, and access control.

5) CT-WG4

CT-WG4 is responsible for specifying protocol in detail between functional units within the core network. In the Non-Standalone system, NTT DOCOMO promoted the drafting of specifications for a system to select an appropriate S-GW for accommodating high traffic.

4. Activities and Contributions in 3GPP TSG RAN

TSG RAN is responsible for the formulation of all specifications describing the radio access network. NTT DOCOMO led technical discussions in the WGs under TSG RAN and contributed greatly to the formulation of 5G RAN specifications by serving as TSG RAN Vice Chairman.

1) RAN-WG1

RAN-WG1, which carries out studies in relation to the radio interface on the physical layer*20, studied, in particular, radio access systems and multiple transmit/receive antenna technologies. For example, in NR, it defined Orthogonal Frequency Division Multiplexing (OFDM)*21 based on multiple subcarrier*22 intervals with the aim of supporting a variety of use cases and a wide frequency band from low-frequency bands used in existing cellular systems to high-frequency bands including the millimeter-wave frequency band.

Here, NTT DOCOMO made a number of technical proposals for band-expansion technology, antenna technology, and initial-stage access technology and made significant contributions to completing specifications by coordinating progress management and concerned individuals as Rapporteur for formulating 5G specifications, serving as RAN-WG1 Chairman, and taking leadership roles in various elemental technologies.

2) RAN-WG2

RAN-WG2, which has the responsibility of studying radio interface architecture and protocol, drafted a specification to enable NR communications to be carried on top of existing LTE communications through Dual Connectivity*23 between LTE and NR. This specification is based on the specification for LTE Dual Connectivity that was promoted by NTT DOCOMO as Rapporteur and standardized in Release 12. It enables high speeds and low latency by NR while making use of the existing LTE network by adopting a split bearer*24 [1] that terminates at a Secondary Node (SN)*25 proposed by NTT DOCOMO for 5G. NTT DOCOMO made significant contributions to completing specifications in RAN-WG2 to achieve diverse use cases and meet requirements for 5G. For example, given that functions and capabilities reported by a terminal to a base station and parameters set in a terminal by the base station can result in an enormous amount

*18 ETWS: A mechanism for delivering emergency information on the occurrence of an earthquake, tsunami, etc.

*19 SOR: A mechanism in which the Home-Public Land Mobile Network (HPLMN) of a certain terminal redirects that terminal currently registered in a certain Visited-Public Land Mobile Network (VPLMN) to another VPLMN.

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

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

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

*23 Dual Connectivity: 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.

of data, NTT DOCOMO led studies on Radio Resource Control (RRC)*26 messages for transferring such data.

3) RAN-WG3

RAN-WG3 is responsible for studying RAN architecture and interfaces. This WG extended the X2*27 interface between eNB*28 base stations and enabled eNB—gNB linkage to achieve Dual Connectivity between LTE and NR. Additionally, to enhance the flexibility of RAN rollout with improved performance and cost efficiency in mind, RAN-WG3 specified a F1 interface to enable a base station to be split into a Central Unit (CU), which terminates the Packet Data Convergence Protocol (PDCP)*29 sublayer and above, and Distributed Unit (DU), which terminates the Radio Link Control (RLC) sublayer and below. It also specified an E1 interface to enable CU to be split into a CU-Control Plane (CU-CP), which terminates the Control Plane*30, and CU-User Data Plane (CU-UP), which terminates the User Plane*31 [1].

Here, to enhance multi-vendor interoperability in these interfaces, NTT DOCOMO submitted many technical contributions by leveraging its experience in achieving multi-vendor capabilities in the commercial LTE network. It also contributed by serving as Moderator*32 to encourage discussions in this area and as Editor of specifications.

4) RAN-WG4

RAN-WG4 bears the responsibility of formulating specifications for base-station and terminal Radio Frequency (RF)*33 performance and Radio Resource Management*34. In addition to frequency bands below 6 GHz as used in LTE/LTE-Advanced, this WG studied the use of sub-millimeter wave*35 and millimeter wave*36 frequency bands introduced for NR (defined in Release 15 as Frequency Range 2 (FR2): 24,250 – 52,600 MHz frequency band). Serving a four-year term as Vice Chairman of RAN-WG4 from 2015, NTT DOCOMO actively submitted technical proposals and promoted discussions toward the formulation of frequency bands taking the 5G frequency allocation plan in Japan into account and toward the drafting of RF performance specifications for base stations, terminals, etc. The legal system surrounding 5G in Japan advanced in step with these specifications.

The use of FR2 heralds the coming of wideband communications, but it is not without its problems from the viewpoint of configuring a RF section. Specifically, it means an increase in power loss and signal propagation loss in the RF section due to high frequencies and a contraction of area coverage brought on by a drop in power density due to wideband communications. To solve these problems, coverage must be ensured by achieving high antenna gain*37 through an antenna array formation*38. However, it is difficult to implement a radio-signal transceiver and antennas at high density in a small space, so for FR2, a conventional RF configuration with connectors for measurement use*39 cannot be applied. For this reason, an Over The Air (OTA)*40 provision was introduced in the FR2 RF specification to enable testing of the RF configuration without connectors.

As shown in **Figure 1**, the OTA provision defines

---

*24 **Split bearer:** In Dual Connectivity, a bearer that is transmitted and received via both Master Node (MN) and Secondary Node (SN) base stations.

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

*26 **RRC:** A protocol for controlling radio resources in a radio network.

*27 **X2:** A reference point between eNodeB, defined by 3GPP.

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

*29 **PDCP:** As a sublayer of Layer 2, a protocol that performs ciphering, integrity check, reordering, header compression, etc.

*30 **Control Plane:** Control processes to transfer data, such as route control of data in use for communications.

*31 **User Plane:** The part of the signal sent and received in communication, which contains the data sent and received by the user.

*32 **Moderator:** Compiles e-mail discussions and reports them to the WG.

*33 **RF:** Referring to the radio frequency analog circuit.

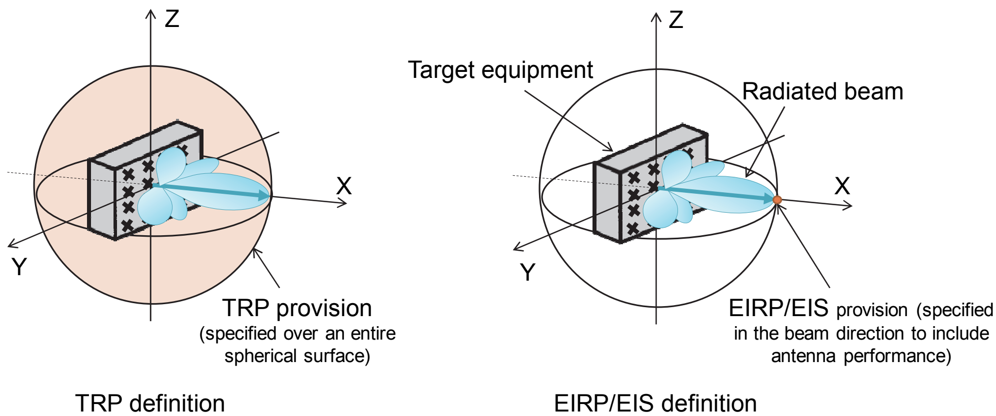


Figure 1 Definitions used in the RF specification of NR base stations and terminals

Total Radiated Power (TRP) emitted from the equipment targeted for measurement as well as Equivalent Isotropic Radiated Power (EIRP)*41 and Equivalent Isotropic Sensitivity (EIS)*42 in the beam direction that includes antenna characteristics.

Focusing on EIRP maximum transmission power in FR2 for a terminal, the adopted provision uses a cumulative distribution*43 of each EIRP value obtained when manipulating the beam direction over an entire spherical surface centered about the terminal (**Figure 2**). The purpose of introducing this provision was to statistically guarantee that the beam is correctly oriented in the intended direction (the direction of the base station performing communications) and within the necessary range. The value that must be minimally satisfied by at least one of the measured EIRP values is defined as the Min peak value and the value at X % of the cumulative distribution, that is, the value for which the $(100 - X)$% area in spherical surface space must be guaranteed, is defined as spherical coverage. Thinking that spherical coverage would be essential to ensuring FR2 area performance as an operator, NTT DOCOMO expanded discussions while

*34 Radio Resource Management: A generic term applied to control functions for appropriately managing limited radio resources, making smooth connections between terminals and base stations, etc.

*35 Sub-millimeter wave: Radio signals of frequencies in the millimeter wave range, from approximately 10 to 30 GHz.

*36 Millimeter wave: Radio signals of frequencies in the range from 30 GHz to 300 GHz.

*37 Antenna gain: Radiated power in the direction of maximum radiation usually expressed as the ratio of radiated power to that of an isotropic antenna.

*38 Antenna array formation: The integrated arranging and powering of multiple antennas.

*39 Conventional RF configuration with connectors for measurement use: In the formulation of base-station RF performance specifications, the OTA (see *40) provision has been partially introduced even in the conventional frequency band under 6 GHz.

*40 OTA: A method for measuring radio characteristics transmitted or received from a base station or terminal, by positioning it opposite to a measurement antenna. Configurations have been defined for NR base stations and terminals that have no antenna connectors, so this method has been established for regulating such devices.

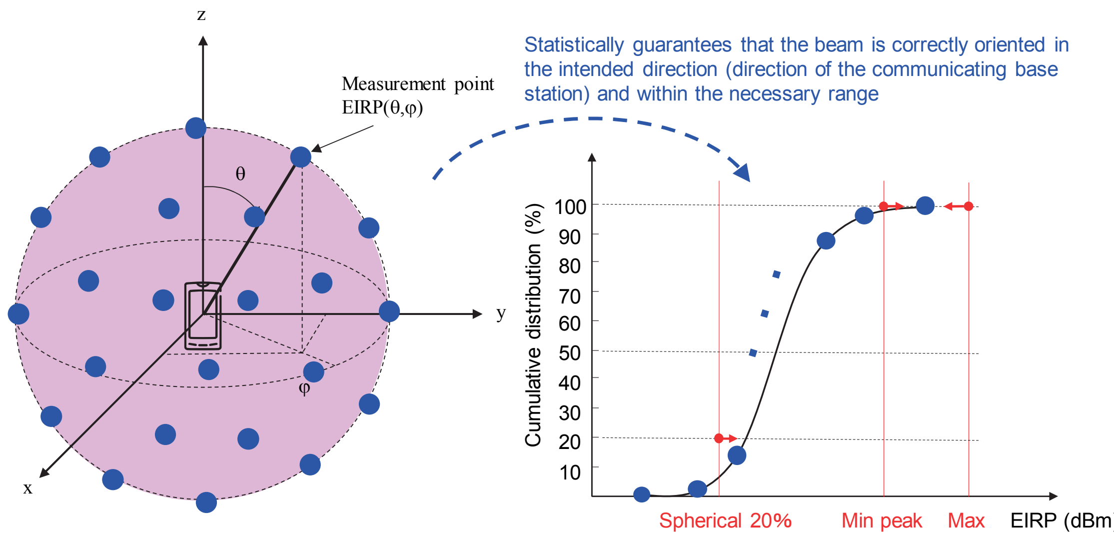


Figure 2 OTA EIRP evaluation technique using a cumulative distribution

gaining the approval of various operators that spherical coverage would preferentially become a high-performance provision among various types of provisions with technical feasibility considered.

5. Activities and Contributions in O-RAN

NTT DOCOMO joined up with AT&T, China Mobile, Deutsche Telekom, and Orange in February 2018 to launch the O-RAN Alliance with the aim of constructing a highly extendible, open, and intelligent RAN for the 5G era. Today, many operators and vendors are participating as members (about 200 subscribed members as of June 26, 2020) and a wide range of studies are being conducted in WGs in such areas as open interfaces to enable interoperability in RAN, virtualization, use of AI and big data, white box hardware, and open source software. Many specifications have already been released. As a result of these activities, the O-RAN Alliance has been attracting attention and generating many expectations.

Among these activities, many operators and

*41 EIRP: The transmission power at the reference point in radio radiation space.

*42 EIS: The received power at the radiated requirement reference point in radio reception space.

*43 Cumulative distribution: The probability that the property being evaluated will be at or below a particular value.

vendors have announced their intention to adopt O-RAN open fronthaul specifications released in March 2019 to facilitate multi-vendor interoperability in the fronthaul interface between the digital processing section (centrally located) and radio section (remotely located) of a base station that up to now has been vendor-specific on a global basis [2]. This declaration is expected to have a major impact on the industry and is attracting much attention as a result.

In actuality, NTT DOCOMO had already achieved an original multi-vendor RAN since the time of the LTE generation using a common fronthaul interface in cooperation with partner vendors. Making use of the know-how gained there, NTT DOCOMO served as SI Rapporteur for base-station functional split carried out for 3GPP Release 14/15 from March 2016 to December 2017. NTT DOCOMO also participated in the xRAN Forum*44 from February 2018 prior to its integration with the O-RAN Alliance and promoted the drafting of fronthaul specifications there in cooperation with approving operators and vendors. Now, as well, NTT DOCOMO is actively promoting fronthaul standardization such as by serving as a co-chair of WG4 that manages open fronthaul specifications. In addition, NTT DOCOMO has achieved multi-vendor interoperability using O-RAN open fronthaul specifications in a commercial 5G network as the world's first, and going forward, it seeks to achieve a global ecosystem*45 of multi-vendor RAN in 5G. Multi-vendor interoperability in RAN expands the portfolio of base-station solutions that can be used and enables quick, flexible, and cost-efficient network construction. These features will become all the more important in 5G having many and varied requirements.

At the O-RAN Alliance, NTT DOCOMO has also served as a co-chair of WG5 that studies the conversion of 3GPP interfaces such as X2 and F1 to open interfaces and contributed to the release of profile*46 specifications to ensure multi-vendor interoperability in those interfaces. From here on, NTT DOCOMO also plans to promote other O-RAN Alliance studies in such areas as virtualization and the use of AI and big data.

6. Conclusion

This article described activities and NTT DOCOMO contributions at 3GPP and the ORAN Alliance toward 5G standardization.

Today, at 3GPP, specifications for Release 16 toward advanced 5G have been completed and technical studies for Release 17 that aim to specify more usage scenarios are progressing. Meanwhile, at the O-RAN Alliance, in addition to further studies on open interfaces, technical studies on the virtualization of the radio network and use of big data are moving forward.

At NTT DOCOMO, we view 5G as the technical foundation for wireless communications over the next 20 years. To achieve further advances, we will continue making proactive contributions to standardization activities at 3GPP and the O-RAN Alliance.

---

*44 xRAN Forum: An industry organization that had been active in promoting highly extensible radio access networks. It is presently integrated with the O-RAN Alliance.

*45 Ecosystem: A system that can include multiple cooperating companies using each other's technologies and assets and consumers and society as well to create a system of flows from R&D through sales, advertising and consumption resulting in co-existence and co-prosperity.

*46 Profile: Refers to the method of using inter-equipment messages as defined by a standardization agreement to ensure interoperability between equipment according to the application.

REFERENCES

[1] T. Uchino, et al.: "Specifications of NR Higher Layer in 5G," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.62–78, Jan. 2019.

[2] NTT DOCOMO Press Release: "Mobile industry leaders to develop O-RAN fronthaul-compliant products and drive multi-vendor radio access networks," Feb. 2019. https://www.nttdocomo.co.jp/english/info/media_center/pr/2019/0222_00.html

Technology Reports (Special Articles) 5G/NR Sub-6/mmW Non-Standalone

Special Articles on 5G (1)—NTT DOCOMO 5G Initiatives for Solving Social Problems and Achieving Social Transformation—

5G Network

Radio Access Network Development Department Yuta Sagae[†1] Shinsuke Sawamukai
Yusuke Ohwatari Kohei Kiyoshima
Core Network Development Department Keiichi Kanbara[†2]
DOCOMO Technology Inc., Packet Network Division Jo Takahashi

NTT DOCOMO launched its 5G commercial service in March 2020 achieving early provision and stable quality by making maximum use of functions and coverage provided by LTE. This article describes the development of radio base-station equipment and core network equipment for providing the 5G commercial service.

1. Introduction

Featuring high speed and large capacity, low latency, and massive connectivity, the fifth-generation mobile communications system (5G) is generating high expectations. In addition to providing richer content as in video services, it is anticipated that 5G will help find solutions to social problems that have so far been difficult to resolve and create new industries at the same time.

After launching its 5G pre-commercial service in September 2019, NTT DOCOMO launched its 5G commercial service in March 2020. As of July 6, 2020, the number of 5G subscribers had already exceeded 170,000. The demand for 5G is expected to increase from here on, so the plan is to enhance

†1 Currently Corporate Strategy & Planning Department
†2 Currently DOCOMO CS, Inc., Solution Integration Department

the terminal lineup and expand 5G coverage in stages.

In this article, we describe the development of radio base-station equipment and core network*1 equipment to provide the 5G commercial service. We ask the reader to refer to an article in the previous issue for a technical overview of the 5G features of high speed and large capacity, low latency, and massive connectivity and a description of the 5G system configuration [1].

2. Overview of 5G Frequency Bands

In 5G, there is a need for a network that can accommodate a variety of use cases and usage scenarios. From a technical perspective, this means adopting new radio technology, that is, 5G New Radio (NR), and supplementing existing frequency bands with those of even higher frequencies [2]. Since a 5G technical overview has already been given in the last issue, we here present an overview of the frequency bands taken up in Japan's frequency allocation plans for 5G. We will also describe the technical features of each of these frequency bands.

Three frequency bands have been allocated in Japan for 5G: the 3.7 GHz band (3.6 – 4.1 GHz), 4.5 GHz band (4.5 – 4.6 GHz), and the 28 GHz band (27.0 – 29.5 GHz, among which the 28.2 – 29.1 GHz interval is unallocated) (**Table 1**). The first two frequency bands are called the "sub-6" bands and the third one is called the millimeter Wave (mmW) band*2.

The sub-6 bands each feature a 100 MHz bandwidth/operator within Japan's 5G frequencies. Compared with LTE, they enable wideband usage and can achieve the same coverage as the LTE 3.5 GHz band. The mmW band, meanwhile, is significantly different from the frequencies that have come to be used by LTE, and expectations are high for the spot-like rollout of services based on transmission speeds of several Gbps through ultra-wideband allocation. In general, however, the higher is the frequency the more difficult is wave propagation, so there will be a need to construct a heterogeneous network that combines the mmW band with existing LTE frequencies and the sub-6

Table 1 Features of Japan's 5G frequencies

	3.7 GHz band	4.5 GHz band	28 GHz band
Allocated frequencies	3.6 - 4.1 GHz (500 MHz bandwidth)	4.5 - 4.6 GHz (100 MHz bandwidth)	27.0 - 28.2 GHz 29.1 - 29.5 GHz (1.6 GHz bandwidth)
Allocated bandwidth	100 MHz bandwidth/operator	100 MHz bandwidth/operator	400 MHz bandwidth/operator
Use of Massive MIMO	Used in MIMO multiplexing		Coverage extension by beamforming
Use with other systems	Satellite systems	Airplane radar altimeter	Satellite systems
Overseas trends	China, Korea, Europe, United States	Planned for future use by China	United States, Korea

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

bands. In addition, antenna downsizing is simple in the case of high-frequency bands, so the rollout of networks using Massive Multiple Input Multiple Output (Massive MIMO)*3 as advanced MIMO technology is anticipated.

It must also be noted that existing systems are operating within Japan's 5G frequency bands, so coexistence and segregation are important. In particular, since satellite system operators are also using the 3.7 GHz band, this band will be rolled out for 5G while making inter-system interference adjustments with those satellite systems. As a consequence, the 4.5 GHz band has been attracting attention as a frequency band that could play an effective role in achieving an early 5G rollout (**Figure 1**). Additionally, looking at overseas trends, the use of the 3.7 GHz band and 28 GHz band has already begun in various countries, and from the perspective of future terminal support, roaming support, etc., these bands should be effective in rolling out high-speed and large-capacity services reflecting the unique features of 5G. The plan is to execute a commercial rollout that will make maximum use of the strengths of each of these frequency bands based on the features of those frequencies, coexistence with existing operators, and global trends.

As a result of approval received from the Ministry of Internal Affairs and Communications (MIC) for base-station installation plans [3], NTT DOCOMO has been allocated the frequency intervals 3.6 – 3.7 GHz and 4.5 – 4.6 GHz for a total of 200 MHz in the sub-6 bands and 27.4 – 27.8 GHz for a total of 400 MHz in the mmW band (**Figure 2**). In this way, NTT DOCOMO can provide a downlink peak rate of 3.4 Gbps in the sub-6 bands and of 4.1 Gbps in the mmW band in combination with the existing LTE system (**Table 2**).

The sub-6 bands and 28 GHz band have been allocated as Time Division Duplex (TDD)*4 bands, but from the viewpoint of spectrum efficiency, the same downlink/uplink resource allocation (TDD

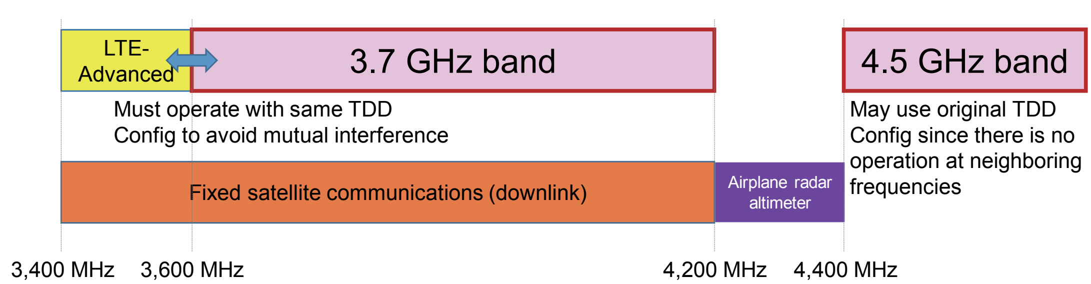


Figure 1 Frequency allocation in 3.7 GHz band and relationship with LTE 3.5 GHz band

---

*3 Massive MIMO: A generic term for MIMO transmission technologies using very large numbers of antennas. MIMO is a signal technology that improves communications quality and spectral efficiency by using multiple transmitter and receiver antennas to transmit signals at the same time and same frequency.

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

Config*5) must be used between neighboring cellular operators. In Japan, the TDD Config shown in **Figure 3** based on the TDD Config agreed upon at the 3rd Generation Partnership Project (3GPP) is being used for 5G operation taking data traffic and 5G service forecasts into account. In particular, to mitigate interference between the 3.7 GHz band and the neighboring LTE 3.5 GHz band, this TDD Config has been designed to use the same timing for downlink/uplink resources (Fig. 3). Additionally, in the 4.5 GHz band acquired solely by NTT DOCOMO, the plan is to establish an original TDD Config tailored to use cases with spectrum efficiency in mind.

3. 5G Commercial Development

3.1 5G Base-station Equipment Development

The 5G network configuration is shown in **Figure 4**. With a view to 5G service development, NTT DOCOMO developed a Central Unit (CU)*6 that consolidates the Base Band (BB)*7 signal processing section supporting 5G, extended existing BB processing equipment known as high-density Base station Digital processing Equipment (BDE)*8,

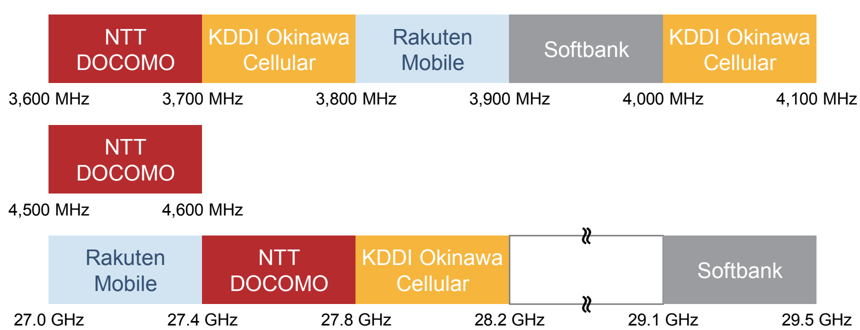


Figure 2 Allocation of 5G frequencies in Japan

Table 2 Technical features

	Sub-6 bands	mmW band
Method of using Massive MIMO	MIMO multiplexing	Coverage extension by beamforming
Coverage approach	Same coverage as LTE 3.5 GHz band	High throughput by wideband use Spot-like rollout
Peak rate (3GPP standard values including LTE)	Downlink 3.4 Gbps, uplink 182 Mbps	Downlink 4.1 Gbps, uplink 480 Mbps
Number of MIMO layers	Downlink 4×4, uplink SISO	Downlink/uplink 2×2 MIMO
Modulation scheme	Downlink 256QAM, uplink 64QAM	Downlink/uplink 64QAM

*5 TDD Config: Parameters determining how to allot uplink and downlink slots. Prescribed by 3GPP specifications.

*6 CU: The digital signal processing section for radio-base-station equipment in the 5G system equipped with a baseband processing section and maintenance/monitoring functions.

*7 BB: The circuit or functional block that performs digital signal processing.

*8 BDE: Digital signal processing equipment for base stations in the LTE system, equipped with a baseband processing section and maintenance/monitoring functions.

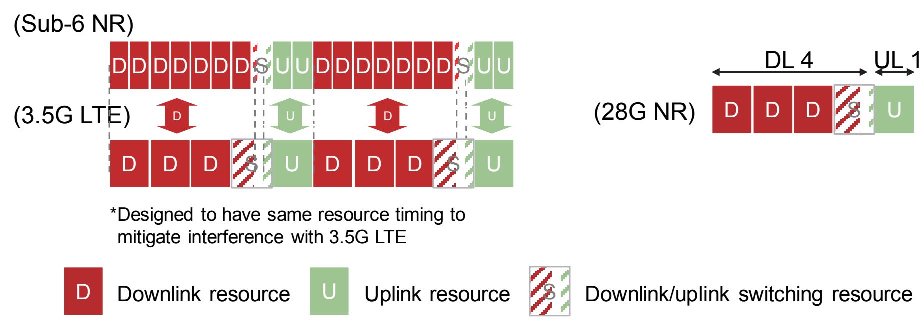


Figure 3　TDD Config used in Japan's 5G frequencies

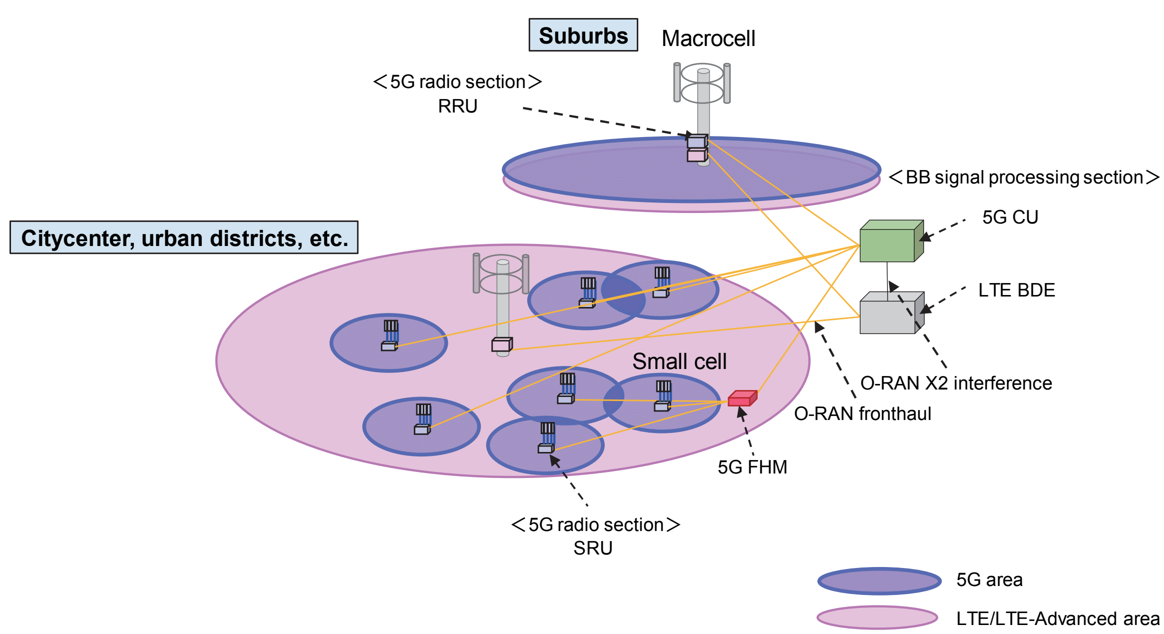


Figure 4　5G network configuration

and developed a 5G Radio Unit (RU)*9 having signal transmit/receive functions. Furthermore, to have a single CU accommodate many RUs, NTT DOCOMO developed a 5G version of the FrontHaul Multiplexer (FHM)*10 [4] deployed in LTE. Each of these three types of equipment is described below.

1) CU

(a) Development concept

With the aim of achieving a smooth rollout of 5G services, NTT DOCOMO developed a

*9　RU: Radio equipment that connects to the baseband processing section via the fronthaul. It also performs the processing required for beamforming in Massive MIMO operation.

*10　FHM: Equipment that multiplexes multiple fronthaul lines between the baseband processing section and radio equipment.

CU that enables area construction without having to replace existing equipment while minimizing the construction period and facility investment. This was accomplished by making maximum use of the existing high-density BDE that performs BB signal processing, replacing some of the cards of the high-density BDE, and upgrading the software to support 5G.

(b) CU basic specifications

An external view of this CU is shown in **Photo 1**. This equipment has the features described below (**Table 3**).

As described above, this equipment enables 5G-supporting functions by replacing some of the cards of the existing high-density BDE. In addition, future software upgrades will load both software supporting conventional 3G/LTE/LTE-Advanced and software supporting 5G. This will enable the construction of a network supporting three generations of mobile communications from 3G to 5G with a single CU.

The existing LTE-Advanced system employs advanced Centralized RAN (C-RAN)*11 architecture [5] proposed by NTT DOCOMO. This architecture is also supported in 5G with the connection between CU and RUs made via the fronthaul. Standardization of this fronthaul was promoted at the Open RAN (O-RAN) Alliance jointly established in February 2018 by five operators including

Photo 1　CU external view

Table 3　CU basic specifications

	3.7/4.5 GHz bands	28 GHz band
Supported system	5G	
No. of cells	6 cells or more	
Downlink max. communication speed (per cell)	3.4 Gbps or greater*	4.1 Gbps or greater*
No. of accommodated users (per cell)	1,500	
Power consumption	4 kW or less	

*Future support planned

*11 Advanced C-RAN: A new Centralized Radio Access Network (C-RAN) architecture proposed by NTT DOCOMO. Being controlled by the same base station, a radio access network makes a linkage between a macrocell (which covers a wide area) and a small cell (which covers a local area) by applying carrier aggregation.

NTT DOCOMO. Since the launch of 5G services, the fronthaul in the NTT DOCOMO network was made to conform to these O-RAN fronthaul specifications that enable interoperability between different vendors, and any CU and RU that conform to these specifications can be interconnected regardless of vendor. The specifications for interconnecting base-station equipment also conform to these O-RAN specifications, which means that a multi-vendor connection can be made between a CU supporting 5G and a high-density BDE supporting LTE-Advanced [6]. This enables NTT DOCOMO to deploy a CU regardless of the vendor of the existing high-density BDE and to quickly and flexibly roll out service areas where needed while making best use of existing assets. In addition, six or more fronthaul connections can be made per CU and the destination RU of each fronthaul connection can be selected. Since 5G supports wideband transmission beyond that of LTE-Advanced, the fronthaul transmission rate has been extended from the existing peak rate of 9.8 Gbps to a peak rate of 25 Gbps while achieving a CU/RU optical distance equivalent to that of the existing high-density BDE.

2) RU

(a) Development concept

To facilitate flexible area construction right from the launch of 5G services, NTT DOCOMO developed the low-power Small Radio Unit (SRU) as the RU for small cells and developed, in particular, separate SRUs for each of the 3.7 GHz, 4.5 GHz, and 28 GHz frequency bands provided at the launch of the 5G pre-commercial service in September 2019. Furthermore, with an eye to early expansion of the 5G service area, NTT DOCOMO developed the Regular power Radio Unit (RRU) as the RU for macrocells to enable the efficient creation of service areas in suburbs and elsewhere.

A key 5G function is beamforming*12 that aims to reduce interference with other cells and thereby improve the user's quality of experience. To support this function, NTT DOCOMO developed a unit that integrates the antenna and 5G radio section (antenna-integrated RU). It also developed a unit that separates the antenna and 5G radio section (antenna-separated RU) to enable an RU to be placed alongside existing 3G/LTE/LTE-Advanced Radio Equipment (RE)*13 and facilitate flexible installation even for locations with limited space or other constraints.

(b) SRU basic specifications

As described above, NTT DOCOMO developed the SRU to enable flexible construction of 5G service areas. It developed, in particular, antenna-integrated SRUs to support each of the 3.7 GHz, 4.5 GHz, and 28 GHz frequency bands provided at the launch of the 5G pre-commercial service and antenna-separated SRUs to support each of the 3.7 GHz and 4.5 GHz frequency bands (**Photo 2**). These two types of SRUs have the following features (**Table 4**).

The antenna-integrated RU is equipped with an antenna panel to implement the

---

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

*13 RE: The equipment that connects with the baseband processor via the fronthaul.

(a) Antenna-integrated SRU (b) Antenna-separated SRU

Photo 2 SRU external views

Table 4 SRU basic specifications

	Antenna-integrated SRU			Antenna-separated SRU	
Frequency band	3.7 GHz band	4.5 GHz band	28 GHz band	3.7 GHz band	4.5 GHz band
Maximum transmission power	–	–	–	2.76 W/100 MHz/branch	4.58 W/100 MHz/branch
Max. EIRP	19.5 W/100 MHz/branch	32.4 W/100 MHz/branch	2.09 W/100 MHz/branch	–	–
Number of branches	4		2	4	
Volume	7ℓ or less			6.5ℓ or less	
Equipment weight	7 kg or less			8 kg or less	
Power consumption	400 W or less				
Power supply	AC 100 V/200 V				

beamforming function. In the 3.7 GHz and 4.5 GHz bands, specifications call for a maximum of 8 beams, and in the 28 GHz band, for a maximum of 64 beams. An area may be formed with the number of transmit/receive beams tailored to the TDD Config used by NTT DOCOMO. In addition, the number of transmit/receive branches is 4 for the 3.7 GHz and 4.5 GHz bands and 2 for the 28 GHz band, and MIMO transmission/reception can be performed with a maximum of 4 layers*14 for the former bands and a maximum of 2 layers for the latter band.

The antenna-separated SRU is configured

*14 Layer: In MIMO, each layer corresponds to a stream—multiple streams may be simultaneously transmitted.

with only the radio as in conventional RE to save space and facilitate installation. With this type of SRU, the antenna may be installed at a different location. Moreover, compared to the antenna-integrated SRU operating in the same frequency band, the antenna-separated SRU reduces equipment volume to 6.5 ℓ or less. The antenna-separated SRU does not support the beamforming function, but features four transmit/receive branches the same as the antenna-integrated SRU for the same frequency band.

(c) RRU basic specifications

The RRU was developed in conjunction with the 5G service rollout as high-power equipment compared with the SRU with a view to early expansion of the 5G service area (**Photo 3**). This type of equipment has the following features (**Table 5**).

Compared with existing Remote Radio Equipment (RRE)*15 for macrocells, the volume of RRU equipment tends to be larger to support 5G broadband, but in view of the latest electronic device trends, NTT DOCOMO

Photo 3　RRU external view

Table 5　RRU basic specifications

	Antenna-separated RRU
Frequency band	3.7 GHz band
Maximum transmission power	36.3 W/100 MHz/branch
Number of branches	4
Volume	18 ℓ or less
Equipment weight	16 kg or less
Power consumption	1 kW or less
Power supply	DC −48 V

*15 RRE: Base-station radio equipment installed at a location somewhat distant from the base station using optical fiber or other means.

took the lead in developing and deploying an antenna-separated RRU that could save space and reduce weight. Maximum transmission power is 36.3 W/100 MHz/branch*16 taking the radius of a macrocell area into account. The RRU features four transmit/receive branches and achieves the same number of MIMO transmission/reception layers as the antenna-separated SRU.

NTT DOCOMO also plans to deploy an antenna-integrated RRU at a later date. The plan here is to construct 5G service areas in a flexible manner making best use of each of these models while taking installation location and other factors into account.

3) 5G FHM

The 5G FHM is equipment having a multiplexing function for splitting and combining a maximum of 12 radio signals on the fronthaul. It was developed in conjunction with the 5G service rollout the same as RRU (**Photo 4**).

If no 5G FHM is being used, each RU is accommodated as one cell, but when using a 5G FHM, a maximum of 12 RUs can be accommodated as one cell in a CU. At the launch of 5G services, this meant that more RUs could be accommodated in a single CU when forming a service area in a location having low required radio capacity (**Figure 5**). Additionally, since all RUs transmit and receive radio signals of the same cell, the 5G FHM can inhibit in-

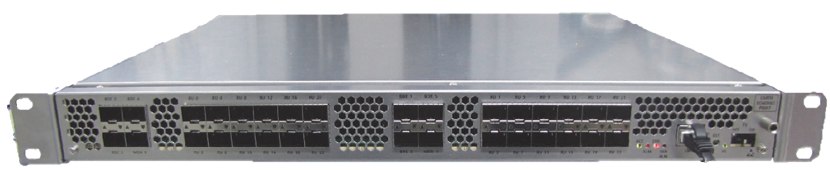


Photo 4 5G-FHM external view

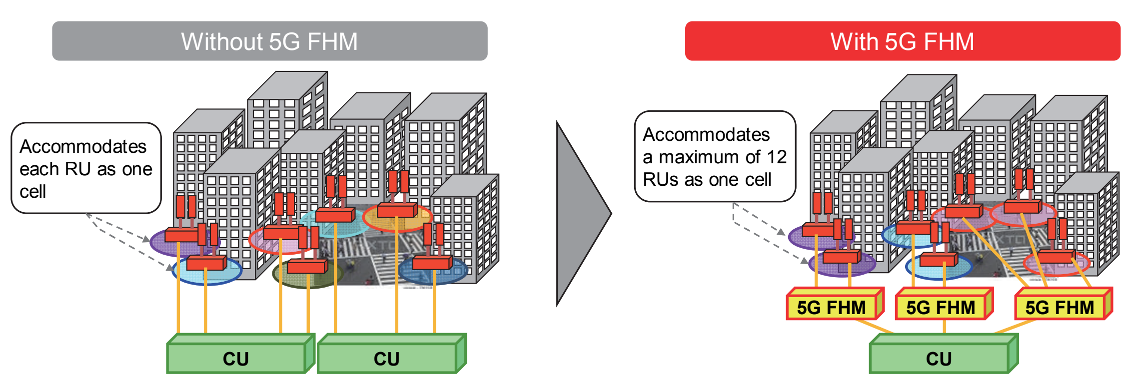


Figure 5 Concept of 5G FHM implementation

*16 **Branch:** In this article, an antenna and RF transceiver.

ter-RU interference and the occurrence of Hand-Over (HO)*17 control between RUs as in the conventional FHM. Furthermore, the 5G FHM supports all of the 5G frequency bands, that is, the 3.7 GHz, 4.5 GHz, and 28 GHz bands, which means that service areas can be constructed in a flexible manner applying each of these frequency bands as needed.

3.2 5G Radio Access Network Support

This section presents an overview of the RAN configuration for achieving 5G services and LTE-NR Dual Connectivity*18, beam management technology, and NR high-speed support as radio access network*19 technologies.

1) RAN Configuration

At the launch of its 5G commercial service, NTT DOCOMO provided services through non-standalone operation, a key feature of NR. Here, "non-standalone" means an operation format that provides services while using LTE/LTE-Advanced areas as an anchor*20 instead of providing 5G areas by NR alone. As shown in **Figure 6**, evolved NodeB (eNB)*21 in NR non-standalone operation connects to a gNB*22 base station that provides NR using an X2*23 interface. In addition, eNB and gNB connect to the Evolved Packet Core (EPC)*24 using S1 interfaces. The use of LTE as an anchor in this way through non-standalone operation made for early commercialization of 5G by enabling the use of existing network infrastructure through shared use of LTE equipment while maintaining the same level of quality with respect to connectivity that had so far been provided. In addition, the connection between eNB and gNB conforms to the O-RAN X2 specifications spearheaded by NTT DOCOMO thereby enabling interoperability between different LTE

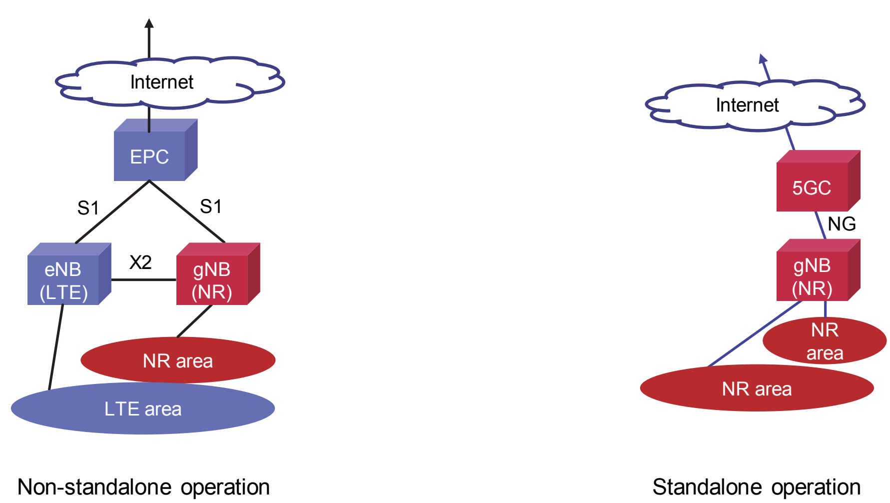


Figure 6 Network configuration in 5G

*17 HO: A technology for switching base stations without interrupting communications when a terminal with a call in progress straddles two base stations while moving.

*18 Dual Connectivity: 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.

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

*20 Anchor: A logical node point acting as a switching point for control signals and user bearers.

and NR operators. In short, non-standalone operation made it possible to roll out 5G areas in a speedy and flexible manner against LTE areas that had already been established.

In contrast, NR standalone operation, whose provision is scheduled for the future, will enable the provision of services through only gNB base stations. In this format, RAN will connect to the new core network, namely, the 5G Core network (5GC), and gNB base stations will connect to each other using an Xn interface and a gNB will connect to 5GC using an NG interface.

2) LTE-NR Dual Connectivity

In the non-standalone configuration described above that combines LTE/LTE-Advanced and NR to provide services, architecture that simultaneously transmits radio signals to the User Equipment (UE) by both LTE and NR is called LTE-NR Dual Connectivity (**Figure 7**). In this architecture, the simultaneous transmission of both LTE and NR types of radio resource*25 is specified as a split bearer*26, which achieves simultaneous transmission of a maximum of five LTE carrier*27 signals and NR and enables a speedy and flexible rollout of 5G commercial services.

In LTE-NR Dual Connectivity operation in which an LTE base station acts as Master Node (MN)*28, Master Cell Group (MCG) split bearer would have to be performed on the LTE base-station side as the bandwidth on the NR side becomes larger. It would therefore be necessary to augment the equipment on the LTE-base-station side whose capacity is limited compared with NR equipment thereby incurring equipment development and operation costs. Consequently, with the aim of minimizing the upgrading of LTE-base-station equipment and avoiding throughput limitations due to the capacity of that equipment, a Secondary Node (SN)*29 -terminated split bearer and an SN-terminated MCG bearer were specified so that a branch point for user data in LTE-NR Dual Connectivity could be set up as NR equipment acting as a SN (**Figure 8**). The

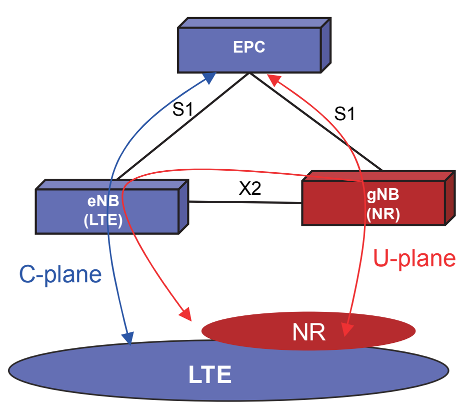


Figure 7 Concept of LTE-NR Dual Connectivity

---

*21 **eNB**: A radio base station for LTE radio access.

*22 **gNB**: A radio base station for NR radio access.

*23 **X2**: A reference point between eNodeB, defined by 3GPP.

*24 **EPC**: The core network on 3GPP mobile communication networks, mainly accommodating Evolved Universal Terrestrial Radio Access (E-UTRA).

*25 **Radio resource**: General term for resources needed to allocate radio channels (frequencies).

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

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

Secondary Cell Group (SCG) split bearer is a method in which user data is transferred on both the MN carrier and SN carrier so that data can be transmitted to the user simultaneously from the SN and MN. This method achieves higher transmission speeds. In addition, the SN-terminated MCG bearer is a method that enables data to be transferred from the SN even if outside the NR area, which makes for more stable communications.

3) Beam Management Technology

New beam management technology has been adopted in the NR system. As described above, the antenna-integrated RU has a configuration enabling the forming of multiple beams (**Figure 9**).

Specifically, in Frequency Range 1 (FR1)*30, this technology uses digital beamforming that forms

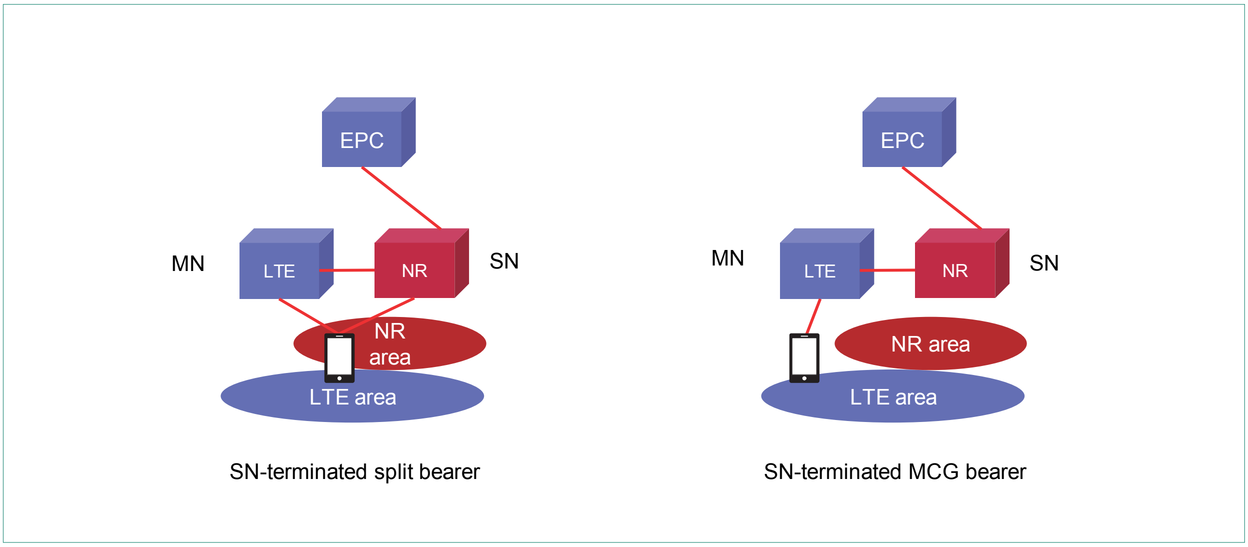


Figure 8　SN-terminated split bearer and SN-terminated MCG bearer

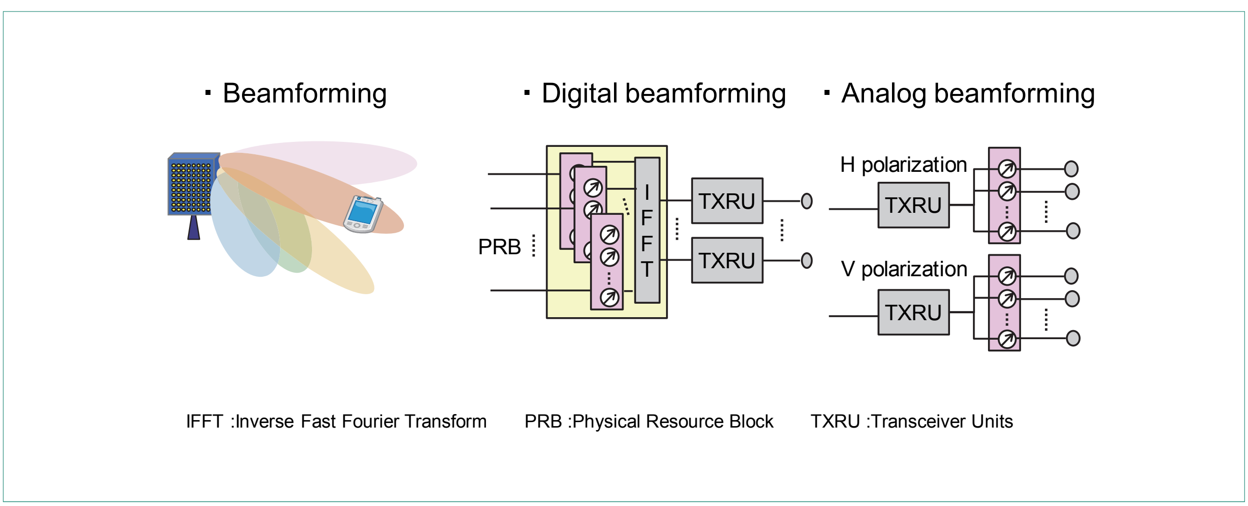


Figure 9　Types of beamforming technologies

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

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

*30 FR1: A frequency band specified in 3GPP ranging from 450 to 6,000 MHz.

beams by applying phase rotation to the BB signal, and in Frequency Range 2 (FR2)*31, it uses analog beamforming that forms beams by controlling the phase in the Radio Frequency (RF) signal*32. The technology includes processing for selecting an optimal beam when beginning an NR connection and processing for switching beams due to a change in radio quality caused by UE movement or other factors. Using an optimal transmit/receive beam according to the position of the communicating UE ensures user coverage even in a high frequency band. At the same time, it can be expected that orienting the beam toward the position of the UE will have the effect of inhibiting radio-wave radiation in unnecessary directions and suppressing inter-cell interference.

4) NR High-speed Support

In 5G, even higher communications speeds can be achieved since Dual Connectivity allows NR to be simultaneously used with LTE/LTE-Advanced. Currently, in LTE/LTE-Advanced, NTT DOCOMO provides services with a downlink peak rate of 1.7 Gbps by combining five instances of a component carrier*33 through carrier aggregation*34. However, in NTT DOCOMO 5G, Dual Connectivity of five LTE/LTE-Advanced component carriers and NR was achieved from the launch of 5G services enabling a downlink peak rate of 3.4 Gbps when using either the 3.7 GHz or 4.5 GHz NR band and a downlink peak rate of 4.1 Gbps when using the 28 GHz NR band.

Furthermore, in uplink communications in the 28 GHz band, in addition to the simultaneous use of two component carriers for a total bandwidth of 200 MHz through carrier aggregation, a total data rate of 480 Mbps has been achieved through the implementation of 2 × 2 MIMO.

The goal going forward is to increase data rates even further through the use of even wider frequency bands. In downlink communications, for example, this will be achieved through carrier aggregation between the 3.7 GHz and 4.5 GHz bands, and in uplink communications, through the carrier aggregation of four component carriers for a total bandwidth of 400 MHz in the 28 GHz band.

3.3 Development of Core Network Equipment

Multiple migration architectures toward the provision of 5G have been proposed at 3GPP, an international standards organization. **Figure 10** shows those architectures that have been specified at 3GPP. Option 1 is the architecture under which LTE has been provided. Options 2 – 5 and 7 are architectures for providing 5G, and each operator may decide which option(s) to adopt. As described above, NTT DOCOMO decided to launch 5G by adopting Option 3 architecture that connects to NR and provides 5G by extending EPC that had been in commercial operation for LTE. This approach made it possible to achieve early provision of the 5G commercial service while ensuring a stable level of quality provided by LTE/LTE-Advanced that was already in place. Many operators around the world adopted Option 3 at the time of their 5G launches.

NTT DOCOMO will continue its studies toward future means of migration including the introduction of 5GC, the new core network.

1) Option 3x Architecture

As described above, user data is transferred by a SCG split bearer process to keep equipment development and operation costs down. In other

*31 FR2: A frequency band specified in 3GPP ranging from 24,250 to 52,600 MHz.

*32 RF signal: A radio-frequency band signal.

*33 Component carrier: A carrier treated as a single frequency block having a maximum bandwidth of 20 MHz in LTE and a maximum bandwidth of 100 MHz and 400 MHz in FR1 and FR2, respectively, in NR.

*34 Carrier aggregation: A technology for increasing bandwidth by simultaneously transmitting/receiving signals over multiple component carriers.

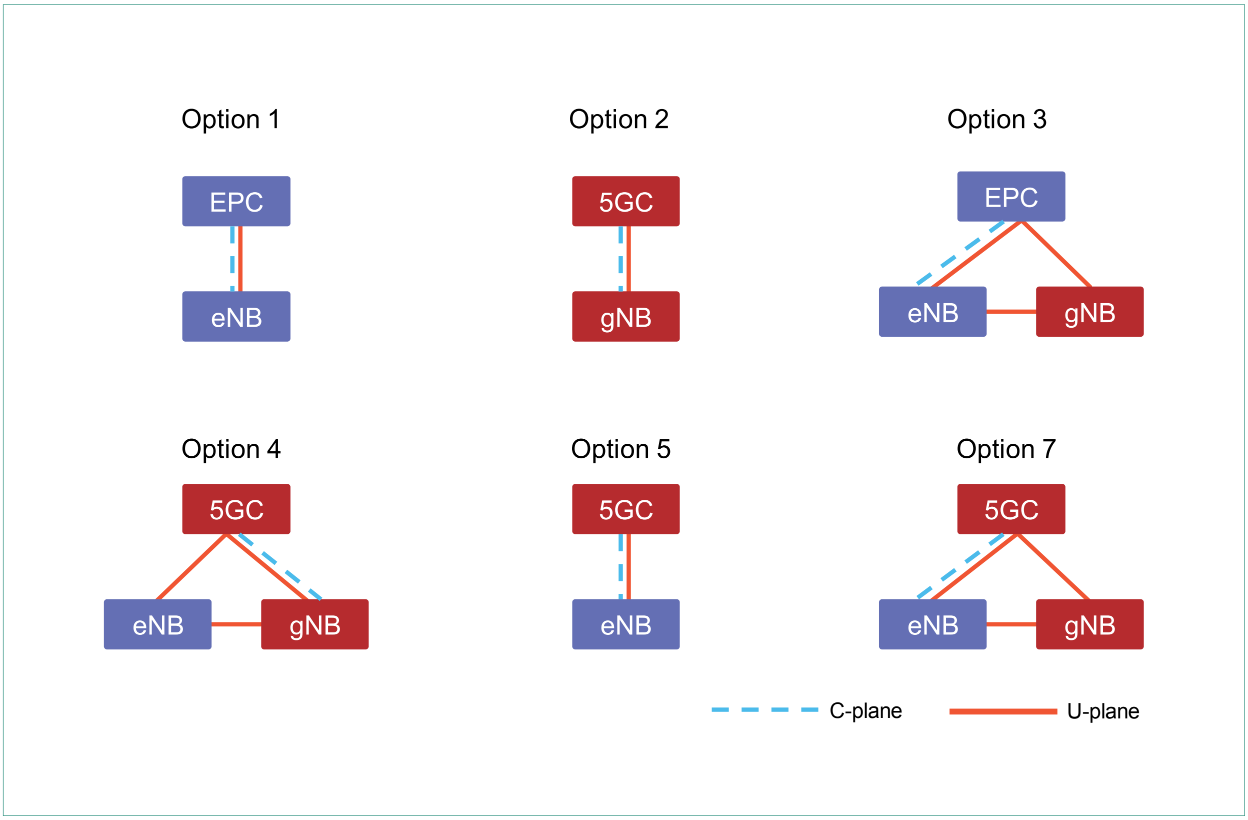


Figure 10　Migration architectures toward 5G

words, control signals are exchanged between EPC and eNB while user data is exchanged between EPC and gNB. This architecture has been specified in the standard as Option 3x.

Option 3x architecture is shown in **Figure 11**. The main feature of this architecture is that it enables NR to be accommodated by extending the S1 interface with eNB and the Non-Access Stratum (NAS)*35 interface with UE, which eases the impact on core network equipment and achieves both stable quality and early deployment.

2)　High-throughput Support

At present, the 5G commercial service provides a maximum downlink throughput of 4.1 Gbps. NTT DOCOMO intends to continue its development efforts toward even higher data rates and larger capacities. However, EPC consists of various types of equipment of diverse levels of performance, and there are some types of equipment that cannot easily provide the throughput required by 5G. With this in mind, and considering that a Serving Gateway/PDN Gateway (S/P-GW)*36 for performing data-transfer processing within EPC needs to be selected, NTT DOCOMO has developed a mechanism for selecting an S/P-GW that can provide 5G throughput.

In more detail, the existing method for selecting an S/P-GW via a Mobility Management Entity (MME)*37 is to use Tracking Area (TA)*38 and Access Point Name (APN)*39 as keys to query the Domain Name System (DNS)*40 and to then select

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

*36　S/P-GW: An S-GW is an area packet gateway accommodating the 3GPP access system. A P-GW is a gateway acting as a point of connection with the Packet Data Network (PDN), allocating IP addresses and transferring packets to the S-GW.

*37　MME: A logical node that accommodates a base station (eNB) and provides mobility management and other functions.

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

*39　APN: An address name set as the connection destination when performing data communications through a network connection.

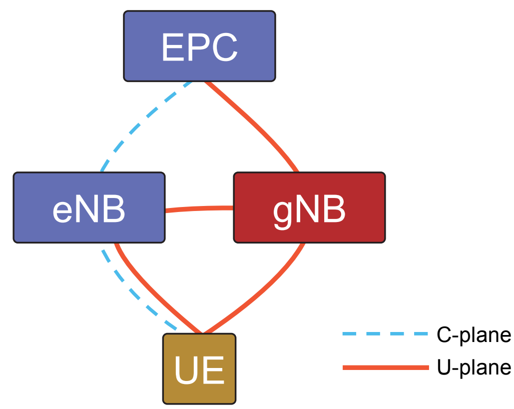


Figure 11 Option 3x architecture

an S/P-GW from the record included in the response. To this method, NTT DOCOMO added a value (+nc-nr) indicating 5G capability to the service parameters (network capability) included in the DNS response. For the 5G user, using this value as a basis for selecting an S/P-GW that can provide 5G throughput achieves high-speed communications.

3) Low-latency Network

NTT DOCOMO began the provision of its docomo Open Innovation Cloud simultaneously with the launch of its 5G commercial service. The docomo Open Innovation Cloud provides a form of Multi-access Edge Computing (MEC)*41. It enables end-to-end communications latency to be shortened by deploying computing resources normally included in the core network at locations near user terminals. It also provides NTT DOCOMO's "Cloud Direct™" service that shortens network transmission latency by optimizing the transmission path between the connected terminal and the cloud platform.

The plan is to provide a service overview and other information on the docomo Open Innovation Cloud as special articles in future issues.

4. Conclusion

This article described the development of radio base-station equipment and core network equipment at NTT DOCOMO to provide a 5G commercial service

Going forward, NTT DOCOMO will pursue co-creation opportunities through 5G with a variety of partners to contribute to the creation of a prosperous society while continuing to develop groundbreaking and advanced technologies.

REFERENCES

[1] Y. Kojo et al.: "Overview of 5G Commercial Service," NTT DOCOMO Technical Journal, Vol.22, No.1, pp.4–9, Jul. 2020.

*40 DNS: A system that associates host names and IP addresses on IP networks.

*41 MEC: A system that installs servers at locations near users. Standard servers are typically placed on the Internet, but MEC servers are installed within the carrier network to reduce latency. This scheme greatly improves response speeds.

[2] Ministry of Internal Affairs and Communications (MIC): "Information and Communications Council, Information and Communication Technology Subcommittee, New Generation Mobile Communication Systems Committee Report (July 31, 2018)," Jul. 2018 (In Japanese). https://www.soumu.go.jp/main_content/000567504.pdf

[3] Ministry of Internal Affairs and Communications (MIC): "Approval to Applications for Authorization of Establishment Plans on Specified Base Stations for Spreading 5G Mobile Communications Systems," Apr. 2019 https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2019_04_10_01.html

[4] M. Fujii et al.: "Base-station Equipment with the Aim of Introducing 3.5-GHz band TD-LTE," NTT DOCOMO Technical Journal, Vol.18, No.2, pp.8–13, Oct. 2016.

[5] T. Yoshihara et al.: "Radio Equipment and Antennas for Advanced C-RAN Architecture," NTT DOCOMO Technical Journal, Vol.17, No.2, pp.19–24, Oct. 2015.

[6] NTT DOCOMO Press Release: "DOCOMO to Commence Deployment of World's First 4G/5G Multi-vendor Radio Access Network Conforming to O-RAN Specifications," Sep. 2019. https://www.nttdocomo.co.jp/english/info/media_center/pr/2019/0918_00.html

Technology Reports (Special Articles) LIME Explanation Models Health Management

Special Articles on Lifestyle-enriching AI Technology

Health Risk Prediction from Health Examination Data

Service Innovation Department Taku Ito Keiichi Ochiai†1
Yusuke Fukazawa†2

From a management perspective, the idea of employee health management has become more important in recent years, to improve productivity and maintain the workforce. Promoting the health of employees is related to increasing productivity and value in an enterprise. Health risk predictions using machine learning are being implemented as a health management measure, but the learning models are black boxes, and reasons for the resulting predictions cannot be given, so it is desirable to provide convincing explanations to users. As such, NTT DOCOMO has developed models that predict health risks and can provide appropriate explanations, and a service that can make lifestyle-habit recommendations that will reduce the risk based on the predictions. The objective of the system is to raise user awareness of the relationship between bodily health and daily activity, using prediction results and convincing explanations, and to promote health by prompting changes in behavior. Users' health risks are visualized using health examination data, and we expect that promoting health will contribute to health management.

1. Introduction

In recent years, the idea of health management has increasingly been emphasized, promoting employee health from a management perspective with the objective of improving productivity and preserving the labor force. There are many initiatives to increase awareness of health, by applying

†1 Currently CrossTec Development Dept.
†2 Currently General Affairs Dept.

machine learning*1 to the results of health examinations and lifestyle habit interviews and then giving feedback on health risk predictions to the subjects. To improve awareness, employees must understand the results of prediction, so machine learning methods able to output results in a form that facilitates understanding of the reasons are needed, so that subjects can reexamine their lifestyle habits. However, most machine learning prediction models are black boxes, so it is difficult to give clear reasons that a particular health risk was predicted. There are simple models such as linear regression*2 that can be applied to prediction models to obtain explanations. These prediction and explanation models are integrated, so there is a trade-off between accuracy of prediction and simplicity of the explanation. The Explainable AI (XAI) concept has emerged to resolve this issue. One XAI method is called Local Interpretable Model-agnostic Explanations (LIME) [1], and involves prediction models and interpretation models that are trained separately.

NTT DOCOMO has used LIME to develop a health risk prediction model for employees and a service that provides lifestyle habit recommendations to reduce risk, based on the predictions. We proposed customizations to LIME to make recommendations better suited to the predictions, relative to the original version of LIME, and introduced them into the service. This article describes the proposed method as well as lifestyle habit recommendations made using the method.

2. Explainable Health Risk Prediction and Lifestyle Recommendation Technology

The proposed method for explainable health risk prediction takes the results of health examinations and lifestyle-habit interviews for a given year as input, and outputs the risk of high blood pressure and metabolic syndrome*3 N years in the future, along with the health examination items that contribute to that risk. The risk prediction method, and the explanation model used for computing the examination items that contribute to the risk are described below. We discuss explanation models including the original version of LIME and a version of LIME improved to increase the consistency of explanations, which we call consistency-emphasizing LIME.

2.1 Health Risk Prediction Algorithm

We used the eXtreme Gradient Boosting (XGBoost)*4 method for predicting health risk. We used health examination data from NTT DOCOMO employees, for whom examinations were conducted for at least four years in a row. It consists of N years of 11 examination items and 13 lifestyle-habit items as explanatory variables. We conducted training with this data to build 33 types of model to predict risk that values for each of the 11 examination items would become dangerous or not, in the three years, N+1, N+2, and N+3. Here, we used special health guidance values set by the Ministry of Health, Labour and Welfare (as of Mar. 30, 2020) as the standard to define "dangerous" values. Definitions for dangerous values are given in **Table 1**. When using Area under the ROC Curve (AuC)*5 to compare with a prediction model that simply uses the value from the previous year, predictions due to XGBoost showed improvements of from 7 to 16% in AUC.

---

*1 Machine learning: Technology that enables computers to acquire knowledge, decision criteria, behaviors, etc. from data, in ways similar to how humans acquire them, from perception and experience.

*2 Linear regression: Regression in which the relationship between the objective variable and the explanatory variable factors is linear.

*3 Metabolic syndrome: A state characterized by visceral fat obesity combined with at least two of the conditions of hypertension, hyperglycemia, and hyperlipidemia.

*4 XGBoost: A type of ensemble learning that has been attracting attention in recent years.

Table 1 Defined dangerous values for each test item

Test item	Defined dangerous values
BMI	25 or greater
Diastolic blood pressure	85 or greater
Systolic blood pressure	130 or greater
Neutral fats	149 or greater
GOT	35 or greater
GPT	35 or greater
HDL cholesterol	40 or less
LDL cholesterol	140 or greater
γ-GTP	50 or greater
Uric acid	7 or greater
Fasting blood sugar	100 or greater

2.2 Explanation Method for Health Risk Prediction Using LIME

Here we describe LIME, which provides explanations for the XGBoost prediction model. An overview of LIME is shown in **Figure 1**. With LIME, the prediction model and explanation model are trained independently. Since any algorithm can be used for the prediction model, an optimized algorithm can be used to achieve accurate results. However, as in Fig. 1, when a non-linear model*6 like XGBoost is used, for example, to predict risk of dangerous Body Mass Index (BMI) values one year later due to behaviors X and Y, it is difficult to interpret the causes directly using linear regression. Thus, we built a model to explain, for example, "what contributed to the increase in BMI

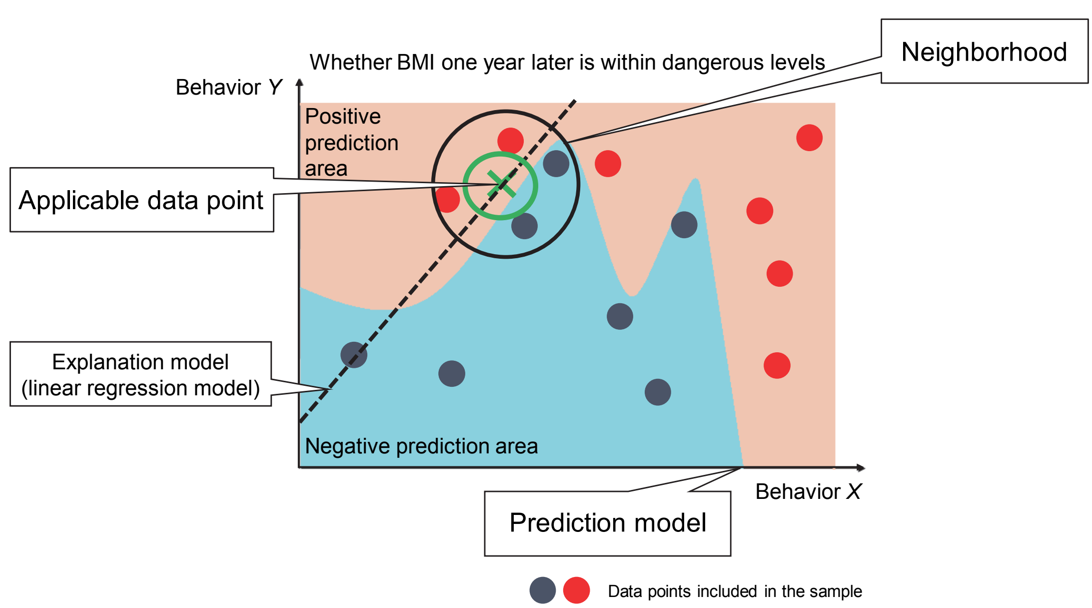


Figure 1 Overview of LIME

*5 AuC: An index for evaluating binary classifier problems. The area under the Receiver Operating Characteristic (ROC) curve will be 0.5 when predicted at random, and will be 1.0 when predictions are entirely correct.

*6 Non-linear model: A model in which the relationship between the objective variable and the explanatory variable factors is non-linear. Non-linear models generally have greater expressive power.

value?" to users for a given data point.

Explanation models extract the data point to be explained and several other nearby data points, and use them to build a linear regression model that approximates the prediction model. Since it is a linear regression model, it is possible to determine which of the explanatory variables contribute significantly, by looking at the combination of explanatory variables and partial regression coefficients*7. Since we provide an explanation using a model that approximates the prediction model near the point to be explained, the explanation provided by the model can change greatly, depending on the data points being explained. Thus, with health risk predictions, the results indicating the lifestyle habits that contribute to the health risk can differ, depending on the employee for whom the health risk is predicted, and explanations can be given for individuals.

2.3 LIME Customization Emphasizing Consistency of Explanations

An overview of consistency-emphasizing LIME is shown in **Figure 2**.

1) Issues with Conventional LIME

Since conventional LIME creates a model that approximates the data points near the points to be explained, the explanation model depends on those nearby data points. Because of this, if there are extreme data points that differ from the general tendency, there is a danger that the explanation could be distorted due to these outlying values.

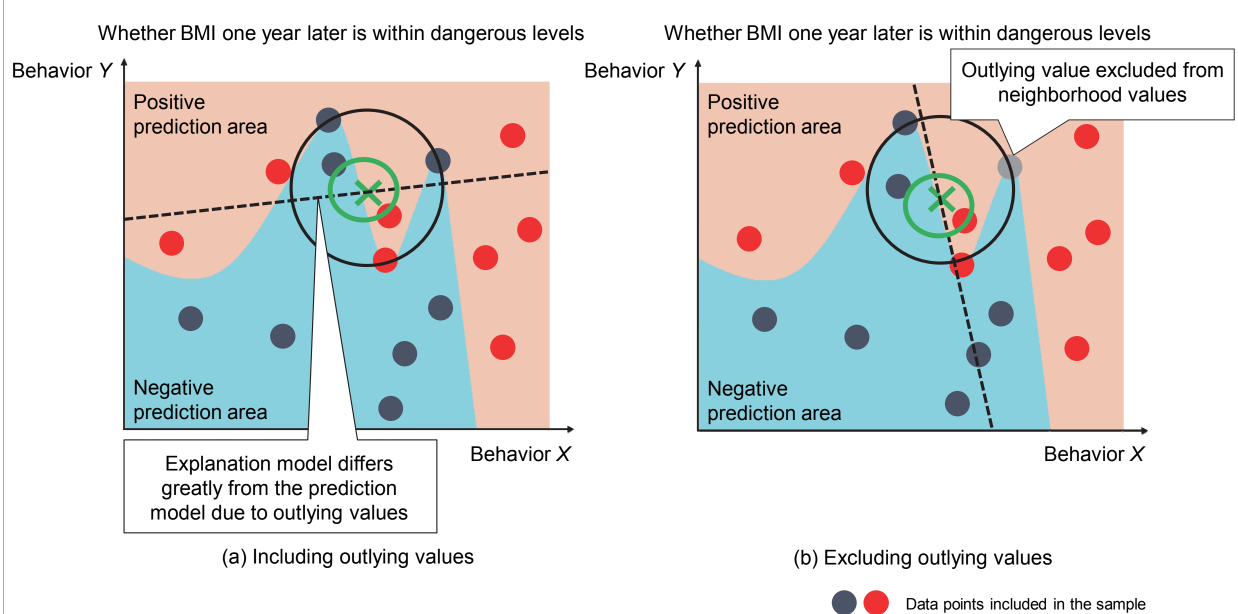


Figure 2　Overview of consistency-emphasizing LIME

*7　**Partial regression coefficient:** In regression analysis, a coefficient for an explanatory variable in the equation obtained.

For example, consider that there could be a sample that shows a temporary weight gain or blood pressure increase due to a disease that occurred suddenly in a given year, as well as cases where subjects became ill due to poor lifestyle habits. Since there are also cases of illness unrelated to lifestyle habits, conventional LIME could generate an explanation model that incorporates these later points since it selects nearby data at random, and this would prevent it from recommending lifestyle habit improvements correctly.

2) Consistency-emphasizing LIME

With consistency-emphasizing LIME, we have made improvements to make predictions more appropriate. Specifically, we added a mechanism that checks whether neighboring points are outlying values when searching for data points near the data point to be explained, and excludes points that are outlying values.

In performing this check, we first compute the slope of the line between the data point to be explained and a nearby data point candidate (slope A). We also compute the derivative of the prediction model at the data point to be explained (derivative B). If the characteristics of the explanatory variables match near the data point to be explained, we expect the signs of slope A and derivative B to match. For example, considering alcohol consumption and predicted BMI value one year later, if we see the characteristic, "BMI one year later increases with alcohol consumption," near the point to be explained, we expect the same tendency for other data points nearby. However, if there are outlying values, there will be data points that are significantly distant from the curve described by the prediction model. This will produce cases where the signs of slope A and derivative B do not match. As such, data points where the signs of these two values do not match are considered to be outlying values with significantly different slope than surrounding data points, and these are excluded from the sample.

A comparison of explanation models including and excluding such outlying values is shown in Fig. 2. In the figure on the left, the explanation model generated differs greatly from the prediction model due to the outlying values, but these values were excluded in the figure on the right, so the explanation model generated is close to the prediction model. This is the algorithm for consistency-emphasizing LIME.

3) Comparison of Original and Consistency-emphasizing LIME

Differences in risk prediction results for original and consistency-emphasizing LIME are shown in **Table 2**. In the table, original LIME and consistency-emphasizing LIME were applied to the same samples, the risk of metabolic disease one, two and three years later was predicted, and the lifestyle habits contributing most to that risk are compared. With original LIME, the sign of the contribution of "Eating quickly" changed between two and three years later. Normally, it would be difficult to imagine that continuing a habit of eating quickly, would yield a result that BMI decreased after two years, and then increased after three years. We can suppose that this result is due to a sample in the neighboring data points, either two years later or three years later, where a sudden change in BMI was recorded. On the other hand, with consistency-emphasizing LIME, this sort of data point is excluded, so counter-intuitive

Table 2 Change in risk prediction results between original and consistency-emphasizing LIME

<Original LIME>

Effects on BMI one-year-later		Effect on BMI two-years-later		Effect on BMI three-years-later	
Lifestyle habit	Effect score	Lifestyle habit	Effect score	Lifestyle habit	Effect score
Alcohol consumed	−0.14	Physical activity	−0.17	Increased body weight	0.08
Alcohol habit	0.09	Eating quickly	−0.08	Eating quickly	0.03
Physical activity	−0.06				

Predictions are not consistent

<Consistency-emphasizing LIME>

Effects on BMI one-year-later		Effect on BMI two-years-later		Effect on BMI three-years-later	
Lifestyle habit	Effect score	Lifestyle habit	Effect score	Lifestyle habit	Effect score
Eating dinner before going to bed	0.05	Eating dinner before going to bed	0.04	Sleep	0.03
Alcohol habit	−0.03	Physical activity	−0.04	Alcohol consumed	0.03
		Sleep	0.03		

predictions like that described above do not occur. This sort of validity is important for presenting risk prediction results that are convincing.

3. Lifestyle-habit Recommendation Technology Service Development

The technology described above was developed into a service on NTT DOCOMO d-Healthcare, and released in April last year as a service that enables NTT Group employees to check their own health risks and also lifestyle habits that contribute to those risks. A screen shot of the service is shown in **Figure 3**.

To use the service, members of the NTT Health Insurance Union first give permission for results of their own health examinations registered in "NTT Health Portal Navi" to be transferred to d-Healthcare. A library[*8] that performs the computations described above is then applied to the data, to output health risks and the lifestyle habits contributing to those risks. The model used in the library was trained using over 10,000 health-check data points collected by NTT DOCOMO over several years.

4. Conclusion

As the emphasis on health management is increasing, in this article, we have described a method using machine learning to predict health risks, the difficulty in providing explanations for such predictions, and an approach that solves this issue.

An actual service for company employees was

*8 **Library:** A collection of versatile programs in a reusable form.

Figure 3 d-Healthcare service screenshot

developed, and we have begun offering it to companies outside of NTT, as a service to support health management in corporations. In the future, we plan to continue improving the technology, contributing to improving employee health, and promoting NTT DOCOMO's health management outside of the company.

REFERENCES

[1] M. T. Ribeiro, S. Singh and C. Guestrin: ""Why Should I Trust You?": Explaining the Predictions of Any Classification," KDD'16, 2016.

[2] Association for Preventative Medicine of Japan: "Examining health examination results: Specific health examination (Metabolic syndrome)," (In Japanese). https://www.jpm1960.org/exam/exam01/exam15.html

* Data used here is from Health Data Bank. Explanation of how data would be used was given and permission from subjects was obtained before data was collected.

Technology Reports (Special Article) Recommendation Deep Learning Music

Special Articles on Lifestyle-enriching AI Technology

Music Recommendation Technology that Considers the Time Series of Singing History

Service Innovation Department Shigeki Tanaka Yusuke Fukazawa†

While karaoke is replete with search functions that users can use to select music (by singer, by era, etc.), it is rare for a system to have functions to actively make song recommendations. This is because making recommendations in karaoke is particularly difficult because the subject of the recommendations is a group, there is no singing history available from past visits, and the songs selected change due to the atmosphere. To address these issues, NTT DOCOMO has developed a deep learning recommendation model. This deep learning model considers a time series and learns in conjunction with various music information to make suitable recommendations to an unknown group.

1. Introduction

With the advances in machine learning*1, recommendation technologies have been introduced to various services such as online shopping, that have contributed to improved user experiences and business invigoration. In contrast, making suitable recommendations with karaoke is extremely difficult because karaoke users have the following tendencies:

- Users are a group with no singing history
- Group members select songs based on the composition of the group or the atmosphere in the venue

The collaborative filter recommendation method is a typical method of recommendation and used in various areas. In this method, the interests and preferences of an individual is inferred from the user's histories such as product purchase history or Web browsing history, and products that similar users are interested in are recommended to

† Currently, General Affairs Department

the user as related products. A method of combining individual profiles to expand them to a group profile has also been proposed [1]. Meanwhile in karaoke, many users have no singing history from past visits because they didn't log into the karaoke terminal, so not only is profiling difficult, even the number of people in the group is unknown.

For this reason, as an example, Daiichi Kosho provides a recommendation function that recommends music similar to the last tune that was sung. However, when using karaoke in a group, group members take turns to sing, so even though it is possible to recommend music to the member who sang most recently, if the subsequent member is different, effective recommendation is not possible.

Recommendation is also difficult because members select songs to suit the members of the group or the atmosphere. For example, with groups consisting of coworkers, or friends or families, there is a high probability that the songs likely to be selected will be different. Also, the atmosphere in a karaoke studio changes from the time people enter to when they leave, and many people like to sing a particular song when the atmosphere becomes exciting, or a closing song at the end. Thus, in many cases, the atmosphere of the venue affects song selection, so it is important to be able to read such changes when making recommendations. However, recommendation methods typical of the aforementioned collaborative filters generally capture tastes and preferences over a long term, and therefore do not hold much promise for effectiveness in areas that are constantly changing due to the venue or the atmosphere [2].

To address these issues, NTT DOCOMO has developed a recommendation model that uses deep learning*2.

This model predicts the most likely song or singer that will be subsequently selected by considering a time series and based on various song metadata when a song is selected. This makes it possible to make effective recommendations to groups who have no past history, and also makes it possible to make recommendations that consider the atmosphere of the venue by capturing the flow of songs.

This article describes details of the proposed method, and describes real-time song recommendation engine using this method.

2. Deep Learning Recommendation Model Considers Time Series and Multivariates

NTT DOCOMO's proposed recommendation model recommends subsequent songs or singers through input of various metadata of the song previously reserved.

2.1 Model Overview

Figure 1 shows an overview of the proposed model.

In addition to the ID of the song previously sung, the model inputs information such as the singer name, the composer name and the music genre and converts these into feature values. For example, the singer feature value represents the level of similarity and so forth between singers and the model acquires the feature values that better represent singers through learning. These feature values are input to a Recurrent Neural Network (RNN). RNN has a function that holds information called a hidden state, performs output computation

---

*1 **Machine learning:** A framework that enables a computer to learn the relationships between inputs and outputs by statistical processing of examples.

*2 **Deep learning:** Machine learning using a neural network with a multi-layered structure.

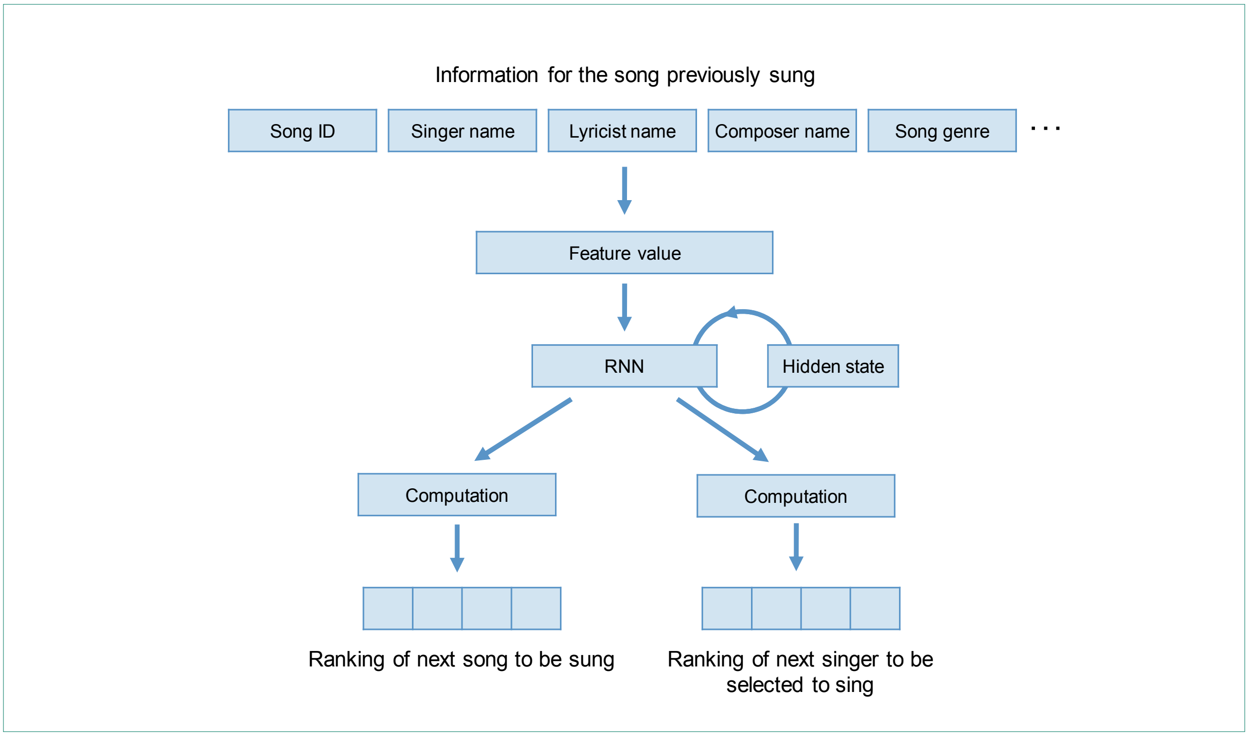


Figure 1 Overview of the proposed recommendation model

from the input feature value and the hidden state, and at the same time updates the hidden state. This mechanism makes it possible to take into account information that was input in the past. Using the RNN output, the model generates rankings for subsequent songs and singers.

The features of this model are that it (1) uses RNN, (2) inputs diverse song information, and (3) simultaneously performs multiple tasks (outputs rankings for subsequent songs and singers).

(1) RNN makes it possible to store a certain amount of information input so far. This makes it possible to capture not only the most recently entered song information, but also capture a time series history from the first song reserved after the group entered the karaoke studio to the song reserved right before recommendation, to enable recommendation that takes into account whose turn it is to sing, etc.

(2) Generally with recommendations, only song IDs are handled as input. In contrast, because understanding of songs is deeper in this model due to its handling of a wider range of song information, the model potentially has better recommendation accuracy, which is the probability that a song a member is about to sing is included in the recommendation results.

(3) Multitasking enables the improvement of resource utilization efficiency. Generally, machine learning models learn specifically for a single task, and if there are multiple tasks, more individual models are generated. Thus,

resource consumption for model learning and model operations increases in proportion to the number of tasks. Design to solve multiple tasks simultaneously is known as "multitask learning," and entails the model learning over a wider field to solve the related multiple tasks it has been given, which contributes to the improvement of accuracy for each task. Furthermore, by implementing two functions in one model, we were able to halve resource consumption compared to the cases where models for each function are prepared.

2.2 Verifying Accuracy

To verify the accuracy of our proposed method, with the cooperation of Daiichi Kosho, we compared it with existing methods using one month of data from a karaoke business. The first three weeks of data were used for each model to learn, then in the last week, we compared the estimation accuracy of each model.

For the existing methods, the following two methods were used.

- Ranking: Always recommends songs that are popular in the learning period.
- Item-kNN (k-Nearest Neighbor Algorithm): An item-based collaborative filter recommendation method that pre-creates a table of similarities between songs during the learning period. This table shows how likely it is for the same user group to sing those respective songs, and the method recommends songs similar to songs sung most recently.

The accuracy comparison with MAP@N*3 resulted in **Figure 2**, and showed that the accuracy of the proposed method exceeding the existing methods by more than 10% in both song and singer recommendations.

Figure 3 shows the movement of accuracy through time by dividing the history from customer entry through to exit of the karaoke studio into three parts and evaluating the averages of

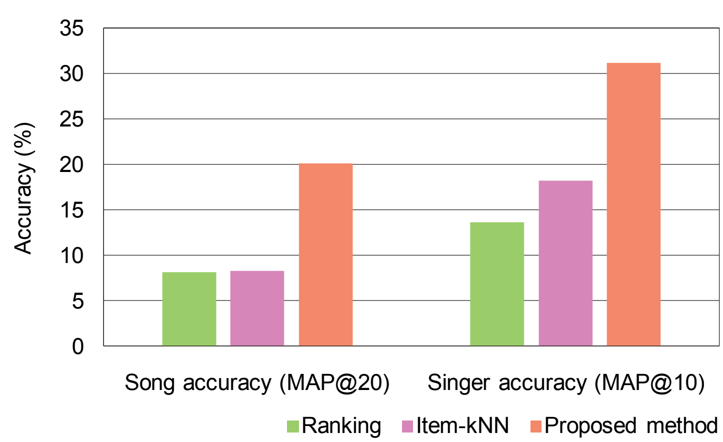


Figure 2 Comparison of accuracy of models

*3 MAP@N: When recommending N items, the probability that the next item selected by the user is included in those items.

accuracies of those respective periods. From the decrease over time of ranking accuracy after entering the room, it can be seen that in general, the user group sings a popular song at the beginning, and then gradually select a variety of songs. Also, Item-kNN accuracy was extremely low after entering the room, rose in the middle and then fell again, which presumably shows tendencies for individual group members to select songs they like at the beginning, to be affected by other members' song selections in the middle, and then finally members to sing their closing song. Compared to both these models, it can be seen that our proposed method achieves greater accuracy in all three periods, and captures changes in the atmosphere of the group.

3. Real-time Song Recommendation Engine

The real-time song recommendation engine was built on Amazon Web Services (AWS)*4 as the system using the proposed model. We are providing these recommendation functions to Daiichi Kosho via an Application Programming Interface (API)*5.

Figure 4 shows an overview of the system.

This system is constructed with a batch server and an API server. The batch server periodically relearns recommendation models from singing history and song information stored in a database, and then sends the learned models to the API server which updates the learned models with the latest ones. Although the batch server is not running except during the above periodic execution, the API server is always running to process recommendation requests. When the API server receives a recommendation request, it performs computations with the learned model based on terminal information and singing history sent as parameters, and then responds with the subsequent song and singer recommendations. While the database singing history is not necessarily updated in real time, real-time update of recommendations on reserving

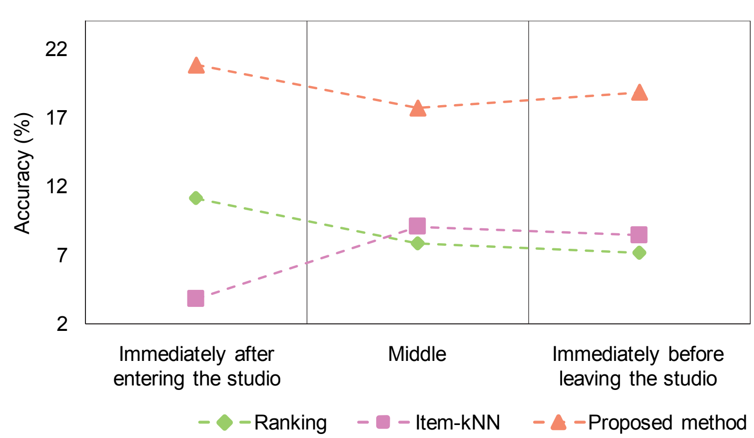


Figure 3 Movements in song accuracy over time for each model (MAP@20)

*4 AWS: A cloud computing service provided by Amazon.com.

*5 API: An interface that enables software functions to be used by another program.

songs is possible because the API server accepts the singing history on the terminal with each recommendation request.

As shown in **Figure 5**, the recommendation function is provided on the Daiichikosho Amusement Multimedia (DAM) terminal pre-reservation screen. Recommendations based on the history so far are shown by tapping on the relevant tab.

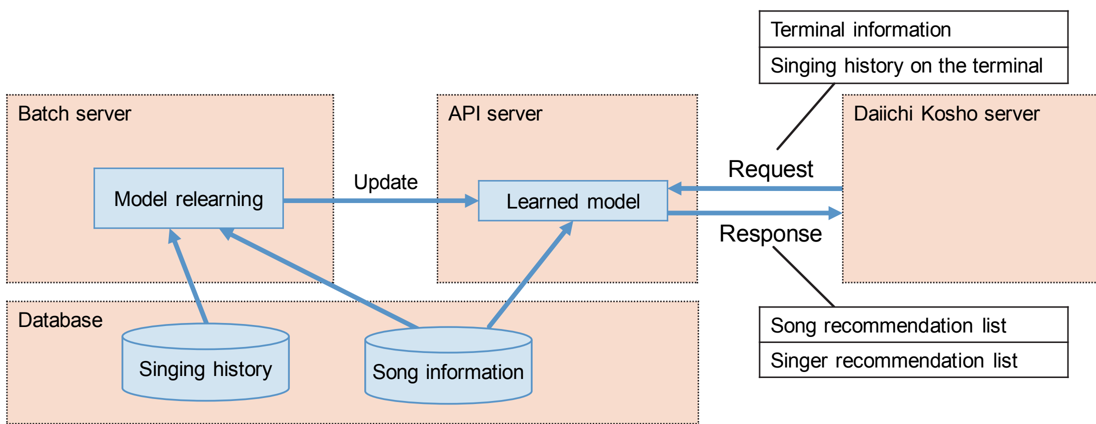


Figure 4　Overview of the recommendation system

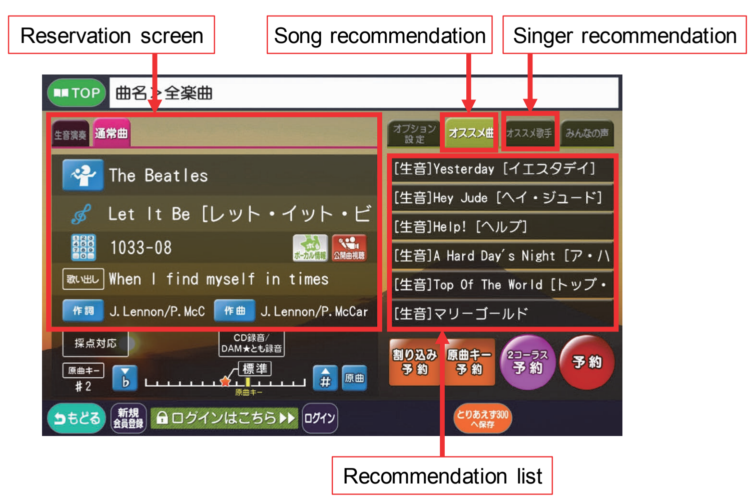


Figure 5　Recommendation display screen on the karaoke terminal

4. Conclusion

This article has described recommendation issues with karaoke systems, a recommendation method that uses deep learning to solve those issues, an evaluation of the performance of the method, and the recommendation system that uses the method.

At the time of writing this article, recommendation functions were being provided to a karaoke business as a trial, and improvements were being made while receiving feedback. In the future, we hope to contribute to user experiences with a formal commercial service widely in use.

REFERENCES

[1] A. Felfernig, L. Boratto, M. Stettinger and M. Tkalčič: "Group recommender systems: An introduction," Springer, 2018.

[2] M. Pazzani and D. Billsus: "Learning and revising user profiles: The identification of interesting web sites," Machine learning, Vol.27, No.3, pp.313-331, 1997.

Technology Reports | Operation System | Dedicated Management Software for Commercial Products | Network Monitoring

Improving Maintenance Efficiency through Resource Assurance System Implementation

DOCOMO Technology, Inc. Solution Service Division Keiji Nomura†1
Masanori Furutani†2 Toshihiro Matsushita
Network Service Operation Department Koji Yamamoto†3

In recent years, many inexpensive commercial products have come to be used as components on the NTT DOCOMO network. Monitoring of these products has been generally performed with product-dedicated management software. For this reason, it has been necessary to use a management screen with a different UI for each product, which has led to the issues of maintenance personnel requiring sophisticated skills and long working times.

To address these issues, and ensure quality of monitoring work, we developed the resource assurance system to integrate the UIs of various management software applications and abstract monitoring work. This enables efficient network monitoring without the need for sophisticated skills, even on large-scale networks.

1. Introduction

The OPS (OPeration System)*1 is used for centralized monitoring of the operating status and alarm occurrence status of the devices that make up the network, and for setting those devices, and is a critical system for stable mobile network operations.

With the increasing importance of mobile networks as social platforms supporting various industries and social lifestyles, efficient operation of

†1 Currently DOCOMO CS Chugoku, Inc.
†2 Currently Network Service Operation Department, NTT DOCOMO, INC.
†3 Currently Core Network Engineering Department

*1 OPS: A general name for systems used for maintaining and operating communications networks.

each service, which has a different Service Level Agreement (SLA)*2, must be achieved on networks as they inevitably expand and become more complex.

By adopting the Smart OPS concept [1], NTT DOCOMO has been making major advancements to the efficiency and sophistication of OPS.

However, due to the increased opportunities to use inexpensive commercial products on NTT DOCOMO networks in recent years, the network maintenance challenges of maintenance personnel requiring advanced skills and long working times have become more prominent. As the "smart OPS" concept aiming to solve these maintenance issues and achieve advanced OPS, we introduced a resource assurance system to make interfaces such as Artificial Intelligence (AI) and End to End Orchestrator (E2EO)*3 commonly available for OPS to give maintenance workers a unified sense of operations by abstracting the differences of various devices. This has achieved improvements in accuracy and work efficiency of monitoring operations, more efficient operations, and significant reductions in OPS development time and cost.

This article describes an overview of the resource assurance system.

2. Issues and Circumstances Surrounding OPS

2.1 Automation of Network Operations

As networks evolve from 3G and 4G to 5G, they will become more complex and the limitations of manual maintenance will be reached.

On March 25, 2020, with the commencement of full-scale 5G services in Japan with their high-speed, high-capacity, low latency communications and simultaneous connection between multiple terminals, network slice*4 was defined as an essential function for the generation of new businesses using 5G. Although users will be able to enjoy many advantages such as high-speed, high-capacity communications and simultaneous multi-terminal connections, telecommunications carriers will have even more network operational issues to overcome such as operational performance limitations due to network complexification and management layering, difficulties in managing memory and data, and speeding up analysis of fault causes and their rectification.

To solve these issues, there are ongoing discussions in a range of groups such as European Telecommunications Standards Institute Zero Touch Network and Service Management (ETSI ZSM)*5, Open Network Automation Platform (ONAP)*6 and Open Radio Access Network (O-RAN) Alliance*7 to achieve Zero Touch Operation, an initiative to automate network operations.

2.2 Expansion of the Use of Commercially Available Products by Telecommunications Carriers

Traditionally, telecommunications carriers have built networks using specialized equipment, but as the conversion of communications to IP has progressed, the opportunities for telecommunications carriers to use commercial products have increased. Monitoring of networks made up of these products is generally performed with product-dedicated management software. In large-scale telecommunications

*2 SLA: A guarantee of the quality of a provided service.

*3 E2EO: Life cycle management of slices based on service orders. A concept of achieving service orchestration over a wide range by linking each Fulfillment-OSS in each OPS network such as the access, core, and link network.

*4 Network slice: A system for achieving next-generation networks in the 5G era, that entails logically dividing a network into service units for use cases and business models, etc.

carriers, various types of network equipment are often used, and hence the types of management software used tend to increase proportionally.

2.3 Issues with Operations

Even at NTT DOCOMO, the trend of using commercial products is the same. NTT DOCOMO centrally monitors and controls the equipment that makes up its network using dedicated OPS. However, with the trend in recent years of using commercial products as equipment used to connect between data centers called transmission equipment, each piece of equipment is monitored and controlled individually using product-dedicated management software. An increase in management software applications leads to requirements for diversified network construction and maintenance skills, which increases operational costs. Also, since management software applications are commercial products, they often do not meet the required level of quality for industry. The following describes specific transport system maintenance issues at NTT DOCOMO **(Figure 1)**.

1) Multiple Management of Configuration Information and UI Handling of Each Management Software Application

Information such as network configuration, equipment configuration and warning information for commercial products is handled by individual management software applications, so that when a fault occurs, information about the fault and connection information for device (network configuration information) must be obtained. Determining the location of faults takes time because the acquired

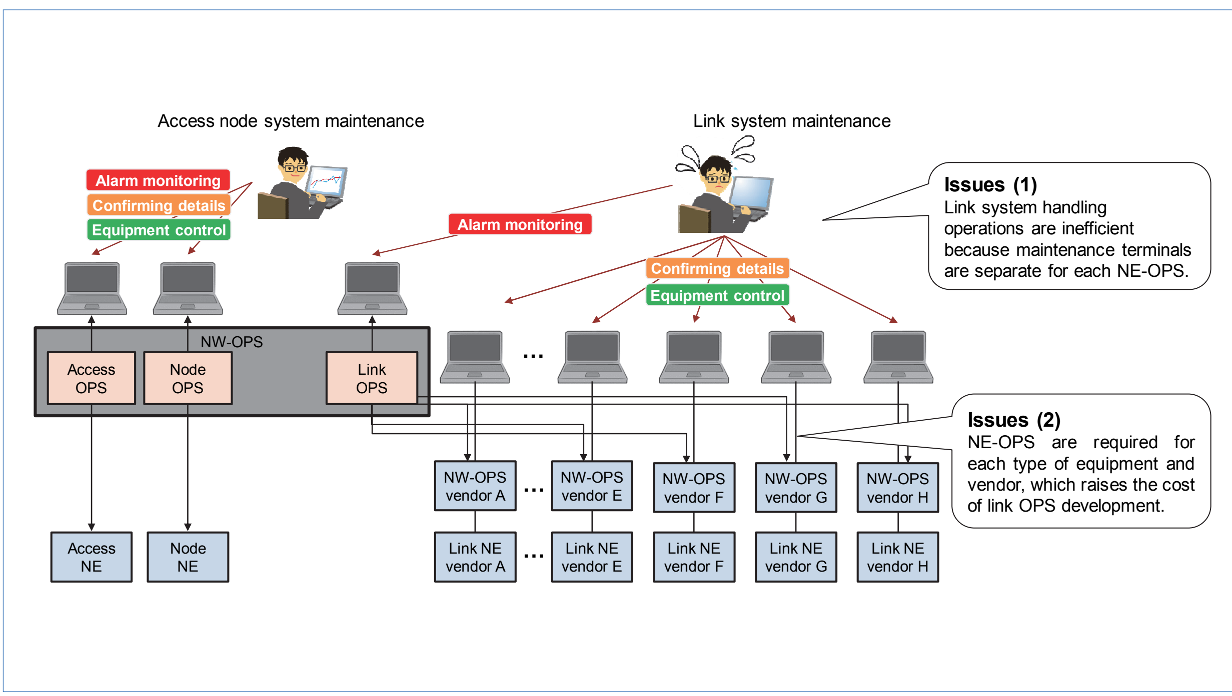


Figure 1　Issues when using management software

*5 ETSI ZSM: ETSI is a European standardization body engaged in the standardization of telecommunications technologies. Headquartered in Sophia Antipolis, France. The purpose of ETSI ZSM is to work on requirements, architecture, and management interface specifications to change management methods of networks and services to realize the autonomous networks required for end-to-end automation, and network slice technology and cross-domain service orchestration automation from use cases.

*6 ONAP: An open source network project. A platform development initiative for full lifecycle management by orchestrating and automating physical or virtual network elements.

*7 O-RAN Alliance: A group of telecommunications carriers and telecommunications equipment suppliers aiming to make the next generation radio access networks more scalable, open and intelligent.

information must be combined, and the entire network configuration understood. Also, determining fault locations requires simultaneous operation of several types of management software to acquire information, which means maintenance personnel must have diverse skills because of the different displays and operating methods of each type of management software.

2) Increased Costs and Time When Implementing New Equipment

In recent years, microservices*8 have become the mainstream OSS products, and there is a trend of building a single system by combining multiple products. Although it is possible to some extent to freely implement functions by combining products, it is necessary to prepare a device UI for each OSS product when implementing new equipment, which entails concerns about high development costs and extended development time.

3) Responding to Faster Provisioning through the Use of Commercial Products

As mentioned, opportunities to use commercial products as equipment to be monitored are increasing and tend to shorten the time it takes to implement new equipment on a network. In network operations, implementation speeds between DOCOMO-only OPS and those of commercial products diverge, which means OPS also have to keep up with the speed of implementation of products.

3. Overview of the Resource Assurance System

The resource assurance system absorbs the differences in monitoring UIs of product-dedicated management software to provide integrated monitoring screens and control functions that are easy to use, and is currently used as a transmission equipment maintenance system (**Figure 2**). The introduction

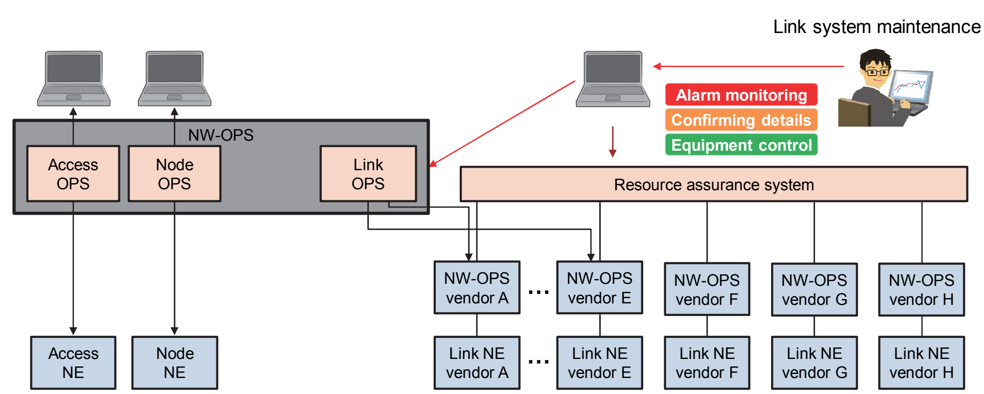


Figure 2 Configuration after resource assurance system implementation

*8 Microservice: A software development technique in which applications are composed of a collection of smaller services aligned with functions, and that communicate with each other using lightweight protocols.

of this system has enabled many advantages, as described below.

3.1 Improving to Monitoring Accuracy and Work Efficiency

Transmission equipment monitoring accuracy and work efficiency have been improved by uniformly displaying monitoring and control screens for the management software of each device, regardless of whether equipment information is physical or logical.

This system's centralized management of connection information of devices managed by multiple management software applications enables quick understanding of the configuration of entire networks made up of different equipment, and converting information such as alarm information indicating equipment status so that it is portrayed with unified expression eliminates the need for maintenance personnel to have a wide range of skills.

3.2 Making Operations More Efficient

Realizing an interface conversion function has made it possible to abstract equipment information, and easy linking with OPS such as already-implemented AI and E2EO under consideration for future implementation, etc., has enabled improved operational efficiency.

Because the display of equipment information such as housing position information (positions such as port*9 number, etc. in the equipment) and alarm information is different for each management software application, the interface for each device must be converted for each system in the OPS. As shown in **Figure 3**, the "mediation section" implemented in this system adopts an abstraction model to convert interfaces so that they have uniform expression. Thus, external systems can use the uniform device information provided by this system after conversion, which does away with the need to convert interfaces for each management software application.

3.3 Dramatically Reducing Development Time and Costs

This system greatly reduces development time and costs to enable monitoring of newly implemented equipment through functions to support and customize a wide variety of standard equipment UIs such as Simple Network Management Protocol (SNMP)*10 and REpresentational State Transfer (REST)*11 that are generally adopted by IP equipment.

As the product library*12, the system's mediation section has UI conversion logic (smart plugins) for devices generally used around the world, and it can be modified as necessary to enable monitoring of newly implemented equipment.

In addition, applications do not need to be modified for future operational changes, as the system has a user customization mechanism that can follow such work.

For example, the system can make it relatively easy to follow regular changes such as the addition or editing of equipment alarm information, and achieve future operation improvements/automation such as automatic recovery processing triggered by alarm information reception and single operation of device control through calling of external shells*13

---

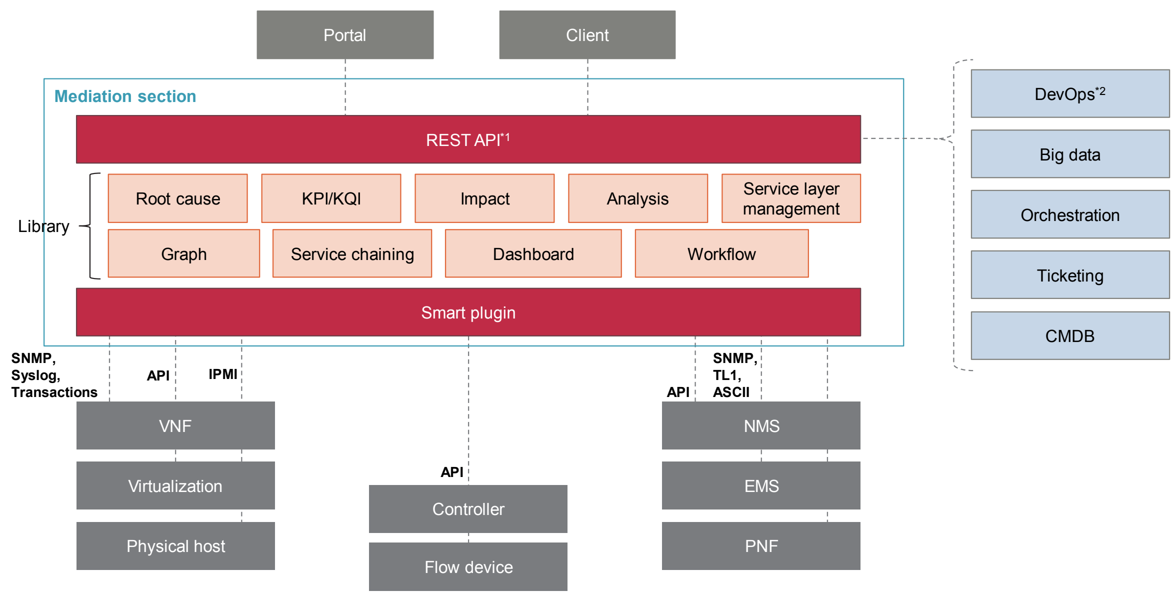
*9 Port: An interface for exchanging data with other equipment.

*10 SNMP: A protocol for defining methods of communicating information for monitoring and controlling network devices on the IP network. v1 has five command groups, to which the two v2c and v3 commands were added for a total of seven command groups. Uses MIB as parameters.

*11 REST: An API that sends requests with GET, POST, PUT, DELETE for each resource (URL) and receives responses in XML or json formats, etc. (the response format is not specified).

*12 Library: A collection of highly versatile programs in reusable forms.

*13 Shell: A type of software that makes up an operating system (OS), that starts programs, terminates running programs, and changes the operating mode by specifying startup parameters, etc. in response to user operations.



ASCII: American Standard Code for Information Interchange
CMDB: Configuration Management Database
EMS: Element Management System
IPMI: Intelligent Platform Management Interface
NMS: Network Management System
PNF: Physical Network Function
TL1: Transaction Language 1
VNF: Virtualisation Network Functions

*1 REST API: A type of program calling convention for external use of Web systems. Created in accordance with the design principle called REST. When REST is applied to a Web API, it is called a REST API.
*2 Development Operations (DevOps): A set of coordinated practices that combines software development (Development) and operations (Operations), and aims to accelerate software/system development and deliver high-quality services at high speed.

Figure 3 Interface provisioning with smart plugins

or URL access, etc. through the customization functions in the system.

Compared to conventional OPS, these functions greatly shorten development time and reduce development costs.

4. Future Outlook

4.1 Handling Network Slicing

Currently, maintenance work for individual parts that comprise networks such as the radio access network[*14] or core network[*15] is performed separately. However, with the introduction of network slicing, monitoring will be possible from the perspective of the services (slices) provided to users because the resource assurance system enables end-to-end display of individual slices.

4.2 Handling Zero Touch Operation

Currently, this is only applied to transmission

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

*15 Core network: A network comprising switching equipment and subscriber information management equipment, etc. Mobile terminals communicate with the core network via a radio access network.

equipment, but the scope of application will be expanded in the future. To advance OPS, various systems that constitute OPS will be able to acquire necessary information such as the linkage with AI, etc., without the need for awareness of equipment differences, by common UI support through the interface functions provided by the resource assurance system. This will enable efficient automation of work.

5. Conclusion

This article has described the resource assurance system.

Going forward, we aim to further handle network slicing, expand the scope of application to network areas other than transmission equipment, link with the networks of other companies, achieve automated network operations through further advancements, reduce downtime by speeding up response to network faults, and speed up the implementation of new equipment to improve the speed of service provision.

REFERENCE

[1] S. Shibata et al: "Overview of Smart OPS," NTT DOCOMO Technical Journal, Vol.21, No.1, pp.18-20, Jul. 2019.

NTT DOCOMO
Technical Journal Vol.22 No.2

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

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