NTT DOCOMO

# Technical Journal

Vol.17 Apr.2016 | No.4

# Making 5G a Reality


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Shortly after the introduction of LTE, we began studying the development of 5G, the fifth-generation mobile communications system, as the mobile communications system for the 2020s. From past experience, we knew that preparing the next-generation mobile communications system requires starting investigations about ten years before. Thus we realized that we had to start soon. However, because at that time LTE-Advanced finally gained momentum in its practical applications, interest in 5G, which still lay in the future, remained at a low level. There were not many partners who listened when we brought up the subject of 5G.

Fortunately, there were engineers and companies who agreed with our thinking. We advanced our studies within NTT DOCOMO as we exchanged views with them, refining the basic concepts of 5G. We also expounded 5G's concepts in as many venues as possible by including 5G-related contents in conferences and lectures on 4G. These efforts paid off. Interest in 5G gradually grew, and opportunities for discussion increased. Dialogues have advanced rapidly in especially the last two years. Study organizations have been established. In academic conferences, many 5G-related sessions are being held. For us who began studying and testing 5G at an early stage, we take pride in being able to take the initiative in a variety of areas. We are thankful to members within this group and other partners who worked hard with us.

However, this is not the time to rest on our laurels. After establishing the basic concepts of 5G, our studies have already entered the standardization and Proof of Concept (PoC) stages. Standardization will begin in earnest from 2016. However, preparations are being made now in 2015. For PoC, we are partnering with 13 major global companies to carry out tests and technical studies. We will present and exhibit the results in many venues. Going forward, we must achieve PoC with technological content that brings more advanced functions to 5G.

Japan is gearing up for the Olympics and Paralympics in 2020. Seizing this opportunity to showcase the country's technological leadership, Japan's academia, industry, and government are conducting studies on a variety of themes. One of these subjects is 5G, and commercial deployment of 5G by 2020 is being sought. NTT DOCOMO has been providing mobile communication services to meet the needs of customers by introducing new generations of mobile communications systems in intervals of roughly ten years. In this sense, 2020 is the right time to introduce 5G. However, with only a little more than four years remaining, this will be a tight schedule, considering the time frame needed for standardization, PoC, and furthermore, full-scale system development. We are prepared for the need of even greater efforts from 2016 onward.

Furthermore, we recognize that to deploy 5G, we need to not only develop mobile communications systems, but to also propose and develop use cases and services in parallel. Toward this end we are soliciting concrete ideas within the company based on one's vision of the world in the 2020s. To promote diverse and outstanding ideas, we are planning ideathons and hackathons and seeking views from people in many different fields. Beginning this year, we are studying PoC implementation of at least some of these outstanding ideas.

As described above, many issues need to be resolved and work remains to be done to introduce 5G. One of NTT DOCOMO's slogans is "Co-creation." With this keyword in mind, we wish to bring 5G a step closer to reality by collaborating with many partners inside and outside the company.

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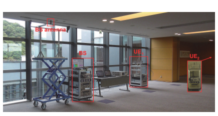

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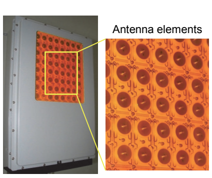


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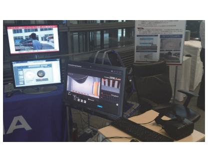

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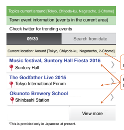

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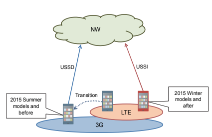


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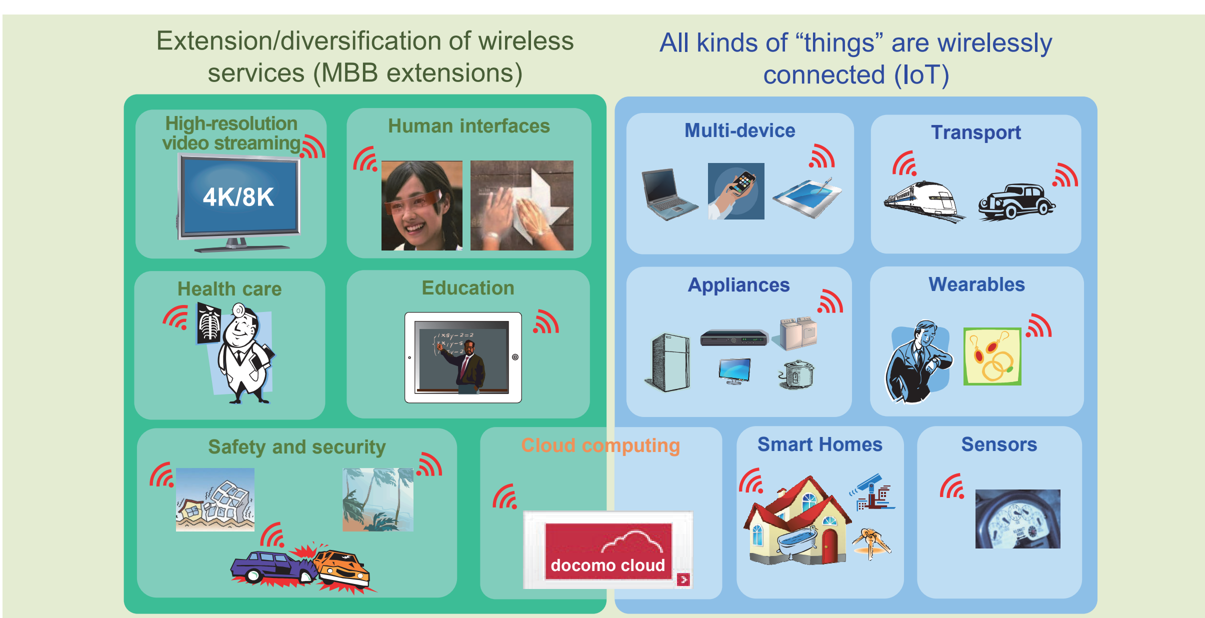


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**Diverse services envisioned for 5G**

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Technology Reports

Special Articles on 5G Technologies toward 2020 Deployment

# NTT DOCOMO 5G Activities —Toward 2020 Launch of 5G Services—

*NTT DOCOMO is researching and developing 5G, the next-generation mobile communications system, toward deployment in 2020. The 5G system is expected to enable a variety of new services including enhanced MBB having even higher bit rates and capacity and IoT connecting all kinds of things to the network by wireless means. This article presents an overview of NTT DOCOMO's 5G activities. It describes services and requirements envisioned for the 5G era, NTT DOCOMO's 5G definition and technical concept, and standardization strategy and activities toward a 2020 launch of 5G services.*

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## 1. Introduction

Today, we can enjoy services and applications as well as videos and music over the Internet in an anytime-and-anywhere, trouble-free manner thanks to the proliferation of smartphones, tablets, and other smart devices. Nevertheless, the demand for even more advanced services is growing. At the same time, mobile communications traffic has increased dramatically since 2010, so in addition to accommodating higher volumes of traffic, telecom carriers will be expected to provide a Mobile Broad Band (MBB) system that can provide these services in all types of environments at an even higher level of user quality. In addition, the Internet of Things (IoT)*1 has been attracting considerable interest in recent years as a world that will connect all kinds of things to the network by wireless means. Going forward, it will become increasingly important for telecom carriers to provide the infrastructure that can support services in new business domains opened up by IoT.

Amid these expectations, there have been lively discussions in recent years on fourth-generation (4G) LTE and a fifth-generation mobile communications system (5G) as the next-generation of LTE-Advanced. Organizations promoting 5G and 5G research projects have been launched in various regions throughout the world and spirited debates on the 5G concept and associated requirements have taken place. In this regard, the 3rd Generation Partnership Project (3GPP), a leading standardization organization for mobile communications systems, held a gathering called "3GPP RAN Workshop



*1 **IoT:** General term for a control and information-communications format that connects various "things" to the Internet and cloud.

on 5G" in September 2015 marking the beginning of serious discussions on 5G standardization.

NTT DOCOMO began studying 5G in 2010 and has since been involved in a variety of 5G activities from proposing technical concepts to promoting transmission experiments and standardization discussions. In this article, we present an overview of these activities and describe, in particular, services and requirements envisioned for the 5G era, NTT DOCOMO's 5G definition and technical concept, and standardization strategy and activities toward the launch of 5G services in 2020.

## 2. 5G Services and Requirements

### 2.1 Services in the 5G Era

There is no direct relationship between services and the mobile communications generation. The 2G and 3G systems can provide advanced services as long as smartphones can be used, and it can be said that 4G can provide most of the services provided by 5G. On the other hand, advances in communications technologies can make the same service more enjoyable in a greater variety of environments. In time, we will see the birth of new services that presume the communications quality of 5G, and before we know it, 5G will become the norm—one day, we will take it for granted.

A diverse array of services can be envisioned for the 5G era. These can be broadly divided into the two trends of enhanced MBB and IoT as shown in **Figure 1**.

(1) Enhanced MBB, or high-speed, high-capacity, and low-latency communications, will enable richer and more sophisticated services and applications over the wireless network. For example, Enhanced MBB raises the possibility of high-definition video streaming (4K*2/8K*3 video),

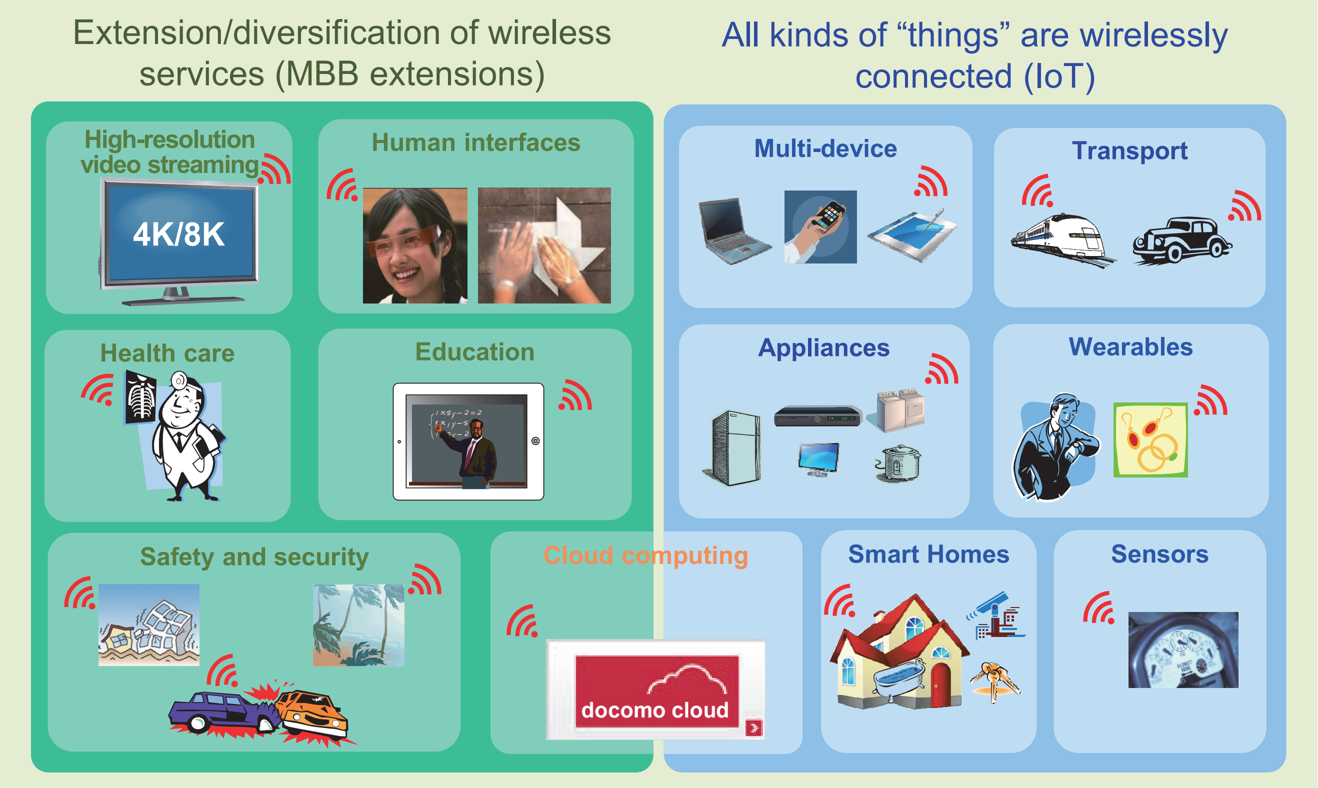


**Figure 1 Diverse services envisioned for 5G**

*2 **4K:** Picture format having a display resolution of 3,840 × 2,160 or 4,096 × 2,340 pixels.

*3 **8K:** Display format having a resolution four times that of 4K (twice that in each of the horizontal and vertical directions).

media-rich social network services, Augmented Reality (AR)*4 services closely coordinated with the huge amount of data on the cloud*5, and media communications using touch, body movement, etc. (haptic communications) as opposed to audio and video. Additionally, it should enable wireless communications to become a lifeline for people and facilitate the provision of services that demand safety and certainty such as autonomous driving.

(2) The IoT world, in which all sorts of things will come to be wirelessly connected to the network, is expected to provide a wide variety of services to users and companies over the wireless network. This will be achieved by connecting vehicles, homes, home appliances, eyeglasses, wristwatches, accessories, robots, sensors, etc. to the network by Machine to Machine (M2M)*6 technology and managing and controlling the huge amount of data so collected in an automatic and intelligent manner.

## 2.2 5G Requirements

To support the many and varied services that 5G is expected to make possible in the future, new requirements to deal with recently evolving trends such as IoT will have to be considered in addition to universal requirements for existing mobile communications systems. In short, a wide range of requirements can be envisioned for 5G as summarized below (**Figure 2**).

(1) Higher system capacity

The volume of mobile communications traffic has been increasing at an explosive rate in recent years with predictions that it will reach 1,000 times that of 2010 levels in the 2020s. Dealing with this explosive increase will require a dramatic jump in system capacity (total bit rate per unit area). This is considered to be the most basic requirement for 5G.

(2) Higher bit rate

Considering the future prolifer-

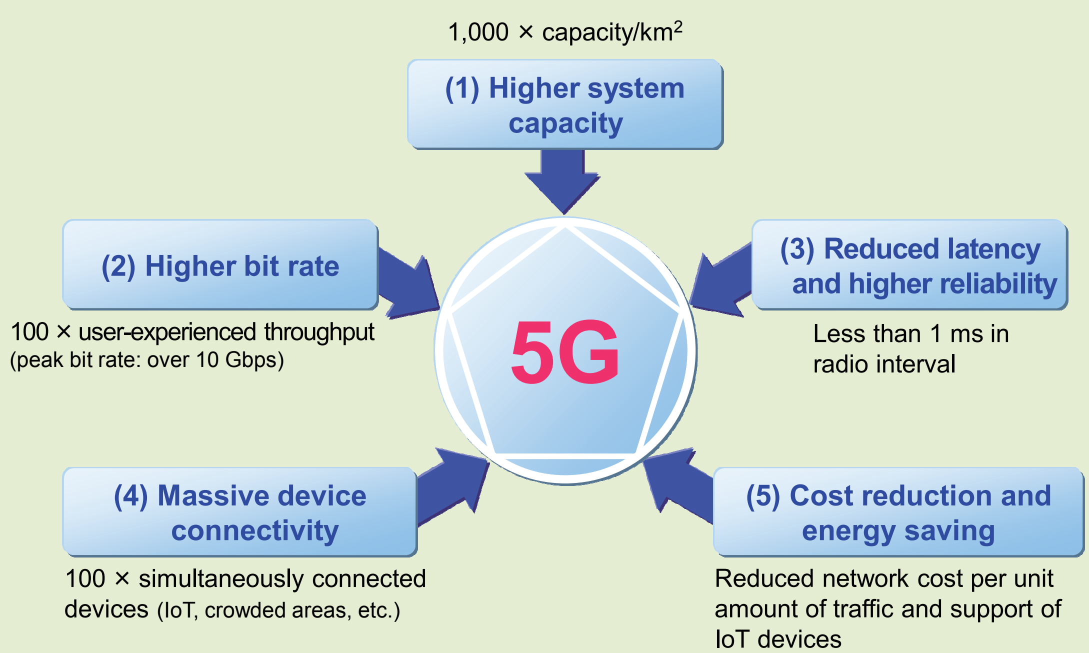


**Figure 2 5G requirements**

*4 **AR:** Technology for superposing digital information on the real world in such a way that it appears to the user to be an actual part of the scene.

*5 **Cloud:** A format and structures for providing services over networks. Server resources can be distributed according to usage conditions, which provide good scalability.

*6 **M2M:** Information communications performed automatically between machines.

ation of rich content and cloud services, it is essential that 5G provide a quantum leap in bit rate too. In particular, it is important that the level of quality required for service provision be satisfied at all times regardless of time of day or location. Specific targets are a user-experienced throughput about 100 times that of LTE (several 100 Mbps – 1 Gbps) in all sorts of scenarios including mobile environments and a peak bit rate over 10 Gbps in a good wireless environment.

(3) Reduced latency and higher reliability

New services such as haptic communications and AR that require a level of latency lower than that in the past are expected to appear in the 5G era. 5G will require a latency of less than 1 ms in the radio interval, or one fifth that of LTE. Additionally, for services that demand safety and certainty such as autonomous driving, high reliability will be required in addition to low latency.

(4) Massive device connectivity

The number of devices constantly connected to the wireless network is predicted to increase dramatically in the IoT era. It will be necessary to support a massive number of simultaneously connected devices in all types of scenarios. These will include environments in which a large number of users have amassed such as stadium and event venues and situations such as natural disasters in which many attempts at accessing the network can be expected to occur simultaneously.

(5) Cost reduction and energy saving

While setting high performance targets in 5G is important to provide even better services to users, it is also necessary to provide those services at reasonable costs to users. This means that network cost per unit amount of user traffic must be greatly reduced. Furthermore, to provide a superb network in a natural environment, such high levels of performance must be provided with as small an amount of energy as possible. Additionally, considering the expanded use of IoT devices in the form of compact sensors that can be attached, for example, to pets, making devices themselves as inexpensive as possible and extending the life of batteries are important. The wireless network must be able to support such IoT characteristics.

The above 5G requirements are also being studied at the Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society (METIS)*7, a European project, and at Next Generation Mobile Networks (NGMN)*8, an alliance of world-leading telecom carriers [1][2]. NTT DOCOMO has been a participant in both of those organizations.

## 3. NTT DOCOMO's 5G Definition and Technical Concept

1) Two Approaches

There are two approaches available for deploying Radio Access Technology (RAT)*9 toward 2020. One is to use LTE and LTE-Advanced in more evolved forms, and the other is to introduce completely new RAT. The former involves continuous evolution while maintaining backward compatibility with the existing LTE system while the latter places priority on improving performance over maintaining backward compatibility with LTE.

2) Technical Concept (eLTE + New RAT)

As shown in **Figure 3**, NTT DOCOMO defines 5G as a combination of continuous evolution in LTE/LTE-Advanced, that is, enhanced LTE (eLTE), and newly introduced RAT (New RAT). This concept achieves improved performance such as dramatic leaps in bit rate and capacity by New RAT applicable to broader frequency bands while providing a basic coverage area*10 and basic services such as broadcasting by eLTE. The 5G system can also incorporate Non-Orthogonal Multiple Access (NOMA) [3] technology that can improve system capacity in existing frequency bands and radio access technologies that can be applied regardless of the frequency band such as fast-retransmit control for achieving low latency. When applying

*7 **METIS:** A 5G-related EU research project that ran from November 2012 to April 2015 with participation by telecom vendors, telecom carriers, universities, and other parties.

*8 **NGMN:** An alliance of world-leading telecom carriers whose objective is to study requirements and operating scenarios for enhancing mobile broadband and contribute to industry.

*9 **RAT:** Radio access technology such as LTE, 3G, and GSM.

*10 **Coverage area:** The area over which a single base station can communicate with UE (cell diameter). As coverage is increased, the number of base stations required decreases.

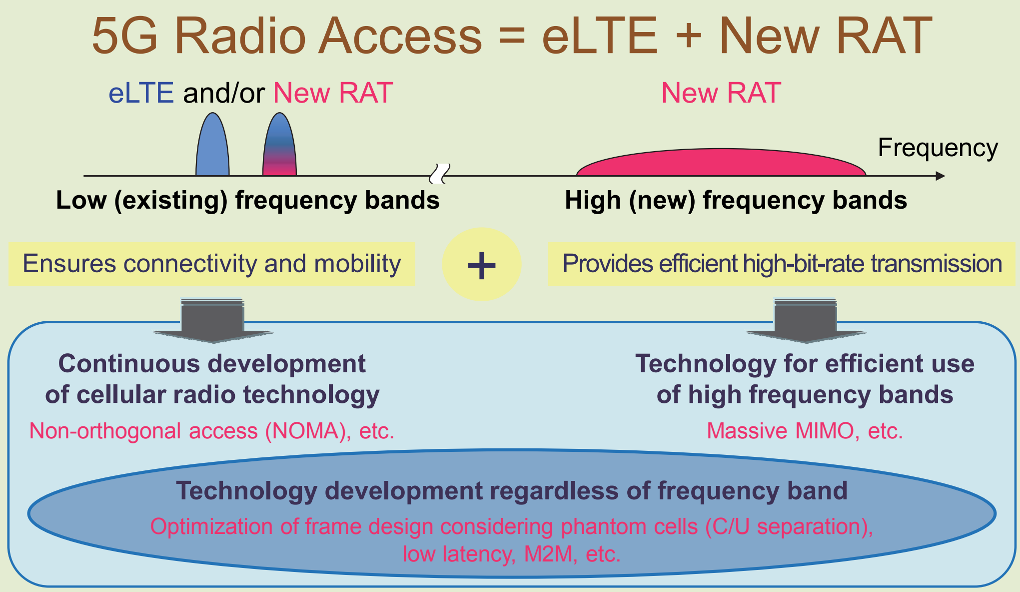


**Figure 3 NTT DOCOMO's 5G technical concept**

such technologies to existing frequency bands, an eLTE approach is desirable to maintain backward compatibility with LTE.

Furthermore, to improve performance while securing sufficient coverage in high frequency bands that have not been used in mobile communications up to now such as those of centimeter waves (3–30 GHz) and millimeter waves (30 GHz and higher), it will be necessary to introduce New RAT that optimizes radio parameters and applies Massive Multiple Input Multiple Output (MIMO) technology [4] that uses a massive number of antenna elements.

Moreover, applying New RAT to existing frequency bands at a particularly early stage will require suitable gain in capacity and user throughput, and a design that enables coexistence with LTE at identical frequencies would be desirable.

3) Deployment Scenario

An example of a 5G deployment scenario that combines eLTE and New RAT in the above way is shown in **Figure 4**. Initial 5G introduction scheduled for 2020 will be achieved by deploying eLTE and New RAT mainly in urban areas that require higher capacities. Here, eLTE and New RAT will interwork through Carrier Aggregation (CA)*11 and Dual Connectivity (DC)*12 technologies [5] to achieve higher capacities while ensuring coverage. In the future, the 5G deployment area will expand considerably from urban to suburban areas, so the addition of very high frequency bands such as those of millimeter waves can be expected as the need arises. This further evolution of 5G in 2021 and beyond will be referred to as 5G+ below.

## 4. 5G Standardization System Strategy

### 4.1 Stepwise Standardization Approach

As shown in **Figure 5**, NTT DOCOMO aims to introduce 5G in 2020 while also planning for its continuous evolution as 5G+ in subsequent years. In 2020, frequency bands that exist today, new frequency bands that will become available by then, and unlicensed bands will all be candidates for 5G frequency bands. However, for 5G+ in later years, discussions at the International Telecommunication Union-Radio communication sector (ITU-R)*13 and at its World Radio communication Conference (WRC)*14-19 in particular may result in the addition of new frequency bands, so we can

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*11 **CA:** A technology for increasing bandwidth while maintaining backward compatibility by simultaneously transmitting and receiving multiple component carriers.

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

*13 **ITU-R:** Radiocommunication Sector of the ITU which recommends methodologies for subjective video quality assessment in addition to administration and coordination activities related to radiocommunications.

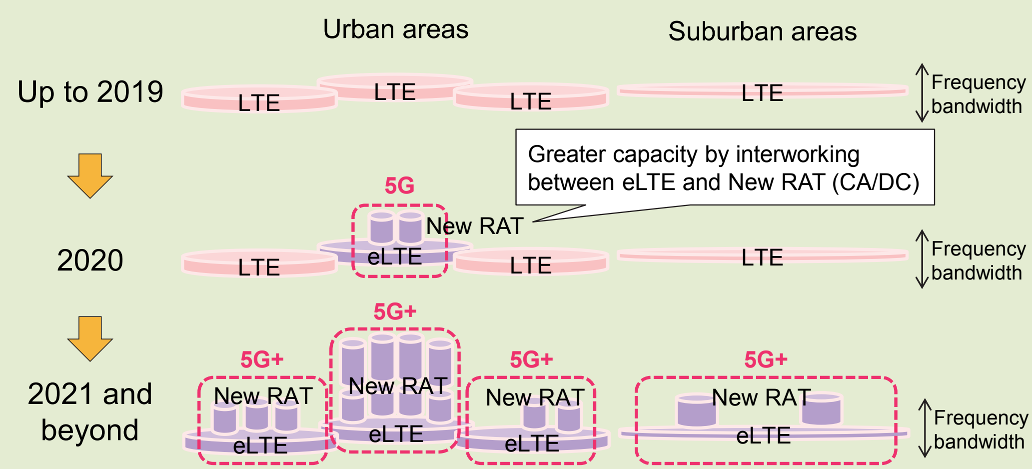



**Figure 4　5G deployment scenario**

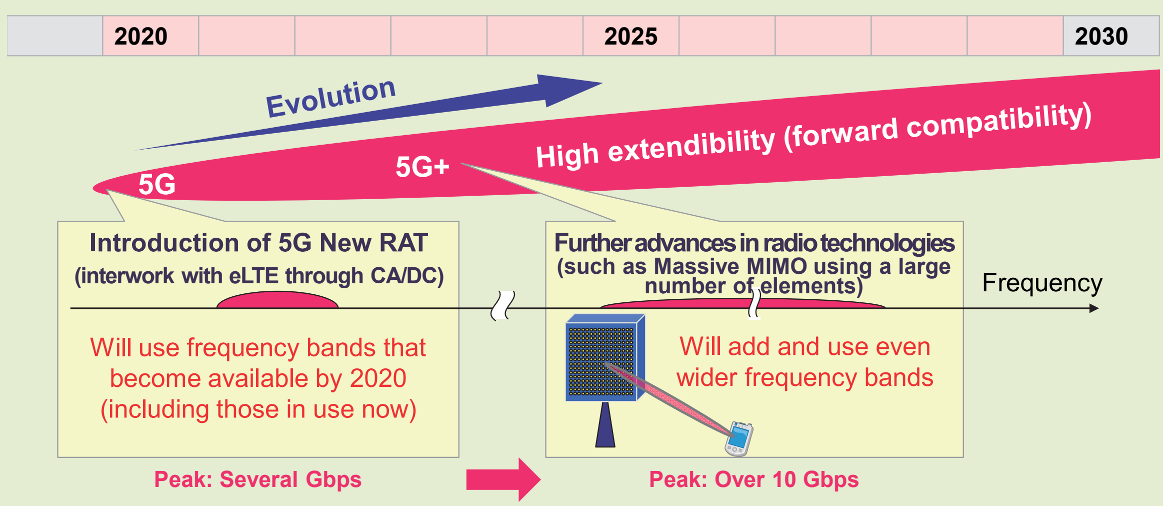



**Figure 5　5G initial introduction and continuous evolution**

envision that technologies applicable to radio access and the network may have to be extended as well.

1)　Stepwise Standardization

To introduce New RAT in 2020, it appears that the standardization of initial specifications at 3GPP would have to be completed by the end of 2018. However, the standardization of radio interface specifications that satisfy the requirements of ITU-R 5G (IMT-2020) needs to be completed only by the end of 2019 at 3GPP based on the ITU-R schedule. For this reason, we consider two-step standardization to be an effective approach, with the first step corresponding to 5G and the second step to 5G+. The goal in this stepwise standardization of New RAT is to complete initial specifications toward 2020 deployment in a limited time period. This, however, will

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

require that a priority be placed on performing good basic design emphasizing future extendibility (forward compatibility) rather than incorporating abundant functions from the start.

As shown in **Figure 6**, 5G is configured as a combination of eLTE and New RAT while 5G+ will evolve continuously while maintaining compatibility with 5G. This is similar to the compatibility relationship between LTE and LTE-Advanced in 4G.

2) Roles of eLTE and New RAT in 5G, 5G+

As described above, both enhanced MBB and IoT can be viewed as service trends in 5G and a sequential expansion of the 5G service area from urban areas requiring high capacity can be expected. Consequently, at the 5G introductory stage in 2020, New RAT will prioritize support for enhanced MBB featuring higher bit rates and higher capacity as required for urban areas (**Figure 7**). At

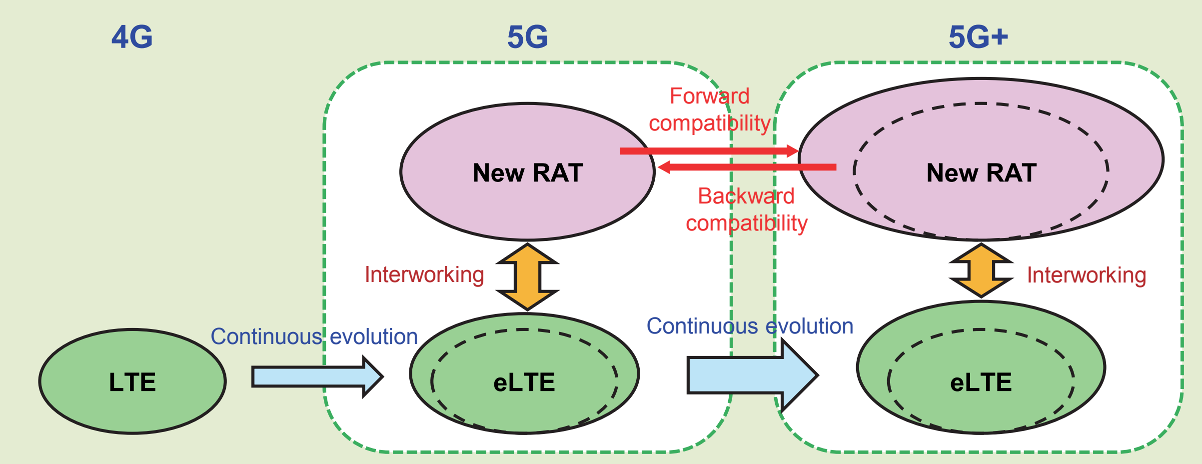



Figure 6　Relationship between 4G, 5G, and 5G+

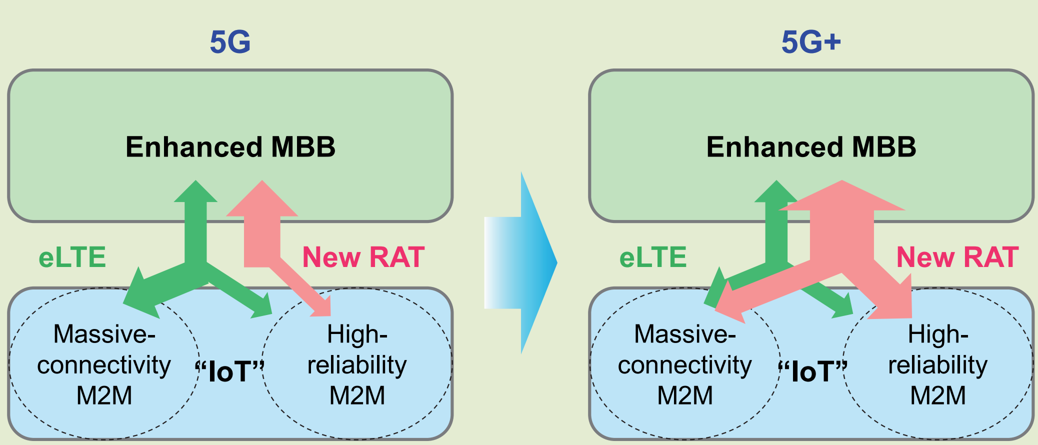



Figure 7　5G service support by eLTE and New RAT the same time, eLTE, which provides full coverage, will supplement the above by supporting a variety of IoT-related functions such as those that support low-cost M2M terminals and M2M communications requiring high reliability. Then, in the future 5G+ period, we can expect New RAT itself to incorporate many functions and to progressively support a variety of services and scenarios including 5G services that are still unknown. In short, NTT DOCOMO considers that 5G services in 2020 will be achieved by combining eLTE and New RAT technologies. Candidates for radio access technologies targeting initial introduction of 5G in 2020 are shown in **Figure 8**. These technologies are described in other special articles in this issue.

### 4.2 Overview of 3GPP Workshop on 5G

A "3GPP Workshop on 5G" was held in September 2015 marking the beginning of 5G standardization at 3GPP. A typical scene at this workshop is shown in **Photo 1**. The workshop featured ten presentations from external organizations (such as the 5G Mobile Communications Promotion Forum (5GMF)), 54 presentations from individual companies, and three joint presentations each from a group of companies, all of which produced lively discussions and Q&A sessions. More than 450 delegates attended the workshop with each company expressing great interest in 5G.

With the aim of completing the standards and specifications necessary for 2020 deployment of 5G services, NTT DOCOMO proposed to 3GPP a stepwise approach to 5G standardization as laid out in joint and independent contributions [6][7]. A general consensus

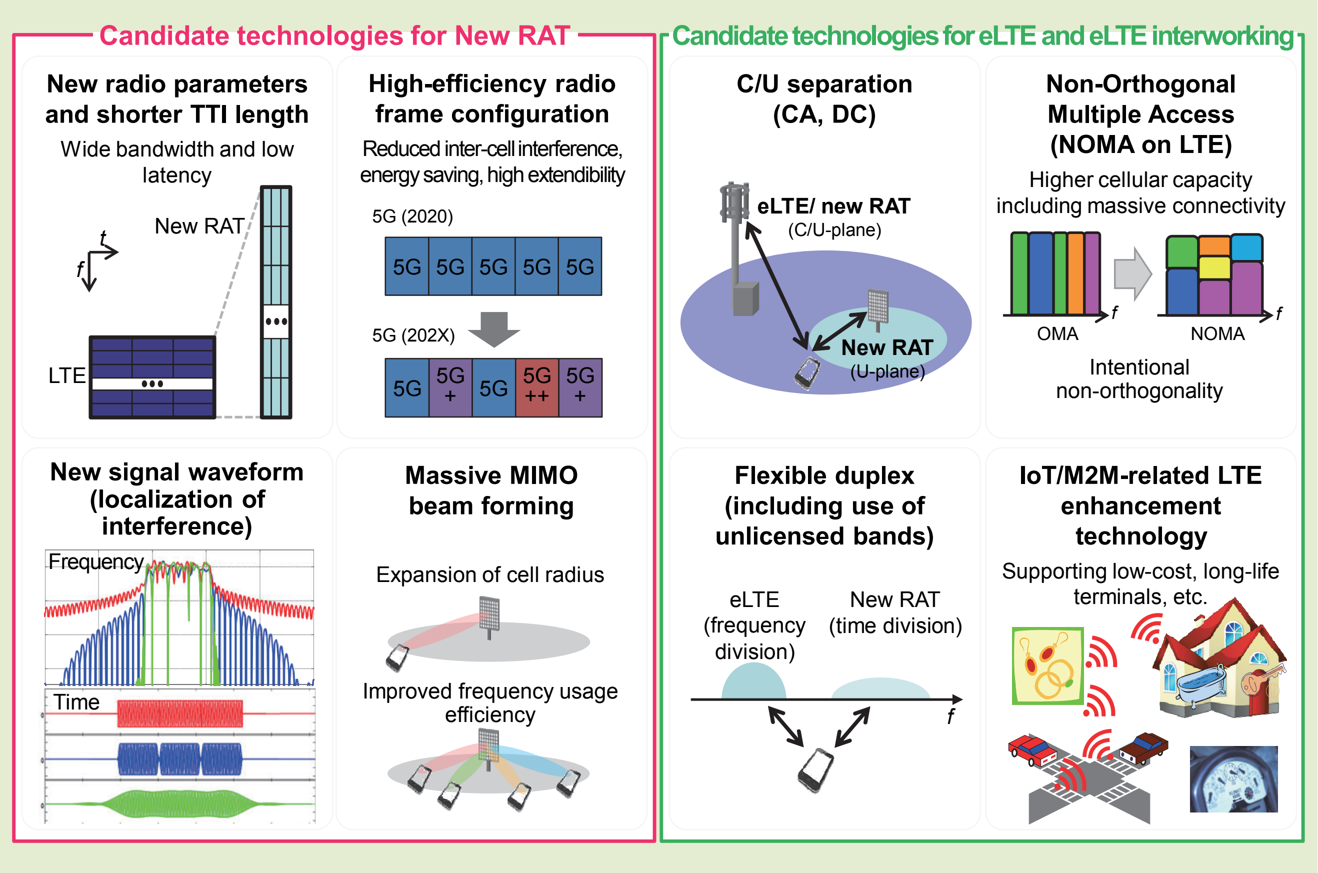



**Figure 8 Candidate technologies for 5G 2020 deployment**

was obtained in discussions held on this stepwise approach, but companies expressed a variety of opinions on the actual technologies to be emphasized in each step of standardization, so the plan is to hold more discussions going forward. According to the 3GPP Radio Access Network (RAN) chairman, policies (plans) regarding the standardization schedule can be summarized as follows [8].

- Begin Study Item (SI) on channel modeling in September 2015 (discuss status of high frequency bands up to December 2015 and begin study in RAN WG1 in first quarter of 2016)
- Begin SI on 5G requirements and scenarios in December 2015
- Begin SI on technology solutions in March 2016 (form a consensus prior to beginning the SI on what priority to assign to functions and topics of discussion in stepwise standardization)
- Complete Phase 1 specifications (Release 15) for New RAT by September 2018
- Complete Phase 2 specifications (Release 16) for New RAT by December 2019

**Photo 1 3GPP workshop scene**

The tentative schedule for 5G and 5G+ is shown in **Figure 9**. The plan here is to introduce 5G including Phase 1 specifications for New RAT in 2020.

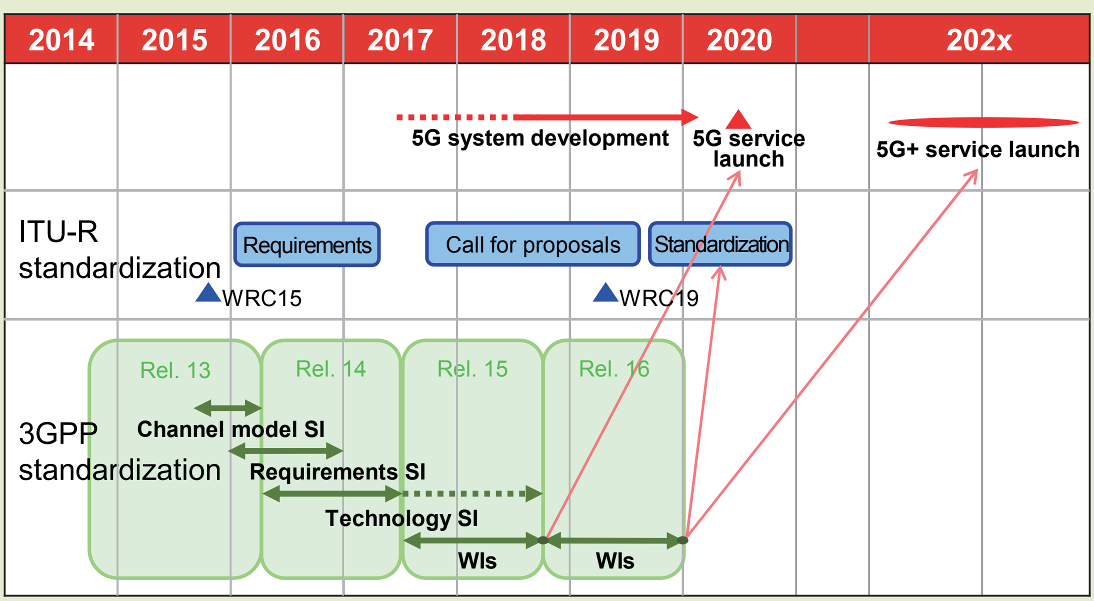



**Figure 9 Standardization schedule (tentative)**

Phase 2 specifications, meanwhile, will satisfy ITU-R requirements and will be rolled out as 5G+ several years later.

# 5. Overview of 5G-related Activities

## 5.1 International and Domestic 5G Activities

5G studies have been gaining momentum throughout the world for several years at international organizations and 5G study groups in various countries and regions, as summarized below.

- ITU-R

At ITU-R, Working Party 5D (WP 5D) is working on IMT-2020, which is the name given to the future IMT system corresponding to 5G. This work aims to extract the main capabilities that need to be achieved and summarize their quantitative values. The plan here is to begin detailed studies on requirements at the February 2016 meeting and to complete specifications sometime in 2020.

- NGMN

NGMN, an alliance of world-leading telecom carriers, released a white paper in March 2015 on use cases, requirements, and technology candidates toward 5G [2].

- European projects

A variety of 5G study projects have been completed or are underway in Europe under the 7th Framework Programme (FP7). These include METIS, a collaborative project between industry and academia begun in November 2012, 5th Generation Non-Orthogonal Waveforms for Asynchronous Signaling (5GNow), Beyond 2020 Heterogeneous Wireless Networks with Millimeter-Wave Small Cell Access and Backhauling (MiWaveS), and Interworking and JOINt Design of an Open Access and Backhaul Network Architecture for Small Cells based on Cloud Networks (iJOIN). METIS, in particular, released more than 30 deliverables before its project completion in April 2015 thereby contributing to the formation of 5G concepts in the research community. In addition to the above, the European Commission*15 announced its Horizon 2020 program as a framework for promoting R&D and innovation in Europe. This program is being publically funded with nearly 80 billion euros over a seven-year period beginning in 2014. As part of this program, the 5G Public Private Partnership (5G-PPP) was established in December 2013 as an institution for coordinating 5G-related projects.

- Asian projects

In Asia as well, 5G studies are progressing as 5G-related projects. In China, two organizations, the IMT-2020 (5G) Promotion Group and FuTURE Mobile Communication Forum have been established and the 863 Program and other 5G projects have been launched as national projects. In the Republic of Korea, the 5G Forum has been established as a collaborative effort among industry, academia, and government. It released a 5G white paper in March 2015.

- Activities in Japan

As 5G studies gain momentum throughout the world, Japan has been preparing its vision for mobile communications and technologies in the 2020s. It has initiated 5G promotional activities both inside and outside Japan by contributing to ITU-R WP5D and collaborating with 5G study groups in various countries and regions. Activities have been particularly active among industry, academia, and government toward a 2020 deployment of a 5G mobile communications system in conjunction with the 2020 Summer Olympics and Paralympics in Tokyo. In September 2013, the 2020 and Beyond Ad Hoc (20B AH) group was established under the Advanced Wireless Communications Study Committee of the Association of Radio Industries and Business (ARIB)*16. This group has released a white paper summarizing the results of its studies [9]. In addition, 5GMF was established in September 2014 under the leadership of the Ministry of Internal Affairs and Communications (MIC) to promote studies in radio access technologies, network technologies, and 5G applications [10].

*15 **European Commission:** The executive body of the European Union. It submits bills, implements decisions, upholds treaties, and otherwise carries out the day-to-day operations of the European Union.

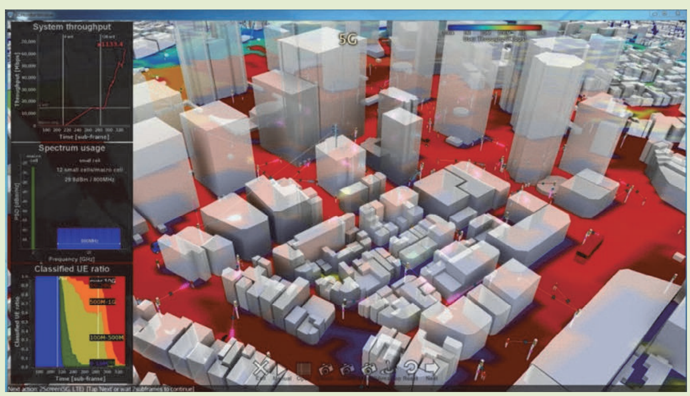
*16 **ARIB:** An organization subordinate to the MIC that sets standards for systems that use the radio spectrum in the fields of communications and broadcasting in Japan.

5GMF plans to hold integrated trials beginning in 2017.

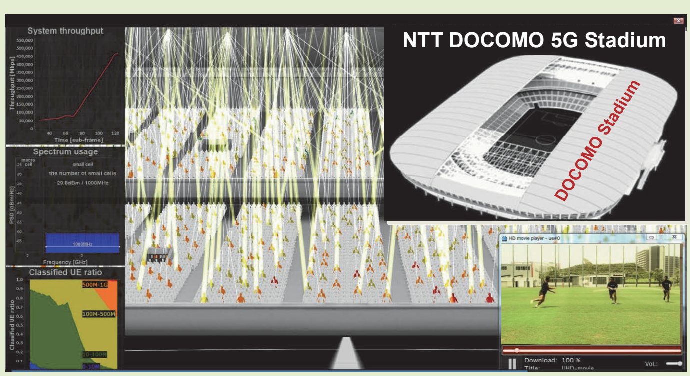
### 5.2 Activities at NTT DOCOMO

NTT DOCOMO has been conducting studies on 5G since 2010, the year in which it launched LTE commercial services, and has been participating actively in some of the 5G-related projects described above. It has also been developing a real-time simulator since 2012 to evaluate the capacity-enhancement effects of candidate technologies in the 5G system, which should also help visualize NTT DOCOMO's 5G technical concept. As shown in **Figure 10**, the combination of 5G RAT, band enhancement, and small cell*17 technology in a model simulating an actual Tokyo urban environment was able to increase capacity by more than 1000 times compared with an LTE macro cell*18 environment. NTT DOCOMO received the Minister of Internal Affairs and Communications Award at CEATEC Japan*19 2013 for an exhibition presenting this study.

Additionally, NTT DOCOMO achieved a bit rate of 10 Gbps as a world's first in an outdoor mobile environment as part of a 5G transmission experiment conducted jointly with Tokyo Institute of Technology in December 2012 [11]. It has also been conducting 5G experiments through separate collaborations with major vendors in the world since 2013. All in all, it has concluded agreements on collaborative experiments with a total of 13 companies as of November 2015 [12]. At the same time, NTT DOCOMO has been conducting its own experiments including the evaluation of indoor/outdoor transmission using NOMA technology [4] and the measurement of radio propagation in high frequency bands [13], this in ad-




Urban location (Shinjuku model)




Stadium model

**Figure 10 Screenshots of demonstration by 5G simulator**

*17 **Small cell:** General term for a cell covering a small area compared with a macro cell and having low transmission power.

*18 **Macro cell:** A cellular communication area with a radius of from several hundred meters to several tens of kilometers used mainly to provide outdoor communications. Macro cell antennas are usually installed on towers or roofs of buildings.

*19 **CEATEC Japan:** The largest international exhibition of imaging, information, and communications technologies in Asia.

dition to studying the core network in the 5G era [14]. These activities are introduced in more detail in other special articles in this issue.

## 6. Conclusion

This article focused on the 5G next-generation mobile communications system that is slated to provide a variety of new services including enhanced MBB for higher speeds and greater capacity and IoT connecting all kinds of things to the network by wireless means. It described research and development activities at NTT DOCOMO and world trends toward 5G. At NTT DOCOMO, we will continue to conduct transmission experiments and promote 5G standardization activities (scheduled to intensify next year) with the aim of launching 5G services in 2020 and supporting the continuous enhancement of 5G (5G+) in the years to come.

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RAT Waveform NOMA

Technology Reports

Special Articles on 5G Technologies toward 2020 Deployment

# 5G Radio Access Technology

*In parallel with the proliferation of smartphones, LTE services that can provide data transmission at even higher bit rates with low latency and high efficiency have been spreading rapidly, and the worldwide rollout of LTE-Advanced as an evolved form of LTE has already begun. Nevertheless, the need for further improvements in user QoE and system performance will surely increase going forward, and in anticipation of this need, studies on the next-generation mobile communications system (5G) have begun. This article describes the direction of technology development and promising component technologies for 5G RAT.*

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## 1. Introduction

Radio communications systems in mobile communications have undergone major changes about every ten years starting with the first generation (1G) deployed in the 1980s and evolving into the current fourth generation (4G) in the form of LTE/LTE-Advanced (**Figure 1**). There are key technologies for each of these generations, such as Code Division Multiple Access (CDMA)*1 for 3G and Orthogonal Frequency Division Multiple Access (OFDMA)*2 and Multiple Input Multiple Output (MIMO)*3 for 4G. The fifth generation (5G), however, will differ from previous generations in that priority will be placed on meeting specific requirements, namely, ultra-high data rate, ultra-high system capacity, ultra-low latency, massive device connectivity, and low power consumption, rather than on implementing completely new, pioneering technology. Here, the key issue will be how to combine a variety of component technologies in the best way to meet these requirements as Radio Access Technology (RAT)*4 matures. In this article, we survey the evolution of RAT toward 5G and describe key technologies from a 5G radio access perspective toward enhanced Mobile Broad Band (MBB) and the Internet of



*1 **CDMA:** The transmission of multiple user signals over the same radio access channel by assigning each signal a different spreading code.

*2 **OFDMA:** A radio access scheme that uses OFDM. OFDM uses multiple low data rate single carrier signals for the parallel transmission of wideband data with a high data rate, thereby implementing high-quality transmission that is highly robust to multipath interference.

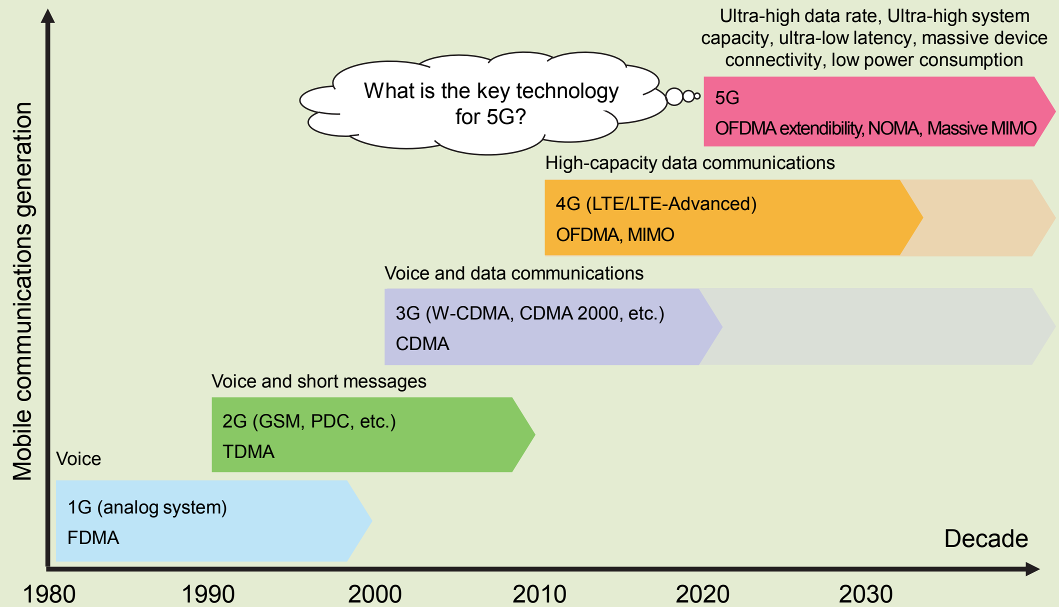


**Figure 1 Evolution of mobile communications systems and representative technologies of each generation**

Things (IoT)*5 era.

## 2. Evolution of RAT toward 5G

### 2.1 Ultra-high Data Rate, Ultra-high System Capacity Approach

The 5G system must achieve a dramatic leap in performance. Specifically, it must provide ultra-high data rate and ultra-high system capacity 100 times and 1,000 times, respectively, that of 2010, the first year of LTE services [1]. Here, we can consider the approach shown in **Figure 2** as a solution to increasing capacity. This approach combines technology for improving spectrum efficiency*6 (Fig. 2 (1)), technology for effectively using wider bandwidths in a variety of frequency bands (Fig. 2 (2)), and technology for operating small cells in dense deployments (Fig. 2 (3)). If, by this approach, spectrum efficiency per cell (bps/Hz/cell), frequency bandwidth (Hz), and number of cells per unit area (cell/km$^2$) in Fig. 2 (1), (2), and (3), respectively, can each be improved by ten times, a calculation of radio communications capacity per unit area (bps/km$^2$) will give a value of 1,000 times existing capacity (corresponding to the volume of the cube appearing in the figure). In addition, applying technologies such as high-efficiency offloading of traffic to wireless LAN is likewise an effective approach to increasing capacity that can be introduced in a mutually complementary manner (Fig. 2 (4)).

At the same time, extending and making effective use of frequency bandwidth in the next-generation mobile communications system will require the exploitation of higher frequency bands in addition to existing frequency bands used by 3G and 4G, and increasing the number of cells will invite higher network costs and increased power consumption. More efficient construction and operation methods are therefore needed. Further improvements in spectrum efficiency are also necessary as described above. In 5G, the above objectives must be achieved through novel

*3 **MIMO:** A signal transmission technology that improves communications quality and spectrum efficiency (see *6) by using multiple transmitter and receiver antennas to transmit signals at the same time and same frequency.

*4 **RAT:** Radio access technology such as LTE, 3G, and GSM.

*5 **IoT:** General term used to refer to control and information communications with the goald to connect all sorts of "things" to the Internet and cloud.

*6 **Spectrum efficiency:** Maximum amount of information that can be transmitted per unit frequency (bps/Hz).

designs and effective technical solutions.

## 2.2 C/U Splitting (Phantom Cell)

NTT DOCOMO has proposed the Phantom cell concept as a means of linking different frequency bands and different RATs [2]. As shown in **Figure 3**, this refers to a network configuration that uses C/U splitting in which the Control Plane (C-plane)*7 and User Plane (U-plane)*8 are split between a macro cell*9 and multiple instances of a small cell*10.

Much like Advanced Centralized Radio Access Network (C-RAN)*11 [3] architecture based on LTE-Advanced Carrier Aggregation (CA)*12 technology, this Phantom cell makes it easy to expand a cell to higher frequency bands without complicating mobility management and control as in handover*13 or other processes. Furthermore, as a feature not provided by Advanced C-RAN, the Phantom cell represents technology

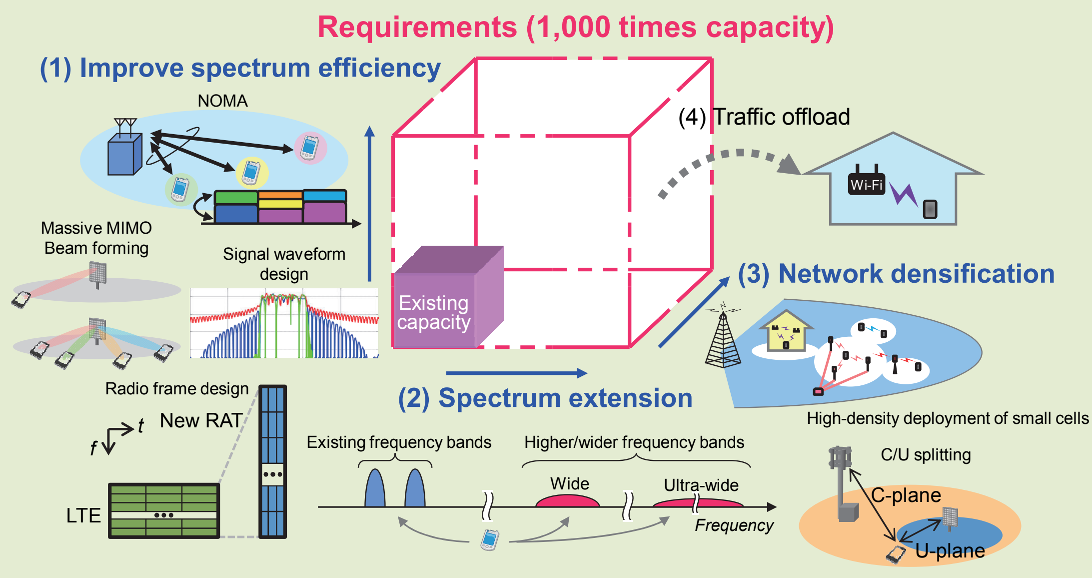


**Figure 2　Evolution of RAT toward 5G**

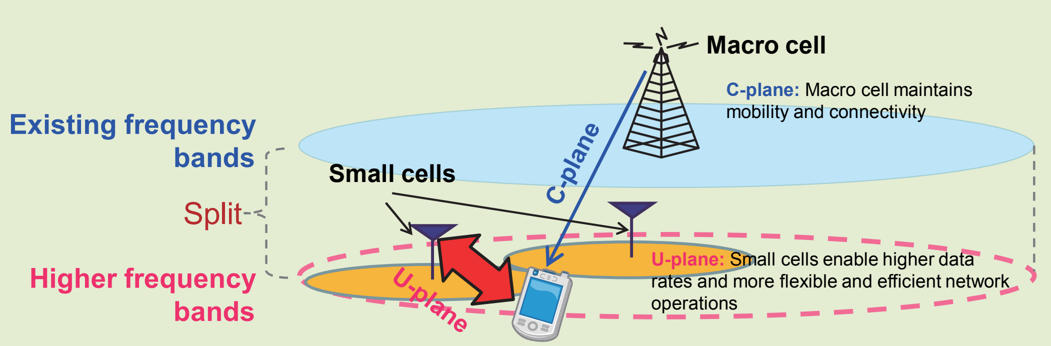


**Figure 3　Concept of C/U splitting (Phantom cell)**

*7　**C-plane:** Plane that handles control signals.

*8　**U-plane:** Plane that handles user data.

*9　**Macro cell:** A cellular communication area with a radius of from several hundred meters to several tens of kilometers used mainly to provide outdoor communications. Macro cell antennas are usually installed on towers or roofs of buildings.

*10　**Small cell:** General term for a cell covering a small area compared with a macro cell and having low transmission power.

*11　**Advanced C-RAN:** Technology for achieving close coordination between a macro cell and small cells and increasing spectrum efficiency.

*12　**CA:** A technology for increasing bandwidth while maintaining backward compatibility by simultaneously transmitting and receiving multiple component carriers.

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

that can achieve C/U splitting even in a distributed base station configuration. In other words, it enables CA technology to be applied even among different base stations with separate baseband units.

Phantom cell technology also negates the need for a physical cell ID*14 in small cells using higher frequency bands, and compared with existing LTE/LTE-Advanced, it can accommodate advanced functional extensions such as virtualization technology for virtualizing cell IDs and technology enabling terminals to efficiently discover small cells [4]. One component technology related to Phantom cells is Dual Connectivity (DC), whose specifications have already been completed at the 3rd Generation Partnership Project (3GPP) as small-cell enhancement technology in LTE-Advanced. The Phantom cell is also basic to the 5G radio access concept of supporting both low and high frequency bands by combining enhanced LTE (eLTE) and New RAT.

## 2.3 New RAT Design

1) Support of Flexible Radio Parameters

In 5G, the introduction of New RAT, while allowing for non-backward compatibility with LTE, must mean a significant increase in performance. Specifically, to achieve bit rates of 10 Gbps and greater, New RAT must support higher frequency bands in addition to wider bandwidths from several hundred MHz to 1 GHz and higher. However, the effects of phase noise*15 can be large in high frequency bands, so there is a need here to improve resistance to phase noise such as by optimizing radio parameters. For example, LTE applies Orthogonal Frequency Division Multiplexing (OFDM) with a subcarrier*16 interval of 15 kHz as a signal format. However, as shown in **Figure 4**, widening the subcarrier interval (shortening the OFDM symbol*17 length) in high frequency bands can reduce the effects of interference between subcarriers and improve resistance to phase noise.

Here, a design that enables LTE radio parameters to be changed in a scalable manner according to the frequency band in use is an effective method for achieving radio parameters ideal for high frequency bands. An advantage of such a design is that terminals supporting both LTE and New RAT (dual mode) and terminals that can simultaneously connect to both low and high frequency bands (DC) would be relatively easy to implement. Furthermore, since the packet Transmission Time Interval (TTI)*18 can be simultaneously shortened by the shortening of the OFDM symbol length (lower left in Fig. 2), latency in the radio access interval can also be reduced.

2) High-efficiency Radio Frame Configuration

In New RAT, a high-efficiency radio frame configuration is deemed necessary. For example, LTE features a Cell-specific Reference Signal (CRS) that is mapped and widely dispersed along the time and frequency axes for use in data demodulation and mobility measurement (**Figure 5**). However, a base sta-

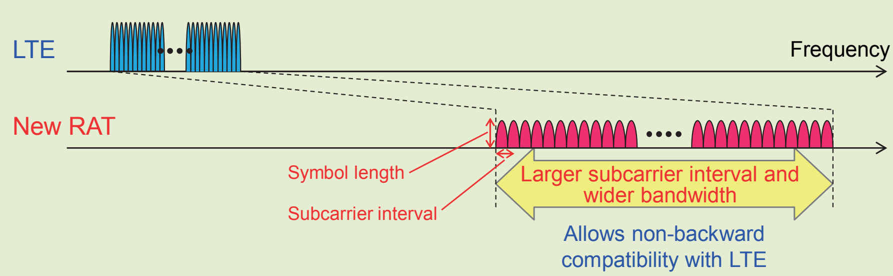


**Figure 4 New RAT design based on scaling radio parameters of LTE**

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

*15 **Phase noise:** Phase fluctuation that occurs due to frequency components other than those of the carrier frequency in a local oscillator signal.

*16 **Subcarrier:** An individual carrier for transmitting a signal in multi-carrier transmission schemes such as OFDM.

*17 **OFDM symbol:** A unit of transmission data consisting of multiple subcarriers. A Cyclic Prefix (CP) is inserted at the front of each symbol.

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

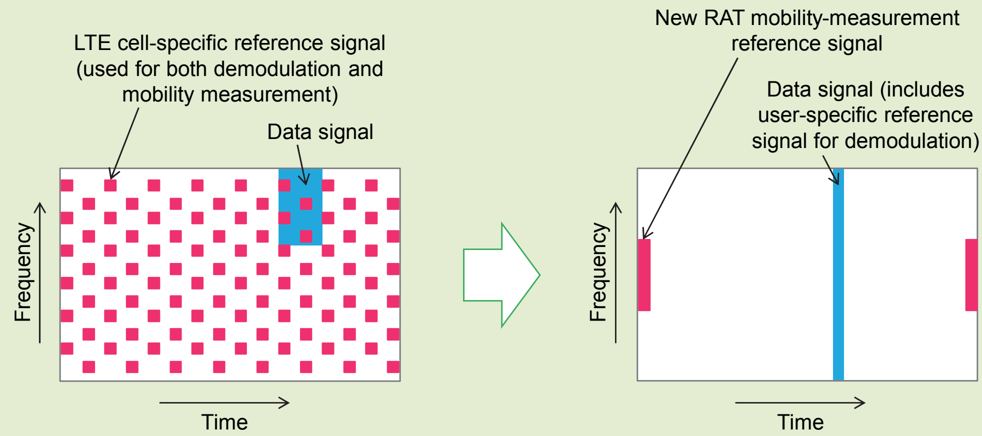


**Figure 5 High-efficiency radio frame configuration**

tion will regularly transmit CRS even during periods of no data traffic. These signals can therefore be a waste of energy while also interfering with other cells in environments having a dense deployment of cells as in urban areas.

Thus, for New RAT, studies are being performed on a high-efficiency radio frame configuration featuring a transmission gap at times of no data traffic. This is accomplished by transmitting the least number of reference signals needed for mobility measurement at relatively long intervals and in a local manner. In this case, reference signals for demodulation will be multiplexed with user-specific data signals. In addition, shortening of the TTI length means that data signals can be transmitted in even shorter time periods, which means that a reduction in power consumption can be expected.

Furthermore, considering the need for supporting a variety of scenarios (such as Device-to-Device (D2D)*19, radio backhaul*20, and multi-hop communications*21) that will be using New RAT in the future, a radio frame configuration with high symmetry between the uplink and downlink would be desirable.

## 3. Component Technologies for 5G Radio Access

The following describes key component technologies for 5G radio access. We omit description about Massive MIMO*22 technology here since it is introduced in another special article in this issue.

### 3.1 Waveform Design

From the point of view of signal waveform, MBB/IoT-related scenarios in the 5G system are targets of consideration (**Figure 6**). For MBB, coverage extendibility and propagation delay must be dealt with, extendibility to high frequency bands should be provided, and robustness to changing propagation channels in a high-speed mobile environment should be achieved. In the case of IoT, support for short packet transmission and asynchronous access in Machine Type Communications (MTC)*23 should be provided.

As shown in **Figure 7**, an effective approach here in 5G is to apply different radio parameters and waveform designs according to the frequency band and frequency bandwidth to be used and the application environment as well. For example, in 5G, we can consider that OFDM-based multi-carrier transmission*24 would be an effective candidate for signal waveforms and that a wide variety of frequency bands could be supported by applying variable radio

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*19 **D2D:** A communication method that enables direct exchange of data between two terminals without a base station as an intermediary.

*20 **Radio backhaul:** Achieving communications between base stations by a radio link.

*21 **Multi-hop communications:** A method that enables two terminals that cannot directly communicate with each other to communicate by having other terminals function as relays.

*22 **Massive MIMO:** Large-scale MIMO using a very large number of antenna elements. Since antenna elements can be miniaturized in the case of high frequency bands, Massive MIMO is expected to be useful in 5G.

*23 **MTC:** General term in 3GPP for machine-based communications using no intermediate human operations.

*24 **Multi-carrier transmission:** A method for modulating and transmitting multiple streams of data on multiple carriers. The OFDM method, for example, is used in LTE and LTE-Advanced.

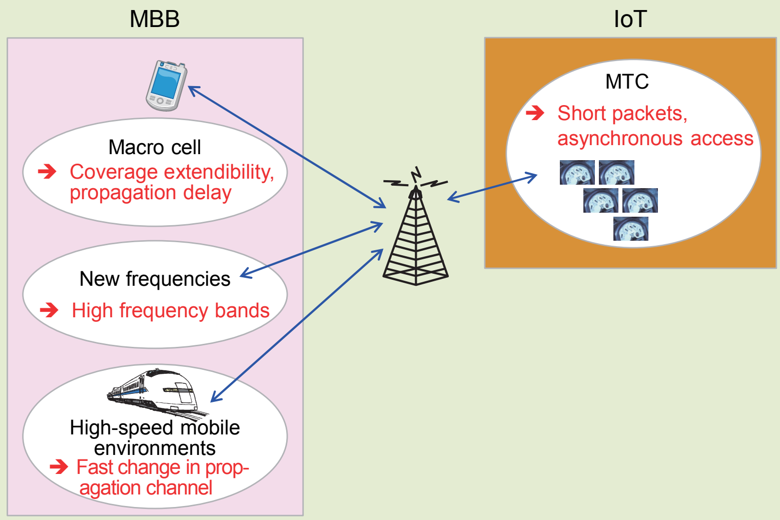


**Figure 6 Examples of MBB/IoT-related scenarios in 5G**

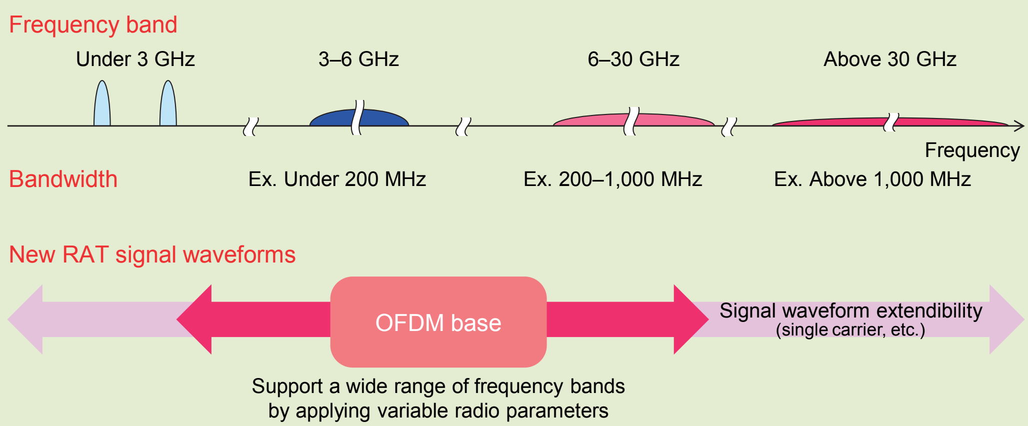


**Figure 7 Examples of candidate signal waveforms for various frequency bands**

parameters. However, from the viewpoint of supporting ultra-wide bandwidths (of several GHz) in very high frequency bands (above 30 GHz), single-carrier transmission*25 also becomes a candidate owing to its superiority in coverage compared to OFDM. Still, OFDM as the baseline transmission waveform in 5G has good affinity with MIMO and can achieve high spectrum efficiency under multipath*26 conditions in wide-bandwidth transmission. OFDM or new signal waveforms based on OFDM should facilitate the support for a wide variety of services. With the above in mind, signal waveforms need to have "high spectrum efficiency," "high localization in frequency/time domains (guard-band reduction by suppressing out-of-band in the frequency domain and limited time response by limiting transmission-signal spreading in the time domain)," and "high orthogonality between subcarriers (affinity with channel

*25 **Single-carrier transmission:** A method for modulating and transmitting a data signal on one carrier.

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

estimation*27 method and other technologies such as MIMO).” To satisfy these requirements, we are studying new signal waveforms that apply a filter to OFDM signals. In the following, we describe Filter Bank MultiCarrier (FBMC), Universal Filtered OFDM (UF-OFDM), and Filtered OFDM (F-OFDM) as new alternative signal waveforms toward 5G. In **Figure 8**, we present the frequency- and time-domain responses for OFDM applying a Cyclic Prefix (CP)*28 (CP-OFDM), which has already been introduced in the LTE downlink, and for the above-mentioned new alternative waveforms for 5G.

(1) FBMC

FBMC applies a filter in units of subcarriers. It applies, in particular, a filter with steep frequency characteristics to maintain orthogonality between subcarriers, but out-of-band radiation*29 is small compared with the other waveforms. On the other hand, the signal waveform response has a wide spread in the time domain, which raises concerns about an increase in overhead and an increase in delay time when applying short packets.

(2) UF-OFDM

UF-OFDM applies a filter in sub-band*30 units. It prevents inter-symbol interference by inserting a guard interval (no-transmission interval) for each symbol instead of a CP. Compared with FBMC, its out-of-band radiation is large, but its waveform spread in the time domain is small. UF-OFDM is therefore applicable to short packets and asynchronous access and is effective in shortening delay time.

(3) F-OFDM

F-OFDM applies a filter in units of sub-bands while maintaining CPs. The insertion of CPs here makes the use of a guard interval unnecessary, so a filter with a long filter length can be applied compared with UF-OFDM. However, compared with FBMC, the time spread of the waveform can be made small. Inter-symbol interference will occur since the edge of the filter exceeds the CP interval, but selection of an appropriate filter can minimize that effect. Similar to UF-OFDM, F-OFDM can be applied to short packets and asynchronous access and it is effective for shortening delay time.

With the aim of providing 5G services in 2020, NTT DOCOMO is collaborating with 13 leading international vendors to accelerate standardization and commercial development and is vigorously promoting 5G studies [5]. In terms of new signal waveforms, we are conducting experimental trials on FBMC and UF-OFDM with Alcatel-Lucent and on F-OFDM with Huawei. We are also

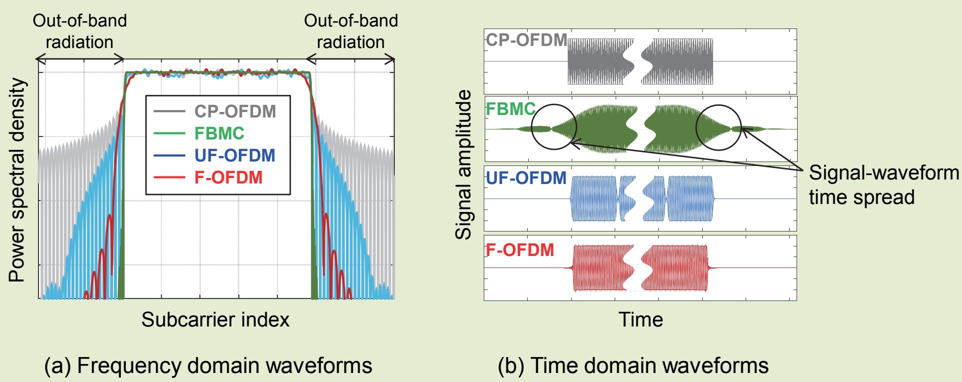


**Figure 8 Response of various signal waveforms in frequency/time domains**

*27 **Channel estimation:** Estimation of the amount of attenuation and phase change in the received signal when a signal is transmitted over a radio channel. The estimated values obtained (the channel data) are used for separating MIMO signals and demodulation at the receiver, and to compute channel data which is fed back to the transmitter.

*28 **CP:** A guard time inserted between symbols in OFDM signals, etc. to minimize interference between prior and subsequent symbols caused by multipath effects.

*29 **Out-of-band radiation:** Emission of power outside the frequency band allocated for communications.

*30 **Sub-band:** A frequency unit making up part of the entire frequency band.

collaborating with DOCOMO Communications Laboratories Europe on detailed studies to compare and evaluate the benefits of different types of signal waveforms and their affinity with MIMO [6].

### 3.2 Dynamic TDD and Flexible Duplex

Mobile communications systems up to 4G basically applied either Frequency Division Duplex (FDD)*31 that separates the uplink and downlink in the frequency domain or Time Division Duplex (TDD)*32 that separates the uplink and downlink in the time domain. However, in mobile communications using wide frequency bands as envisioned for 5G, the possibility exists of applying different types of duplex schemes to different types of frequency bands, so there is a need for "flexible duplex" that can support various types of duplex schemes in a flexible manner. To this end, it would be desirable to support an extension to dynamic TDD that can dynamically change the ratio of downlink subframes and uplink subframes (DL/UL configuration) in TDD, and to support the Phantom cell concept that performs C/U splitting among different frequency bands regardless of the duplex schemes used in those bands. In short, component technologies for "flexible duplex" in 5G can encompass flexible selection and simultaneous connection of communication links such as FDD, TDD, or for that matter, TDD DL only or TDD UL only (one-way TDD in either the downlink or uplink), as well as technology for adaptively selecting frequency bands including unlicensed bands, technology for achieving CA/DC, and countermeasures to interference between the uplink and downlink in such duplex communications.

### 3.3 NOMA

1) Overview

Multiple access methods in mobile communications systems evolved from Frequency Division Multiple Access (FDMA)*33 in 1G to Time Division Multiple Access (TDMA)*34 in 2G and CDMA in 3G, while 4G uses OFDMA that preserves orthogonality among users by multiplexing them over adjacent resources in the frequency domain. In contrast, Non-Orthogonal Multiple Access (NOMA), which is now under study for 5G, is a multiple access method that exploits the power domain to intentionally multiplex users in a non-orthogonal manner over the same resources in the frequency domain. Thus, when applied to the downlink, signals intended for multiple users within a cell are combined and transmitted simultaneously using the same radio resource by the base station. This scheme is expected to further improve spectrum efficiency and is considered to be a promising component technology for LTE evolution and 5G [7].

2) Basic Principle

The basic principle of the NOMA method is shown in **Figure 9**. Among User Equipment (UE) connected within a cell with their downlinks as a target, the base station selects a pair of terminals with one near the base station in the center of the cell having good reception ($UE_1$ in the figure) and the other near the cell's edge having poor reception ($UE_2$ in the figure), and multiplexes and transmits the signals to those terminals using the same time slot and same frequency resource. Here, more transmit power is allocated to the signal intended for $UE_2$ than to the signal intended for $UE_1$. Now, turning to the receive side, inter-user interference occurs at $UE_1$ near the base station since this terminal receives a multiplexed signal consisting of $UE_1$ and $UE_2$ signals. However, a simple interference cancellation process can be used to separate these two signals as long as a certain power difference exists between them.

For example, at $UE_1$ near the base station, such a process can first decode only the signal intended for $UE_2$ that has been allocated strong transmit power and use this decoded signal to create a signal replica*35, which can then be subtracted from the receive signal before separation after which the signal intended for $UE_1$ can be decoded. This signal separation process is called Successive

*31 **FDD:** A scheme for transmitting signals using different carrier frequencies and frequency bands in the uplink and downlink.

*32 **TDD:** A scheme for transmitting signals using the same carrier frequency and frequency band but different time slots in the uplink and downlink.

*33 **FDMA:** The transmission of multiple user signals using mutually different frequencies within the same radio access system band.

*34 **TDMA:** The transmission of multiple user signals using mutually different times within the same radio access system band.

*35 **Replica:** A regeneration of the received signal using predicted values for the transmitted signal.

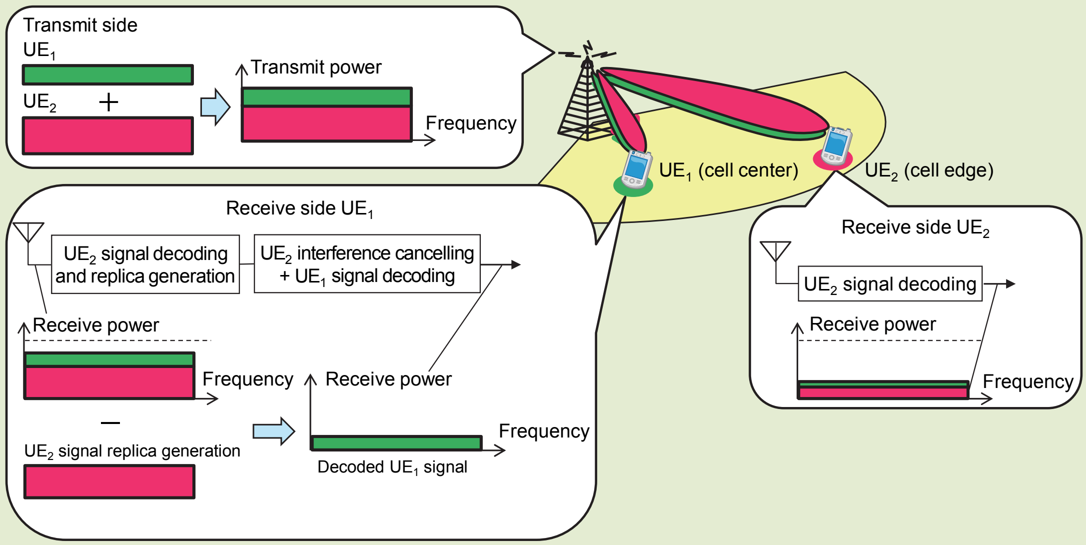


**Figure 9 Basic principle of NOMA**

Interference Cancellation (SIC)*36, and while it has been under study since the 3G era, the need for advanced processing on the terminal side has made it difficult to implement. Today, however, rapid progress in terminal processing power will make such technology feasible in the near future.

Next, on the UE$_2$ side, the fact that low transmit power has been allocated to the UE$_1$ signal that constitutes an interference signal to the UE$_2$ signal means that the signal intended for UE$_2$ can be directly decoded without applying SIC.

In addition, the need for applying NOMA can be dynamically selected in subframe*37 units in the base station's scheduler, which means that NOMA can coexist on a network that supports existing LTE/LTE-Advanced terminals. NOMA can also be combined with technologies that are being applied in LTE. For example, combining NOMA with MIMO in LTE would make it possible to multiplex data streams*38 at a number exceeding the number of transmit antennas thereby increasing system performance.

3) Performance Evaluations and Transmission Experiments

To assess the effectiveness of NOMA, NTT DOCOMO performed performance evaluations using computer simulations and transmission experiments using prototype equipment [8]–[11]. In this study, the radio frame configuration was based on that of LTE Release 8 and the target of these evaluations was Transmission Mode 3 (TM3) and Transmission Mode 4 (TM4) that respectively does not and does feed back a user Precoding Matrix Index (PMI)*39 to the base station.

(1) NOMA link level evaluation

Given the application of a Code Word level SIC (CWIC) receiver*40, **Figure 10** shows multiplex power ratio ($P_1$) of a cell-center user versus required Signal to Noise Ratio (SNR)*41 for which BLock Error Ratio (BLER) of the cell-center user applying CWIC satisfies $10^{-1}$. Here, we set the number of multiplexed users to 2 and applied 2-by-2 closed-loop Single User (SU)-MIMO*42 (in which feedback information from the user terminal is unnecessary) based on LTE TM3 [12]. The Modulation and Coding Scheme (MCS)*43 of each user was 64 Quadrature Amplitude Modulation (64QAM)*44

*36 **SIC:** A signal separation method in which multiple signals making up a received signal are detected one by one and separated by a canceling process.

*37 **Subframe:** A unit of radio resources in the time domain consisting of multiple OFDM symbols (generally 14 OFDM symbols).

*38 **Data streams:** Separate streams of data when performing parallel transmission as in MIMO. For example, the maximum number of data streams when applying 2-by-2 MIMO is 2.

*39 **PMI:** A matrix based on precoding weights for controlling the phase and amplitude of the transmit signal.

*40 **CWIC receiver:** An SIC receiver that decodes the interfering-user signal, generates an interfering replica signal, and applies an interference cancellation process.

*41 **Required SNR:** The minimum value of SNR required for performing MIMO signal separation to obtain a predetermined error rate or better.

*42 **SU-MIMO:** A technology for transmitting and multiplexing multiple signal streams by multiple antennas between a base station and terminal with one user as target.

*43 **MCS:** Combinations of modulation scheme and coding rate decided on beforehand when performing AMC.

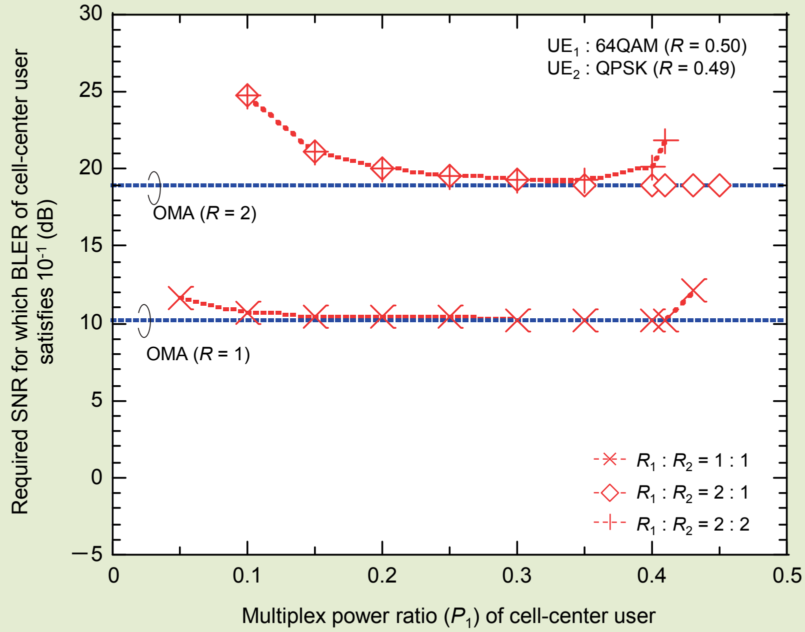


**Figure 10 NOMA link-level evaluation results**

(code rate: $R$ = 0.5) for the cell-center user and Quadrature Phase Shift Keying (QPSK)*45 ($R$ = 0.49) for the cell-edge user. Furthermore, in combining NOMA and MIMO, there are multiple combinations of the number of MIMO transmission streams (transmission rank) for each user as determined by the receive quality at each user's terminal. In this study, we used three combinations of rank values for the cell-center user and cell-edge user ($R_1$ : $R_2$), namely, 1:1, 2:1, and 2:2. Additionally, for comparison purposes, the figure includes characteristics for Orthogonal Multiple Access (OMA)*46 applied in LTE (i.e., OFDMA). Now, examining these results, it can be seen that the effects of inter-user interference increased and required SNR increased in the region corresponding to $P_1$ greater than 0.4. However, in the region corresponding to $P_1$ from 0.2 to 0.4 in which the probability of applying NOMA multiplexing is high, about the same required SNR was achieved as that when applying OMA. This result indicates that CWIC has high interference cancellation performance.

(2) NOMA system level evaluation

The results of a system level evaluation of throughput gain by NOMA over OMA are listed in **Table 1**. Here, we set the number of multiplexed users to 2 and the antenna configuration to 2-by-2, and applied LTE TM3 and TM4 [12]. Furthermore, assuming that inter-user interference can be ideally cancelled out, we show results for sub-band scheduling*47 that performs resource allocation and MCS selection in sub-band units and wideband scheduling*48 that performs resource allocation and MCS selection using the entire band. It can be seen from these results that NOMA achieves a gain over OMA in all cases, and when applying TM3 and Case 3, that NOMA improves cell throughput and cell-edge user throughput by 30.6% and 34.2%, respectively. These

*44 **64QAM:** A digital modulation method that allows for transmission of 6 bits of information simultaneously by assigning one value to each of 64 different combinations of amplitude and phase.

*45 **QPSK:** A digital modulation method that uses a combination of signals with four different phases to enable the simultaneous transmission of two bits of data.

*46 **OMA:** A multiple access scheme that prevents mutual interference between adjacent resources on the time or frequency axis. Orthogonal mutual access on the frequency axis is OFDMA.

*47 **Sub-band scheduling:** A scheduling method that feeds back the average Channel Quality Indicator (CQI) in sub-band units to the base station and allocates user resources and MCS likewise in sub-band units.

*48 **Wideband scheduling:** A method that feeds back the average CQI of the entire band to the base station and schedules the user using the entire band.

results demonstrate that NOMA has an enhancement effect with respect to user throughput.

(3) Results of measurements using prototype transmission equipment

Finally, we present the results of an experiment in an indoor radio-wave environment using prototype equipment. This NOMA prototype transmission equipment is shown in **Figure 11** (a) and examples of measurement results are shown in Fig. 11 (b). As shown in Fig. 11 (a), $UE_1$ and $UE_2$ are both stationary, the former installed near the base station and the latter at a point about 50 m from the base station (to the right outside the view in the photo). On evaluating throughput characteristics when applying 2-by-2 SU-MIMO, results showed NOMA could obtain a gain of approximately 80% over OFDMA.

New multiple access methods using non-orthogonal schemes in this way have been attracting much attention in recent years and have been taken up as key topics in overseas projects and international conferences [13]. In particular, study of these methods commenced in April 2015 at 3GPP, a leading international standardization body, as a Study

**Table 1　NOMA system-level evaluation results**

| | | 2 × 2 MIMO, TM3 | | | 2 × 2 MIMO, TM4 | | |
|---|---|---|---|---|---|---|---|
| | | OMA | NOMA | Gain | OMA | NOMA | Gain |
| Case 1: Sub-band scheduling and sub-band MCS selection | Cell throughput | 21.375 | 27.053 | 26.56 % | 21.97 | 27.866 | 26.84 % |
| | Cell-edge user throughput | 0.472 | 0.633 | 34.11 % | 0.544 | 0.777 | 42.83 % |
| Case 2: Sub-band scheduling and wideband MCS selection | Cell throughput | 21.59 | 26.29 | 21.77 % | 22.291 | 27.499 | 23.36 % |
| | Cell-edge user throughput | 0.476 | 0.62 | 30.25 % | 0.552 | 0.769 | 39.31 % |
| Case 3: Wideband scheduling and wideband MCS selection | Cell throughput | 19.068 | 24.894 | 30.55 % | 19.577 | 25.515 | 30.33 % |
| | Cell-edge user throughput | 0.401 | 0.538 | 34.16 % | 0.451 | 0.649 | 43.90 % |

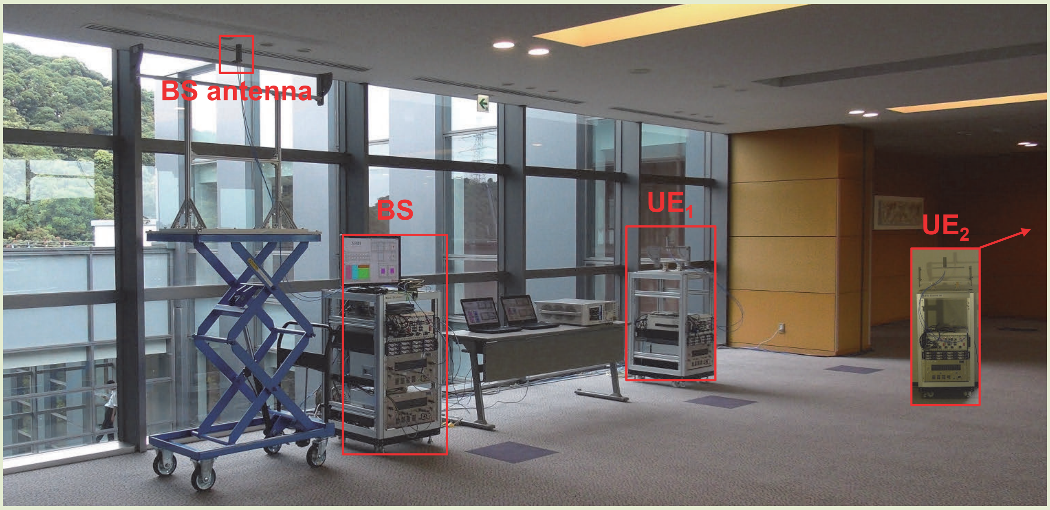


**Figure 11 (a)　External view of NOMA prototype transmission equipment (indoor experiment environment)**

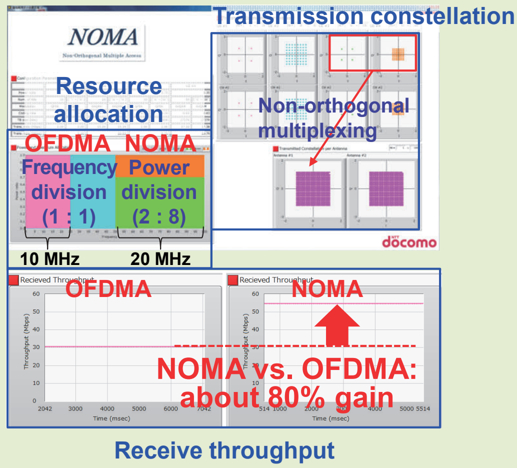


**Figure 11 (b)　Example of measurement results in NOMA transmission experiment**

Item (SI)*49 for LTE Release 13 [14] [15]. In addition, NTT DOCOMO is evaluating NOMA in the uplink in addition to the downlink in a collaborative project with DOCOMO Beijing Communications Laboratories [7] [16].

### 3.4 IoT-related Technologies

In 5G, it is essential that support be provided for IoT in addition to MBB. However, IoT covers a variety of categories with a variety of requirements, and the New RAT design would need to be tailored to each category to meet the requirements. In IoT, key categories that are now attracting attention are massive Machine Type Communications (mMTC) and Ultra-Reliable and Low Latency Communications (URLLC) [13].

One example of mMTC is a large number of sensors that send out small and short packets. In this case, the design of signal waveforms that support coverage expansion and asynchronous communications is important. In addition, mMTC would benefit from NOMA [16] in the uplink to improve control channel capacity and increase the number of simultaneously connected devices, and it would also benefit from the design of a control channel that requires no control information (e.g., a channel access method that makes pre-authorization when transmitting data unnecessary (grant free access*50)). Next, an example of URLLC would be a service like autonomous driving. Key technologies for supporting URLLC would be high-speed uplink/downlink switching and mobile edge computing to exploit the low latency features of the 5G New RAT [17]. Furthermore, in the case of automobiles and trains in which mobility is an issue, group mobility and mobile backhauling take on importance [18].

## 4. Conclusion

This article described the 5G radio access technology concept and the promising component technologies for realizing it. The idea here is to effectively combine a wide range of frequency bands from existing low frequency bands to the Extremely High Frequency (EHF) band*51 to both maintain coverage and increase capacity while expanding bandwidth. The 5G New RAT therefore needs to be designed to support such a wide range of frequency bands from existing frequency bands to higher frequency bands. Looking to the future, NTT DOCOMO is committed to exploring new ways to further improve spec-

*49 **SI:** The phase of studying a technical issue before starting the work on technical specifications.

*50 **Grant free access:** A radio-channel access method that requires no pre-authorization from the base-station side prior to data transmission. This method enables a terminal to transmit data to the base station at any time.

*51 **EHF band:** Frequency band in the range of 30-300 GHz with wavelengths of 1-10 mm. Also called “millimeter Wave (mmWave) band.”

trum efficiency by studying both frequency-band-specific technologies and frequency-band-agnostic technologies.

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5G | Massive-element Antenna | Beamforming

Technology Reports

Special Articles on 5G Technologies toward 2020 Deployment

# 5G Multi-antenna Technology

*NTT DOCOMO is researching and developing the fifth-generation mobile communications system (5G) toward the provision of super-high-speed, super-high-capacity wireless communications services. In 5G, the aim is to widen the bandwidth of transmission signals by using frequency bands higher than those of existing frequency bands. However, as radio propagation loss increases in high frequency bands, this loss must be compensated for by adaptively controlling antenna directivity using massive-element antennas as 5G multi-antenna technology. This article describes 5G multi-antenna technology and discusses the feasibility of super high bit rates above 10 Gbps.*

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*Satoshi Suyama*
*Tatsuki Okuyama*
*Yuki Inoue*
*Yoshihisa Kishiyama*

## 1. Introduction

NTT DOCOMO is researching and developing "5G" toward the provision of super-high-speed, super-high-capacity wireless communications services [1] [2]. The idea behind 5G is to increase transmission bit rates by using frequency bands higher than those of existing frequency bands and widening the signal bandwidth. However, as radio propagation loss increases in high frequency bands, the application of massive-element antennas each consisting of more than 100 antenna elements has been studied as 5G multi-antenna technology [1]–[5]. Application of a massive-element antenna makes it possible to compensate for the radio propagation loss by adaptively controlling antenna directivity*1 and increase bit rate by the spatial multiplexing of signals. In this article, we begin by describing the operation and effect of massive-element antennas as 5G multi-antenna technology, which NTT DOCOMO has been promoting worldwide through technical studies and transmission experiments [6]. We then describe technical issues in the application of massive-element antennas in high frequency bands and NTT DOCOMO's efforts in resolving those issues. Next, we present the results of computer simulations using massive-element antennas and discuss the feasibility of super-high-speed communications.



*1 **Antenna directivity:** The directional characteristics of the radiated or received strength of the antenna.

## 2. Operation and Effect of Massive-element Antennas

### 2.1 Introduction of Massive-element Antennas through Phantom Cells

1) C/U Separation by Phantom Cells

The Phantom cell concept shown in **Figure 1** has been proposed as a basic 5G architecture [2]. Here, a conventional macro cell*2 contains multiple instances of a small cell*3 (or quasi-macro cell) in an overlay*4 configuration. In this scheme, the macro cell uses the Ultra High Frequency (UHF) band (0.3–3 GHz) employed by the existing system while overlaid small cells use higher frequency bands, namely, the low Super High Frequency (SHF) band (3–6 GHz), high SHF band (6–30 GHz), and Extremely High Frequency (EHF) band (30–300 GHz). This scheme also establishes a connection link for the Control Plane (C-plane)*5 that handles control signals via the macro cell and a connection link specifically for the User Plane (U-plane)*6 that handles user data via overlaid cells, i.e., C/U split connections. While the macro cell maintains the service area using the UHF band, the overlaid cells widen signal bandwidth and achieve super high bit rates using high frequency bands.

2) Introduction of Massive-element Antennas in High frequency band Cells

Achieving super high bit rates greater than 10 Gbps requires bandwidths of several 100 MHz. To this end, we have been studying the use of high frequency bands, but it is known that radio propagation loss increases at higher frequencies. This issue can be resolved by introducing massive-element antennas in high frequency band cells. In such a configuration, high frequency bands become available for use by suppressing the radio propagation loss through the application of massive-element antennas. Macro-cell-assisted operation of massive-element antennas is also possible.

### 2.2 Beamforming Effect of Massive-element Antenna

1) Beamforming by Massive-element Antenna

When using a flat antenna array with a uniform antenna spacing as a massive-element antenna in the 20 GHz band (**Figure 2**), and when setting the element spacing to half the wavelength (7.5 mm), it becomes possible to mount 256 elements in an area approximately 12 cm square. Generally, for the same area, the number of elements that can be mounted can be significantly increased when using higher frequency bands (shorter wavelengths). A massive-element antenna can be used to generate sharp beams (antenna directivity) by controlling the amplitude and phase of signals transmitted (received) from each element. This process is called “beamforming,” which has the effect of compensating for radio propagation loss.

2) Beamforming Effect

The beamforming effect in the 3.5, 10, and 20 GHz bands given a total transmission power of 33 dBm*7 for all an-

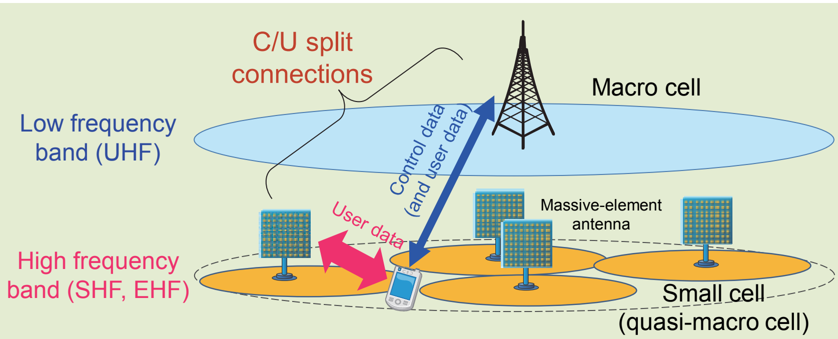


**Figure 1 Combination of Phantom cell concept and Massive MIMO**

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*2 **Macro cell:** A cellular communication area in which one base station can cover a radius of from several hundred meters to several tens of kilometers.

*3 **Small cell:** General term for a cell covering a small area compared with a macro cell and having low transmission power.

*4 **Overlay:** The arranging of cells each covering a relatively small area within a macro cell area.

*5 **C-plane:** Plane that handles control signals. The process of exchanging control signals to establish communications, etc.

*6 **U-plane:** Plane that handles user data. The process of transmitting and receiving user data.

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

tenna elements is shown in **Figure 3**. Specifically, this figure shows beam-arrival distances for each of these frequency bands and for massive-element-antenna sizes of 20, 40, and 80 cm square. On comparing these results for the same number of elements, it can be seen that arrival distance becomes shorter as frequency becomes higher, but that it does not significantly decrease for the same antenna size even at 20 GHz. However, while the arrival distance jumps to 490 m for a 100 (10 × 10) element antenna in the 10 GHz band, more than 400 (20 × 20) elements would be needed to achieve about the same arrival distance for the same antenna size in the case of a 20 GHz antenna. In other words, the number of elements increases and costs rise as frequency increases. As a result, finding measures for reducing such costs in massive-element antennas has become an issue in 5G multi-antenna technology.

### 2.3 User Multiplexing and Spatial Multiplexing in Massive-element Antennas

1) Massive MIMO Effect by Massive-element Antenna

Multiple-Input Multiple-Output (MIMO)*8 transmission using a massive-element antenna is called "Massive MIMO" [7] [8]. As shown in **Figure 4**, appropriately controlling a massive-element antenna in Massive MIMO can expand the communication area through propagation loss compensation and can also increase the system capacity of the high frequency band cell through user multiplexing that simultaneously connects multiple users [9]. Massive MIMO can also increase the communication bit rate for an individual user through spatial multiplexing of more than one data stream*9.

However, to achieve these capabilities, a precoding*10 process is needed in the transmitter to prevent interference

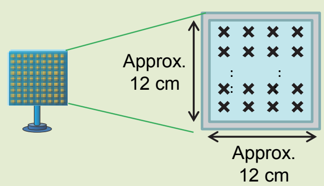


**Figure 2 Effect of introducing Massive MIMO**

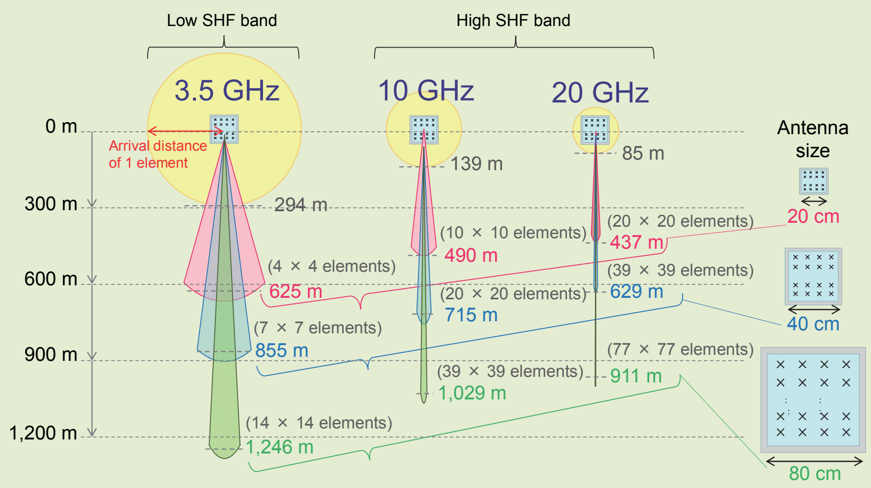


**Figure 3 Beamforming effect**

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

*9 **Stream:** A data sequence transmitted over a propagation channel using MIMO transmission.

*10 **Precoding:** A process for improving the quality of signal reception by multiplying signals before transmission with weights according to the current radio propagation channel.

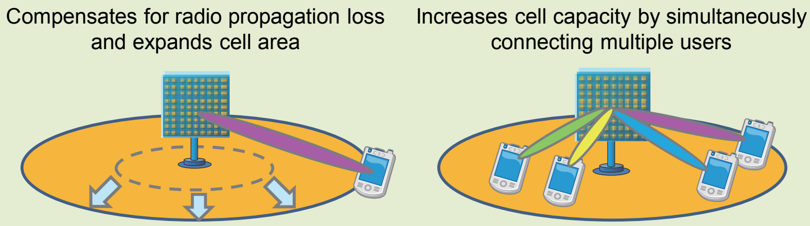


**Figure 4 Effects of introducing Massive MIMO**

between users and between streams. Furthermore, to achieve high-accuracy precoding, Channel State Information (CSI)*11 that conveys the state of the radio propagation channel is also needed in the transmitter, so CSI as estimated on the terminal side has to be fed back to the base station. A method that combines this CSI with CSI obtained by Time Division Duplex (TDD)*12-based channel reciprocity*13 can also be considered [7].

2) Optimal Operation of Massive MIMO

The antenna elements in Massive MIMO are used for both beamforming and user/spatial multiplexing and are therefore allocated as needed. However, for a fixed number of antenna elements, this means that the beamforming effect will suffer as the user/spatial multiplexing number increases. There is therefore a need to operate Massive MIMO in an appropriate manner in unison with CSI. Additionally, decreasing the user/spatial multiplexing number (increasing the number of antenna elements allocated to beamforming) can enhance the beamforming effect while also achieving a quasi-macro cell as shown in Fig. 1. Covering a wide area in this way can facilitate the construction of an efficient service area even in a suburban environment.

## 3. Technical Issues in High Frequency Band Massive MIMO and Efforts toward Deployment

### 3.1 Technical Issues in High-frequency-band Massive MIMO

As described above, the use of high frequency bands is essential to significantly improve system capacity and bit rate in 5G. However, there are not a few technical issues that need to be resolved to introduce Massive MIMO in high frequency bands, as described below.

- The spatial characteristics of the radio propagation path in high frequency bands assuming the use of a massive-element antenna have not yet been sufficiently explained [10]. Furthermore, in addition to propagation loss, shadowing loss due to structures and obstacles is large in high frequency bands compared with low frequency bands, so the shadowing effects caused by the body of a user holding a mobile phone must also be taken into account [10].
- To implement Massive MIMO in equipment at low cost, it will be necessary to achieve the high-frequency-band Radio Frequency (RF)*14 circuit and baseband*15 processing circuit on one chip to the extent possible using, for example, a silicon Complementary Metal Oxide Semiconductor (CMOS)*16 Integrated Circuit (IC). Recently, however, it has become possible to implement RF circuits for even the EHF band on silicon CMOS, so conditions for using high frequency bands in terms of implementing circuits are coming to be established.
- Although it is technically difficult to achieve high gain in a high frequency band power amplifier, Massive MIMO makes it possible to incorporate a power amplifier for each antenna and thereby greatly reduce the trans-

*11 **CSI:** Parameters indicating attenuation, phase rotation, and delay of a transmission signal after passing through a radio propagation channel between transmitter and receiver.

*12 **TDD:** A bidirectional transmission/reception method. It enables bidirectional communications by using the same frequency band in the uplink and downlink while allocating signals to different transmission times.

*13 **Channel reciprocity:** In bidirectional communications, the effects of same channel fluctuation on the receive signal in the uplink and downlink.

*14 **RF:** The carrier frequency of the radio signal.

*15 **Baseband:** Signal band before modulation or after demodulation.

*16 **CMOS:** A type of semiconductor circuit characterized by low power consumption that conducts very little current in a steady state.

mission power required per power amplifier. Achieving high gain here is consequently not a problem. On the other hand, the frequency synthesizer*17 exhibits a relatively high level of phase noise*18, so in 5G, that effect must be considered when setting radio parameters such as the subcarrier*19 spacing.

- Given the need to prepare many RF circuits in a number corresponding to the number of antenna elements, studies are also being performed on integrating filters and antennas [11]. Another problem here is that downsizing devices will require high-precision processing. Massive MIMO will require technology for fabricating and wiring circuits at super high densities, but the effects of mutual coupling between antennas and devices in such a super-high-density configuration can be large. To reduce such effects, there will be a need for calibration*20 so that the characteristics between antenna elements match.
- Although an array antenna*21 consisting of several tens of elements has already been achieved in the form of an adaptive array antenna*22 and Active Antenna System (AAS)*23, it will be necessary in 5G to greatly reduce costs compared with that of past systems in order to deploy many Massive MIMO base stations for use in high frequency bands.

### 3.2 Toward Massive MIMO in Low SHF Band

1) Distributed Massive MIMO

Massive MIMO presumes the use of massive-element antennas. In the low SHF band, concentrating more than 100 antenna elements at a single location results in a fairly large antenna as shown in Fig. 3. One method for avoiding such a large antenna is distributed Massive MIMO that arranges compact low-SHF-band many-element antennas at multiple locations so that antenna size becomes comparable to that of high-SHF-band massive-element antennas.

2) Combining Concentrated and Distributed Deployments According to Usage Environment

In the case of low-SHF-band Massive MIMO in a localized arrangement, a massive-element antenna will be installed on the roof of a building, for example, and sharp beams will be formed toward individual users from a relatively high location. In contrast, distributed Massive MIMO emits radio signals from multiple compact many-element antennas thereby mitigating the shadowing effects in an environment with many obstacles. Thus, in terms of usage environments, we can consider the use of localized Massive MIMO in the suburbs or comparatively large public squares or plazas and the use of distributed Massive MIMO in shopping malls or business districts. In actuality, however, a service area must be constructed with a flexible combination of concentrated and distributed deployments and a mechanism for doing so must be developed.

Fundamental transmission experiments have been held using a massive-element antenna consisting of 128 elements (**Figure 5**) as technical verification of concentrated Massive MIMO [12]. Furthermore, as technical verification of distributed Massive MIMO, fundamental transmission experiments have been held on installing compact many-element an-

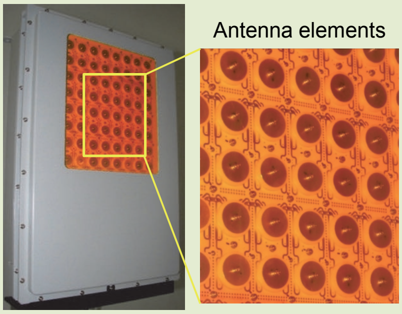


**Figure 5 Example of a localized Massive MIMO antenna (128 elements)**

*17 **Synthesizer:** Device for frequency and waveform modulation.

*18 **Phase noise:** Phase fluctuation that occurs due to frequency components other than those of the carrier frequency in a local oscillator signal.

*19 **Subcarrier:** An individual carrier for transmitting a signal in multi-carrier transmission schemes such as OFDM.

*20 **Calibration:** Pre-correction of imbalance in characteristics among antennas when arranging multiple antenna elements, etc. to emit signals in a suitable manner.

*21 **Array antenna:** An antenna consisting of a matrix of multiple elements.

*22 **Adaptive array antenna:** An antenna array that can orient radio waves in the direction of their arrival at the receiver by controlling the phase of individual antenna elements.

tennas in high-density distributed deployments with coordinated multipoint transmission. These antennas are capable of flexible antenna configurations as shown in **Figure 6** [13].

### 3.3 Toward Massive MIMO in High SHF Band and EHF Band

Compared with the low SHF band, Massive MIMO in the high SHF band and EHF band features wideband signals and a greater number of antenna elements. There is therefore a need for cost-saving measures in the configuration of radio equipment that achieves Massive MIMO.

1) Full Digital Massive MIMO

The configuration of a typical Massive MIMO transmitter employing Orthogonal Frequency Division Multiplexing (OFDM)*24 is shown in **Figure 7**. This transmitter requires Digital to Analog Converters (DACs) and upconverters in the same number as transmitter antenna elements. Similarly, it also requires the baseband processing circuits that perform an Inverse Fast Fourier Transform (IFFT)*25 and attach a Cyclic Prefix (CP)*26 to signals as signal processing in exactly the same number as transmitter antenna elements. In this configuration, digital precoding using CSI becomes possible in the frequency domain*27 in a high-performance process called "full digital Massive MIMO." However, implementing full digital Massive MIMO in the high SHF band and EHF band is not without its problems. For example, it requires DACs and Analog to Digital Converters (ADCs) that are expensive and that consume relatively more power as a result of wider signal bandwidths, and it also requires massive-element RF circuits for which high-performance operation is difficult.

2) Hybrid Beamforming

Beamforming means orienting a beam

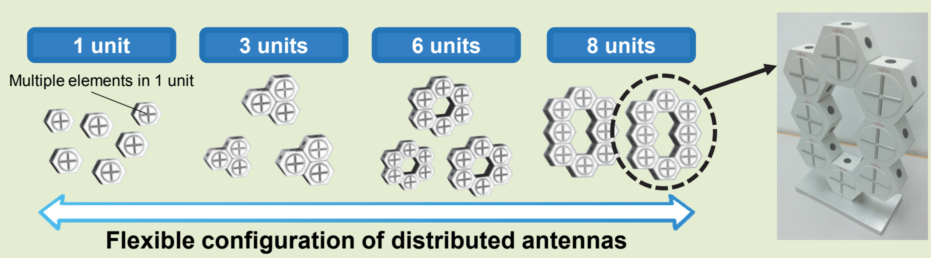


**Figure 6 Distributed-type arrangements of compact many-element antennas**

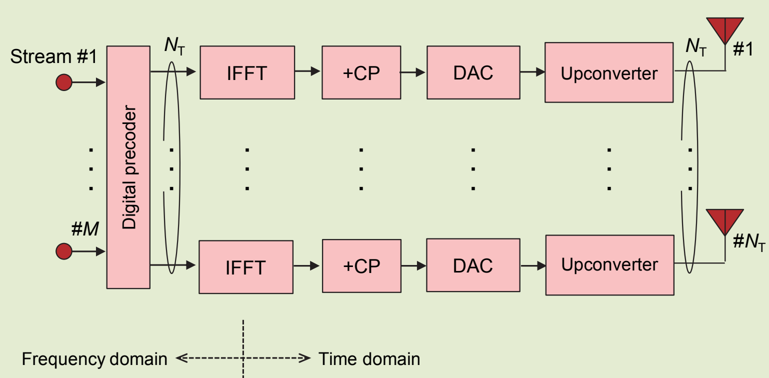


**Figure 7 Typical Massive MIMO transmitter using OFDM (full digital Massive MIMO)**

*23 **AAS:** A system that integrates antenna elements and RF circuits that have traditionally been separated thereby providing a more efficient system.

*24 **OFDM:** A parallel-transmission technique that divides data among multiple mutually orthogonal carriers.

*25 **IFFT:** A calculation technique for achieving high-speed processing of an inverse discrete Fourier transform that converts a sampled frequency domain (see *27) signal into a sampled time domain (see *28) signal. The inverse transform of a Fast Fourier transform (FFT) that corresponds to high-speed processing of a discrete Fourier transform.

*26 **CP:** A guard time inserted between symbols in OFDM signals, etc. to minimize interference between prior and subsequent symbols caused by multipath effects.

in the direction of radio-signal radiation (arrival), so common beamforming across the entire band can be considered after allowing for a certain amount of performance degradation. In this case, commonalizing the beamforming process across all subcarriers would enable beamforming to be moved to a position after IFFT processing and only beamforming in digital precoding to be moved to the time domain*28.

To achieve low-cost Massive MIMO transmitters, studies have been performed on a hybrid beamforming configuration that combines digital precoding and analog beamforming as shown in **Figures 8** and **9** [14] [15]. This configuration moves only the beamforming process in the full digital configuration to the time domain and replaces it with analog beamforming achieved by vari-

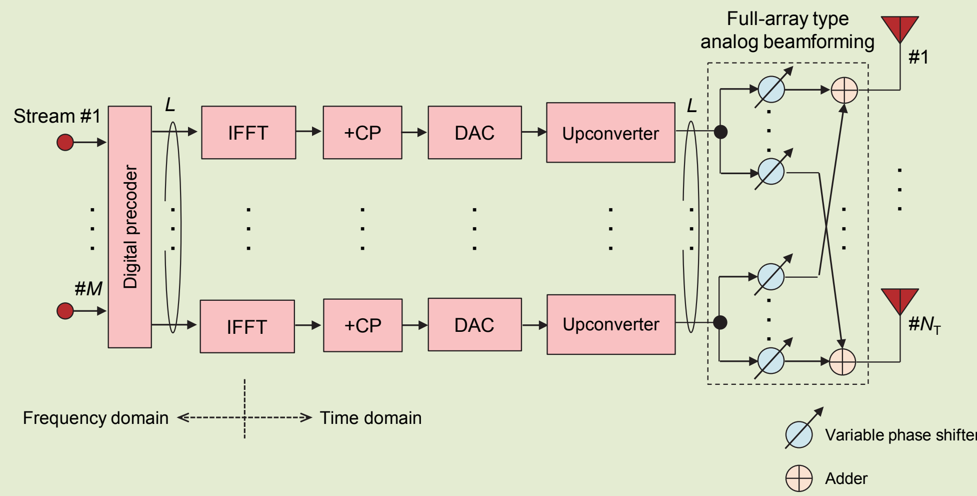


**Figure 8 Full-array type hybrid beamforming**

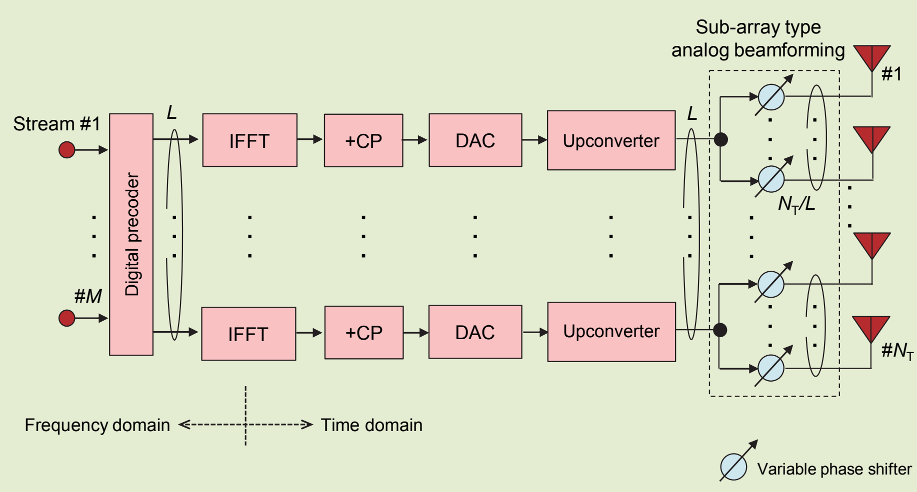


**Figure 9 Sub-array type hybrid beamforming**

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

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

able phase shifters*29 in the RF circuits. In such a hybrid beamforming configuration, only beam-number $L$ worth of DACs and upconverters need be prepared and the number of IFFT processes can be reduced.

Two types of hybrid beamforming can be considered here: a full-array type using all antenna elements as shown in Fig. 8 and a sub-array type using only some of the antenna elements as shown in Fig. 9. The full-array type requires adders*30 and many more variable phase shifters, but its performance is much higher.

3) Configuration with Analog Beamforming Only

As an even simpler configuration, there is also a method that uses only analog beamforming. In this case, there is no need for digital precoding, so the beamforming circuit can be simplified. Despite this advantage, if narrow beams generated by such analog beamforming cannot be made mutually orthogonal, inter-beam interference cannot be reduced. It would then be necessary to reduce the number of beams and increase the number of antenna elements for generating each beam. The potential of analog beamforming in the high SHF band and EHF band has been demonstrated by transmission experiments [16] [17].

4) FBCP Algorithm for Hybrid Beamforming

To achieve super high bit rates greater than 10 Gbps at bandwidths of several 100 MHz, the spatial multiplexing of streams using multiple beams will be required. Under this condition, a hybrid beamforming configuration can be considered from a cost-reduction perspective, and Fixed analog Beamforming and CSI-based Precoding (FBCP) as a specific algorithm for implementing such hybrid beamforming has been proposed [18]. This algorithm is summarized below.

(1) Spatially scan beams by angle-fixed analog beamforming and select $L$ number of beam candidates in order of beams with highest received power at the terminal

(2) Transmit a reference signal using the selected beams generated by analog beamforming and estimate CSI at the terminal

(3) Feed back the estimated CSI to the base station, execute digital precoding using that CSI, and perform communications

As described above, reference-signal insertion loss can be minimized by transmitting a reference signal by the selected beams instead of transmitting it by all spatially scanned beam candidates.

## 4. Feasibility of Super High Bit Rates by Massive MIMO in High SHF Band

We set out to quantitatively clarify the feasibility of super high bit rates by Massive MIMO in the high SHF band through computer simulations. In these simulations, we compared the characteristics of full digital Massive MIMO with those of two types of hybrid beamforming using a 256-element antenna in the 20 GHz band. We applied the FBCP algorithm to hybrid beamforming.

Simulation conditions are listed in **Table 1**. Here, we made the number of receiver antenna elements the same for all users and fixed the total number of transmission streams to 16, which were divided up evenly among users in a Multi-User (MU) environment. As shown in **Figure 10**, we positioned the user in the Single User (SU) environment directly in front of the base station, and in the MU environment (no. of users $N_U$=4), we positioned the users in front of the base station at 20° intervals. Furthermore, for the modulation schemes and coding rates*31 shown in Table 1, we applied combinations of them using Adaptive Modulation and Coding (AMC)*32. In particular, the combination of 256 Quadrature Amplitude Modulation (256QAM)*33 and coding rate $R$=3/4 enabled a maximum transmission rate of 31.4 Gbps by 16-stream MIMO spatial multiplexing.

### 4.1 Comparison of Full Digital and Two Types of Hybrid Beamforming

The throughput characteristics of $L$=$N_T$=256 full digital Massive MIMO and hybrid beamforming using two types

*29 **Variable phase shifter:** A device for changing the phase of a radio signal to another phase.

*30 **Adder:** A device for adding multiple electrical signals and outputting the result.

*31 **Code rate:** The proportion of data bits to the number of coded bits after channel coding. For example, if the code rate is 3/4, for every 3 data bits, 4 coded bits are generated by channel coding.

*32 **AMC:** A method for making transmission more efficient by adaptively changing the combination of modulation scheme and coding rate according to the propagation environment.

*33 **256QAM:** Quadrature Amplitude Modulation (QAM) is a modulation method using both amplitude and phase. In 256QAM, 256 ($2^8$) symbols exist, so this method allows for the transmission of 8 bits at one time.

of analog beamforming configurations are shown in **Figure 11**. For hybrid beamforming, we set the number of selected beams to $L$=32 for both $N_U$=1 and $N_U$=4 number of users and presented total throughput for all users in the case of $N_U$=4.

These simulation results show that full digital Massive MIMO and the two types of hybrid beamforming can achieve a throughput greater than 20 Gbps for average Signal to Noise Ratio (SNR)*34 above 16 dB. In addition, total throughput for all users can reach 20 Gbps for an average SNR lower than that of $N_U$=1. The reason for this is that interference between users in a MU environment can be appropriately reduced so that high-intensity radio signals arriving at multiple users can be used. Furthermore, the full-array type of analog beamforming achieves characteristics superior to those of the sub-array type, which is particularly noticeable for $N_U$=4. The reason for this can be given as follows. The number of antenna elements used for forming one beam in the full-array type is more than that in the sub-array type resulting in a narrow beam. Thus, in a MU environment, the effects of inter-user interference are small and an inter-user interference reduction effect can be obtained even for a relatively small number of beams.

Moreover, for $N_U$=1, the characteristics of full digital and full-array type of hybrid beamforming are nearly equivalent, which means that hybrid beamforming can achieve throughput close to that of full digital while keeping transmitter cost down.

**Table 1 Simulation conditions**

| | |
|---|---|
| Carrier frequency | 20 GHz |
| Bandwidth | 400 MHz |
| No. of active subcarriers | Pilot: 32; data: 2,000 |
| No. of antenna elements | $N_T$ = 256, $N_R$ = 16 |
| No. of users | $N_U$ = 1, 4 |
| Total no. of streams | $M$ = 16 |
| Total no. of beams | $L$ = 16, 32, 64, 128 |
| Modulation schemes | QPSK*1, 16QAM, 64QAM, 256QAM (w/AMC) |
| Channel coding | Turbo code*2<br>Coding rate $R$ = 1/2, 2/3, 3/4 (w/AMC) |
| Fading*3 | 16 path Nakagami-Rice fading*4<br>($K$ = 10 dB) |

*1 QPSK (Quadrature Phase Shift Keying): A digital modulation scheme that uses a combination of four signals with different phases to enable the simultaneous transmission of two bits of data.
*2 Turbo code: A type of error correction code that performs decoding repeatedly using reliability information of decoding results thereby achieving robust error correction.
*3 Fading: Fluctuation in the received level of a radio signal due to terminal movement or multipath effects.
*4 Nakagami-Rice fading: Model of a multipath environment that includes radio signals that arrive directly (with no reflection) from the base station (signal strength is high).

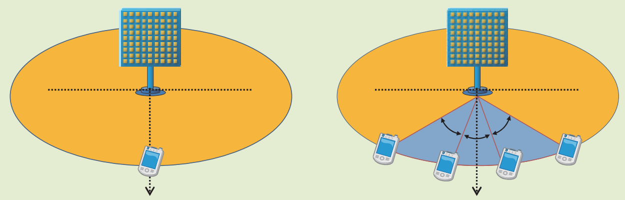


**Figure 10 User arrangement**

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

### 4.2 Effect of $L$ Number of Beams in Hybrid Beamforming

As described above, throughput in the case of hybrid beamforming depends on number of beams $L$. Specifically, characteristics improve as $L$ becomes larger, but on the other hand, making $L$ smaller is advantageous for lowering costs, so there is a need here to optimize the number of beams used. Total throughput for all users versus number of beams $L$ is shown in **Figure 12**. In this simulation, we set number of users to $N_U$=1 and 4 and average SNR to a constant value of 15 dB. We also set the characteristics of full digital to a fixed value irrespective of $L$ since it performs no analog beamforming. Note that the value $L$=128 is not feasible in terms of cost reduction, but it is included in this evaluation to show how hybrid beamforming approaches the characteristics of full digital.

As shown by these results, hybrid-beamforming characteristics approach those of full digital as $L$ increases. In particular, as $L$ is divided up for beamforming and user multiplexing in a MU environment ($N_U$=4), characteristics improve dramatically at $L$=32 compared with $L$=16, which indicates that inter-user interference can be appropriately reduced at around $L$=32 in this environment. In addition, at $L$=128 for $N_U$=1, full-array type of hybrid beamforming actually exhibits characteristics higher than those of full digital. However, in this evaluation, no control of received quality according to the environment is performed; full digital can be expected to have higher throughput if such control were included.

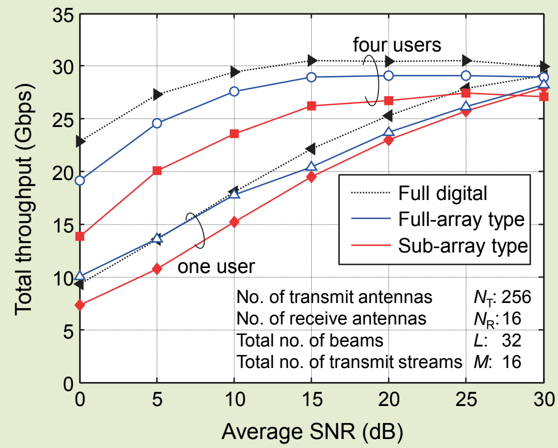


**Figure 11 Total throughput versus average SNR**

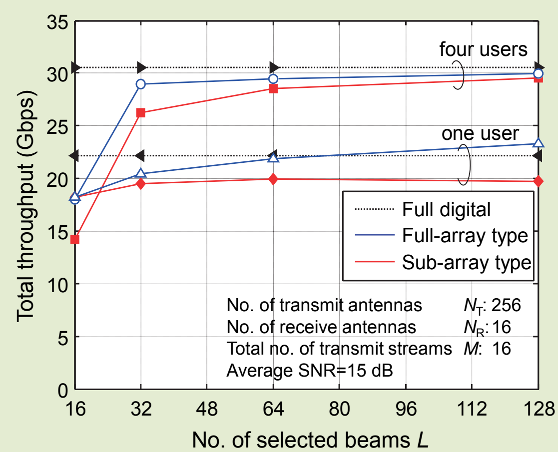


**Figure 12 Total throughput versus no. of selected beams by analog beamforming**

The simulation results presented above demonstrate that super high bit rates in the 20 GHz band are feasible when using a massive-element antenna and that hybrid beamforming with appropriately set parameters can achieve characteristics close to full digital.

## 5. Conclusion

In this article, we first described the operation and effect of massive-element antennas as 5G multi-antenna technology, a field in which NTT DOCOMO has taken a worldwide leading position. We then described technical issues surrounding massive-element antennas in high frequency bands and NTT DOCOMO's efforts in implementing practical antennas of this type. Finally, we presented the results of computer simulations in evaluating super high bit rates using a massive-element antenna in a high frequency band and discussed the feasibility of achieving super-high-speed communications in this way. Going forward, we plan to evaluate the possibility of super-high-speed communications by conducting outdoor transmission experiments using massive-element antennas.

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5G | High Frequency Band | Radio Propagation Characteristic

Technology Reports

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# Radio Propagation for 5G

*NTT DOCOMO is currently studying a fifth-generation mobile communications system (5G) intensely. This system is expected to use high frequency bands, so clarification of the propagation characteristics in these high frequency bands is the most important issue in radio propagation research for 5G. This article gives an overview of the issues and current state of study in radio propagation, and describes results obtained by NTT DOCOMO in field tests and studies done using radio propagation simulation technology.*

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## 1. Introduction

NTT DOCOMO is currently studying the radio access network*1 for a fifth-generation mobile communications system (5G) based on a phantom cell concept*2 as shown in **Figure 1** [1]. This concept assumes an overlay*3 structure with small cells*4 in various shapes arranged within a macrocell*5, and that wider bandwidth will be secured to implement ultra-high-speed transmission, in the Super High Frequency (SHF)*6 band (over 6 GHz) or Extremely High Frequency (EHF)*7 band (mainly 30-100 GHz). In order to decide the carrier frequencies*8 in these high frequency bands, the frequency characteristics for various types of propagation must be known, and this is the most important issue in radio propagation research for 5G. This article first gives an overview of issues and the current state of study of radio propagation together with trends in 5G-related projects. It then introduces some of the results obtained in field testing done by NTT DOCOMO so far, and describes results of studies using radio propagation simulation technology for high frequency bands, which will be needed in the future.

## 2. Issues and Current Study of Radio Propagation

### 2.1 Issues with 5G

1) Frequency Bands under Study

Since high frequency bands are expected to be used with 5G, propagation characteristics (propagation losses*9 and multipath*10 characteristics) must be



*1 **Radio access network:** A general term for the wireless access segment of a communications network.

*2 **Phantom cell concept:** A system concept in which small cells are overlaid on macrocells (see *5), and the macrocell base stations are used for control signals, while the small cell (see *4) base stations are used for data signals.

elucidated for the 6 to 100 GHz range. So far, results of several studies on the 20 to 30 GHz and 50 to 70 GHz ranges have been reported by organizations such as New York University (NYU) and the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)*11, although most in the 50 to 70 GHz range have been on the 60 GHz band [2] [3]. On the other hand, there are very few reports on the 10 to 25 GHz and 40 to 55 GHz bands, and these will require study in the future.

2) Factors Affecting Propagation

**Figure 2** summarizes factors expected to have a significant effect on propagation characteristics in high frequency bands. Of these, (1) rainfall attenuation and (2) losses due to trees and plants have been clarified in International Telecommunication Union, Radiocommunications Sector (ITU-R) reports [4] [5]. Further, the effects of (3)

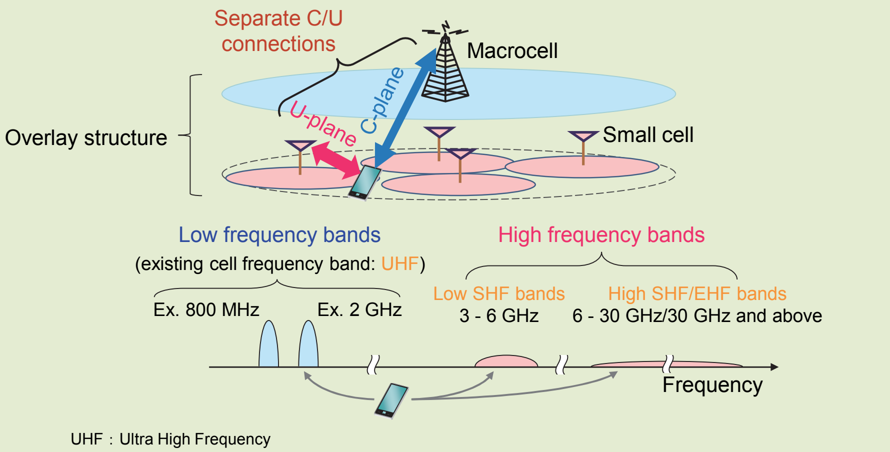


**Figure 1 Phantom cell concept**

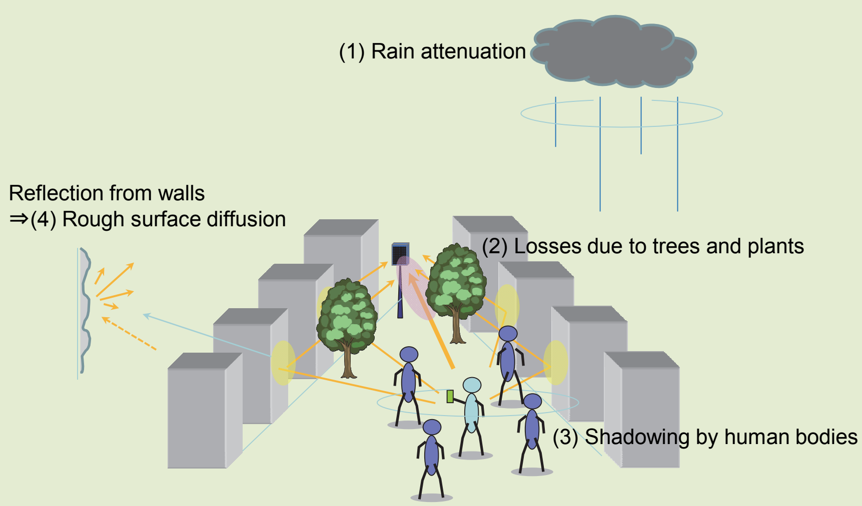


**Figure 2 Factors affecting propagation in high frequency bands**

*3 **Overlay:** A structure in which small cells (see *4) are arranged within a macrocell (see *5).

*4 **Small cell:** A cell covering a relatively small area of radius less than approximately 500 m. Also called a microcell.

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

*6 **SHF:** Radio waves in the range of frequencies from 3 to 30 GHz.

*7 **EHF:** Radio waves in the range of frequencies from 30 to 300 GHz. Also called millimeter waves.

*8 **Carrier frequency:** A carrier frequency is a radio wave that is modulated in order to transmit information.

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

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

shadowing by human bodies has been considered in a channel model*12 proposal [6] from the Millimeter-Wave Evolution for Backhaul and Access (MiWEBA)*13 project. However, this model deals mainly with the 60 GHz band, and further study will be needed to determine it applies to other frequencies. It will also be important to understand the characteristics of (4) rough surface diffusion using ray tracing*14 and other propagation simulation techniques [7].

### 2.2 Trends in 5G Related Projects

The METIS [2] and MiWEBA [6] research projects in Europe are well known projects related to 5G. The characteristics of studies conducted by these projects are summarized in **Table 1**.

1) METIS

METIS has proposed two channel models, depending on the application. The first is the Geometry-based Stochastic Channel Model (GSCM) generally used by the ITU-R and 3rd Generation Partnership Project (3GPP) for evaluating systems. GSCM gives statistical characteristics to each path based on measured data. It applies to frequencies of 70 GHz and below, but only parameters for generating models for 6 GHz and below are available for urban microcell environments. For indoor environments, only parameters for 6 GHz and under and 50 to 70 GHz bands have been prepared, so the frequency ranges expected for 5G are not adequately covered. The other model is called the Map-based Model, and calculates propagation characteristics using ray tracing. This model applies to frequencies of 100 GHz or less, but few comparisons of results computed by this model with measured data have been done, so verifying the accuracy of these results will be an issue for future work.

2) MiWEBA

MiWEBA has proposed a model called the Quasi-Deterministic Model. This model uses paths computed using ray tracing and considers paths statistically, so it is a hybrid of the GSCM and Map-based Models from METIS. It is being used mainly for the 60 GHz band of frequencies, so care must be taken when applying it to other frequency bands.

Besides those described above, there are other projects that have begun studying channel models for 5G, including the 5G Millimeter Wave Channel Model Alliance [8] formed at the prompting of the National Institute of Standards and Technology (NIST) and the Millimeter-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications (mmMAGIC) [9] at the 5G Infrastructure Public-Private Partnership (5GPPP).

## 3. Propagation Characteristics in Real Environments Investigated by NTT DOCOMO

Propagation loss characteristics in urban microcell environments and multipath characteristics in indoor environments, as obtained in propagation field testing by NTT DOCOMO, are explained below.

**Table 1 5G related projects**

| Project | Channel model type | Frequency | Scenarios |
|---|---|---|---|
| METIS | GSCM | 70 GHz and below | Urban micro, urban macro, offices, shopping malls, highways, open-air festivals*1, stadiums. |
| | Map-based Model | 100 GHz and below | Urban micro, urban macro, rural macro, offices, shopping malls, highways, open-air festivals |
| MiWEBA | Quasi–Deterministic Model | 57 to 66 GHz | Open areas, street canyons*2, hotel lobbies |

*1 Open-air festivals: Scenarios such as outdoor concert venues.
*2 Street canyons: Scenarios in which a street is surrounded by tall buildings and the base station antenna is positioned lower than the surrounding buildings.

*11 **METIS:** A next-generation wireless communications system research project in Europe.

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

*13 **MiWEBA:** A research project in Europe studying application of millimeter wave technologies for mobile communications systems.

*14 **Ray tracing:** A method of simulating propagation characteristics by treating radio waves like light and tracing their paths.

### 3.1 Propagation Loss Characteristics

1) Overview of Measurements

Measurements were performed in the area around Tokyo Station. The measurement area is shown in **Photo 1**, and the average building height and road width are approximately 20 m and 30 m respectively. For the measurements, a Continuous Wave (CW) , for which it is easy to measure the reception level, was transmitted from a base-station antenna mounted on the basket of a basket-lift truck, the signal was received by a mobile station antenna mounted on the roof of the measurement car, and the received power was recorded. The measurement parameters are shown in **Table 2**. The data was processed, calculating the median over spans of 10 m which were moved in 1 m steps, and these were used to derive propagation losses.

**Photo 1 Measured area**

2) Measurement Results

The relationship between radio propagation losses and distance is shown in **Figure 3** [10]. These results were calculated by regression formula of measured path loss values using distance and frequency values. The figure shows that for both the line-of-site and non-line-of-site cases, propagation losses increase as the distance increases. Losses also increase as the frequency increases. For example, in the line-of-site case, propagation losses increase by about 30 dB from 0.81 GHz to 37.1 GHz. Propagation losses increase further in the non-line-of-site case, so technology to compensate of propagation losses is particularly important.

### 3.2 Multipath Characteristics in Indoor Environments

1) Experiment Overview

Here, we describe the characteristics

**Table 2 Measurement specifications**

| Parameter | Value |
|---|---|
| Center frequency | 0.81 GHz, 2.2 GHz, 4.7 GHz, 26.4 GHz, 37.1 GHz |
| Transmission power | 43 dBm (0.81 GHz, 2.2 GHz), 40 dBm (4.7 GHz, 26.4 GHz), 37 dBm (37.1 GHz) |
| Transmitted signal | Continuous wave |
| Base station antenna height | 1.5 m, 6 m, 10 m |
| Base station antenna | Sleeve antenna |
| Mobile station antenna height | 2.7 m |
| Mobile station antenna | Sleeve antenna |
| Distance between base station and mobile station | 56 - 959 m |

of radio waves arriving at the base station as obtained in indoor propagation experiments. In order to enable separating multipath in the time direction, in experiments we used delay time measuring equipment to measure multipath delays [11]. The center frequency of the measured signal was 19.85 GHz and the bandwidth was 50 MHz. Experiments were done in an office as shown in **Figure 4**. The office contained desks and chairs of height approximately 1 m, and metal lockers of height approximately 2 m. There were also several meeting rooms, booths containing office equipment and walls with concrete pillars and glass windows. The ceiling was at a height of 2.7 m and was made of plaster board. In measurements, the transmitter was considered to be the mobile station which emitted a signal in all directions using a sleeve antenna*15 at a height of 1.5 m. The receiver was considered to be the indoor base-station

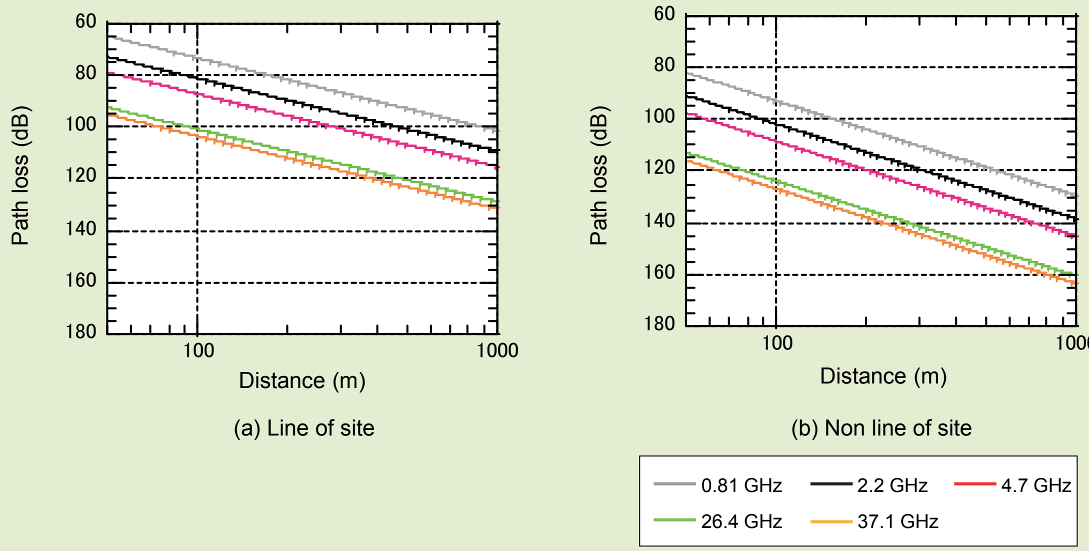


**Figure 3 Path loss/distance characteristics**

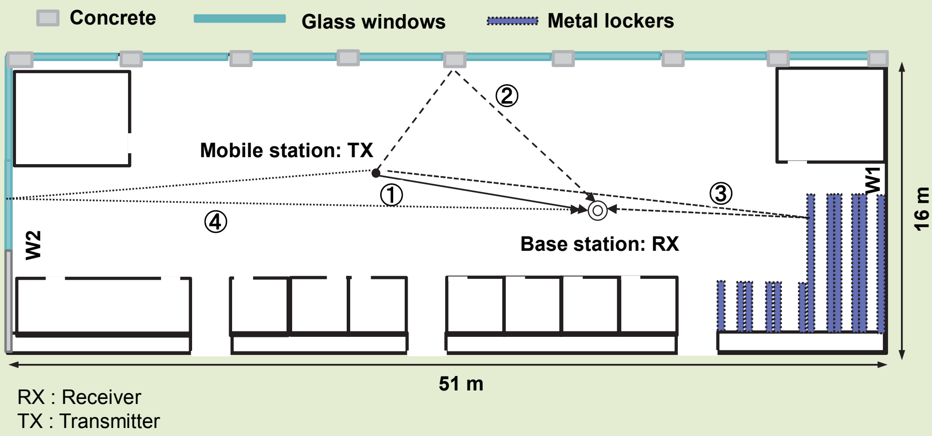


**Figure 4 Office measurement area**

*15 **Sleeve antenna:** A type of antenna that emits a signal of mostly-uniform intensity in the horizontal plane.

and had an antenna height of 2.3 m. A horn antenna*16 was used for the base station in order to obtain delay profiles*17 and measure arrival directions of radio waves, while varying the azimuth and elevation angles. The antennas were kept within line-of-sight.

2) Measurement Results

The results obtained from measurements are shown in **Figures 5** and **6**. Fig. 5 shows the received power vs. azimuth and elevation angles, while Fig. 6 shows the received power vs. azimuth and delay. The circle marks in each figure represent propagation paths obtained in analysis of the measured results. For elevation, the case when the horn antenna was horizontal was defined as 0°, and positive values indicate positions above horizontal. For azimuth, 0° indicates the horn antenna was par-

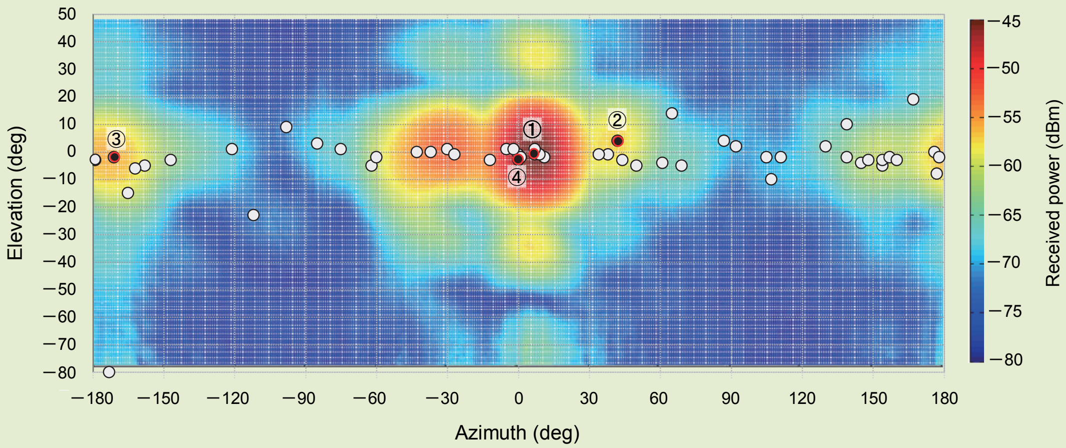


**Figure 5 Relation between arrival direction and received power**

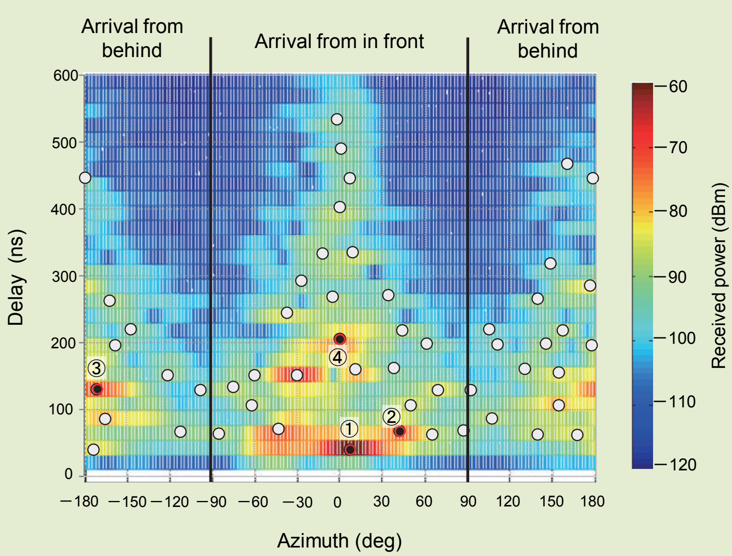


**Figure 6 Relation between arrival direction, delay time and reception power**

*16 **Horn antenna:** A type of antenna with a cone or pyramid shape, which emits a signal that is strong in a particular direction.

*17 **Delay profiles:** Waveforms that indicate the relationship between received powers and propagation delay times between the signal arriving directly to the receiving station and scattered signals.

allel to the normal vector of wall W2, and positive values correspond to positions of the right side of the normal vector. Fig. 5 and 6 show that there were many paths. These paths were distributed almost uniformly for azimuth angle, and concentrated around 0° for elevation. Results verified that the direct path and the main paths which were reflected regularly by walls (also be shown as Fig. 4, #1 to #4), had strong received power. Note that path #4 is considered to be reflected by the metal frame of the glass window.

## 4. Propagation Simulation Technology

### 4.1 Ray Tracing Methods

Ray tracing is a typical technology used to estimate the propagation characteristics in urban areas. Here, street environments often involve tall buildings lining the street, so a propagation model with walls lining the street is often assumed for ray tracing. For this model, many rays emitted from the transmitter and arriving at the receiver must be considered in order to obtain an accurate result, including paths composed of rays arriving at the receiver after reflecting multiple times between buildings on both sides (blue line in **Figure 7**), those reflecting from the edges of buildings on corners (red line in Fig. 7), and reflections from the ground.

### 4.2 Intersection-building Model

For ray tracing, conventional models assumed square corners at the edges of buildings at intersections. **Figure 8** shows a comparison of results calculated with a conventional model and measured values. The conventional model matched measured values well in (a), for the relatively low frequency of 800 MHz, but in (b) for 37 GHz, the accuracy of the estimate degraded dramatically as distance from the intersection increased. This error will need to be reduced, since use of high frequency bands (6 to 100 GHz) is expected for 5G systems.

However, most real buildings have rounded corners rather than square corners, as shown in Fig. 7. As such, NTT DOCOMO has proposed modeling the edges of buildings at corners with curved surfaces of specified radius, $a$ [12]. As such, the conventional model could be said to use a radius of zero ($a$ = 0). Below, this model using curved surfaces

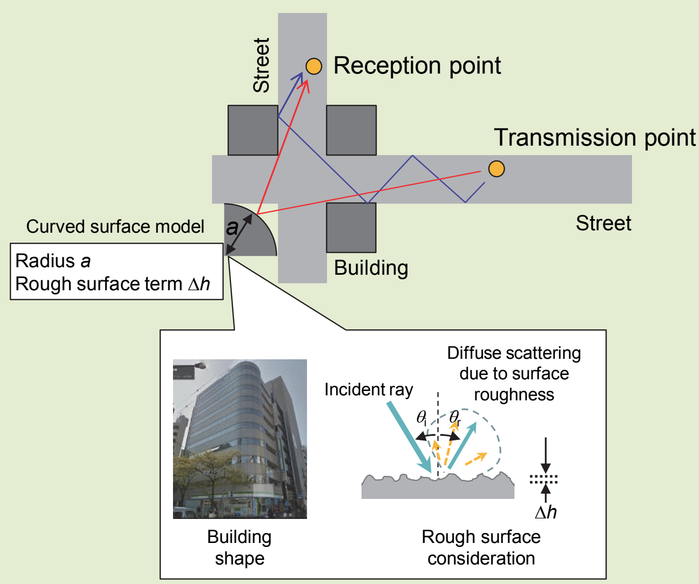


**Figure 7 Analysis model**

will be referred to as the proposed model.

Conventional models also handled building faces as smooth surfaces, but in the EHF band, with wavelengths of millimeter order, the roughness of building surfaces can no longer be ignored. **Figure 9** shows error characteristics relative to surface roughness, *h* (See Fig. 7). In fact, for ray tracing, the proposed model considering curved surfaces for ray tracing was used ($a$ = 7 m, comparable to real buildings), and an average value of the Root Mean Square (RMS) error*18 difference between calculated and measured values was used. For frequencies below 4.7 GHz, there is almost no variation with surface roughness, but its effects increase dramatical-

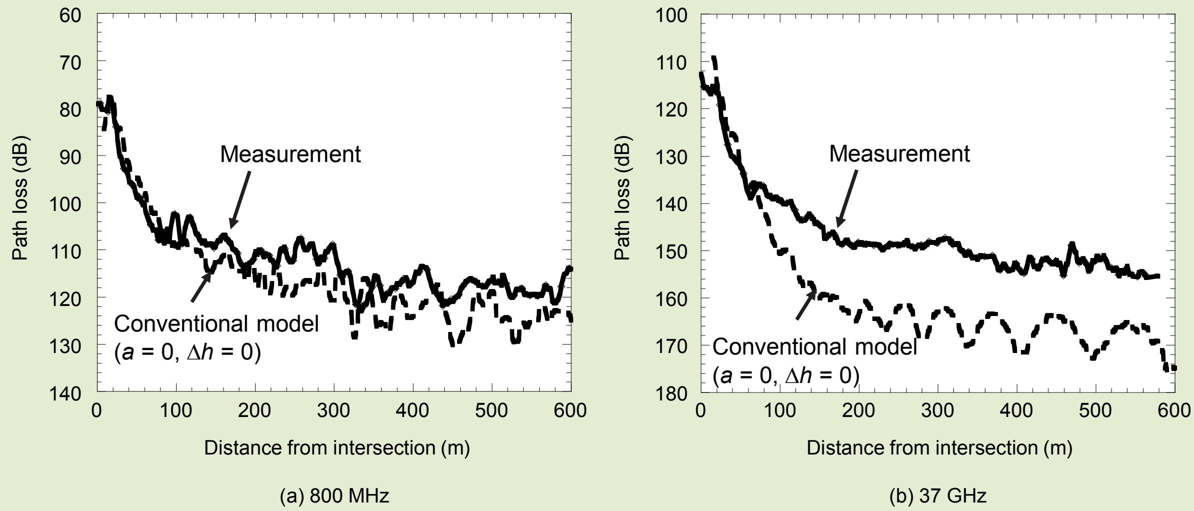


**Figure 8 Transmission loss/distance characteristics**

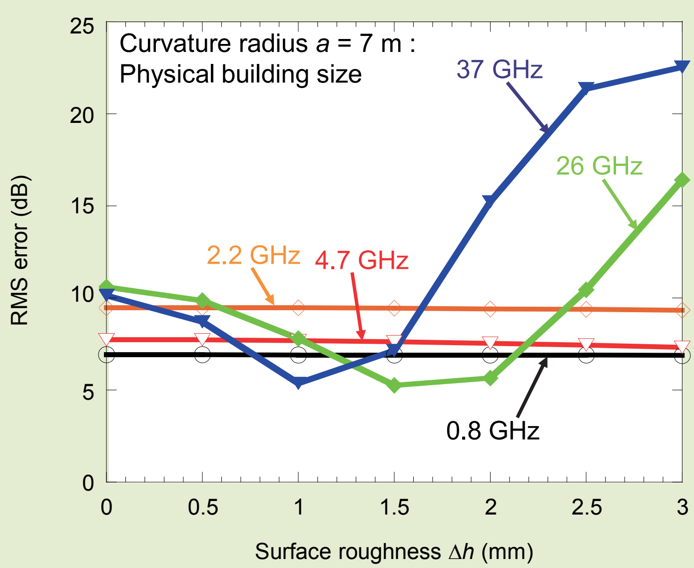


**Figure 9 Surface roughness effects**

*18 **RMS error:** A value that is the square root of the average of squared error values.

ly for frequencies of 26 GHz and above. These results show that for a surface roughness of approximately 1.5 mm, the error for 26 GHz and above can be reduced.

### 4.3 Verifying Accuracy

**Figure 10** shows the frequency characteristics of RMS error for the conventional model and the proposed model relative to measured values. Note that considering the results above, values of $a$ = 7 m and $\Delta h$ = 1.5 mm are used for the proposed model. The figure shows that, rather than the error increasing with frequency as indicated by the conventional model, with the proposed model the error can be reduced to 10 dB or less for all frequencies. In other words, for ray tracing, the proposed model can be used to simulate signal propagation for high frequency bands.

## 5. Conclusion

High frequency bands are expected to be used with 5G, so radio propagation characteristics must be elucidated in order to study 5G systems. This article has described issues related to radio propagation and results obtained in studies done so far. The results discussed here are partial results obtained by NTT DOCOMO. For details of the actual measurements, see references [10] and [11]. For details of the propagation simulation techniques, see reference [12]. In the future, we will perform measurements in a wider range of environments and in frequency bands for which little has been reported.

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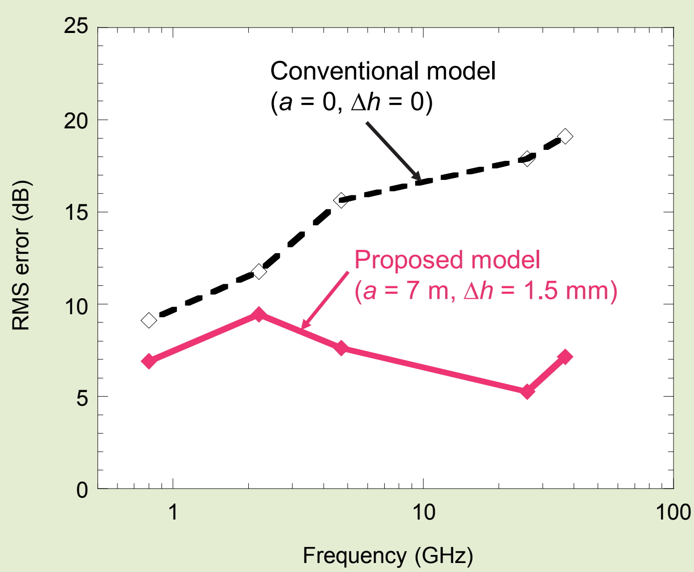


**Figure 10 RMS error/frequency characteristics for conventional and proposed models**

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5G | Future Core Network | Network Slicing

Technology Reports

Special Articles on 5G Technologies toward 2020 Deployment

# Future Core Network for the 5G Era

*Networks in the 5G era will need to operate efficiently for services that have a wide range of requirements. This article describes a vision for a future core network, a 5G radio access technology being studied to realize this vision, technologies related to network slicing, and trends in standardization related to future networks that include these technologies.*

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## 1. Introduction

An NTT DOCOMO 5G white paper [1] anticipates that by 2020, services will have advanced and diversified, with all kinds of items, such as vehicles, homes, and wearable devices, connecting to wireless networks as shown in **Figure 1**, gathering information and performing administration and control, both automatically and intelligently.

**Figure 2** shows various services categorized according to the number of terminals and service requirements. The service requirements needed from 5G networks will be diverse, but with current networks, most of the traffic originates from smartphones and feature phones. As such, the network has been built suited to that traffic, namely region A in the figure, and all services are provided with that network, but this domain is expected to expand to region B due to the development of technologies and equipment.

On the other hand, as Internet of Things (IoT)*1 services develop, demand will also expand to services in region C provided at low cost with large numbers of low-specification terminals, such as smart meters and environmental sensors. It will also expand to region D, with services having fewer users than ordinary cellular services but having special, stringent requirements such as low delay or high reliability. Examples include factory automation and other industrial services and transport systems such as congestion mitigation using inter-vehicle communication. Future networks require balancing to fulfill various service requirements and reduce costs.

Considering these factors, a 5G radio access technology that is able to realize higher data rates, greater capacity and less delay than current 4G radio access technologies (LTE/LTE-Advanced) is highly anticipated.



*1 **IoT:** A general term for the network of diverse objects connected to the Internet or the cloud for control and data communications.

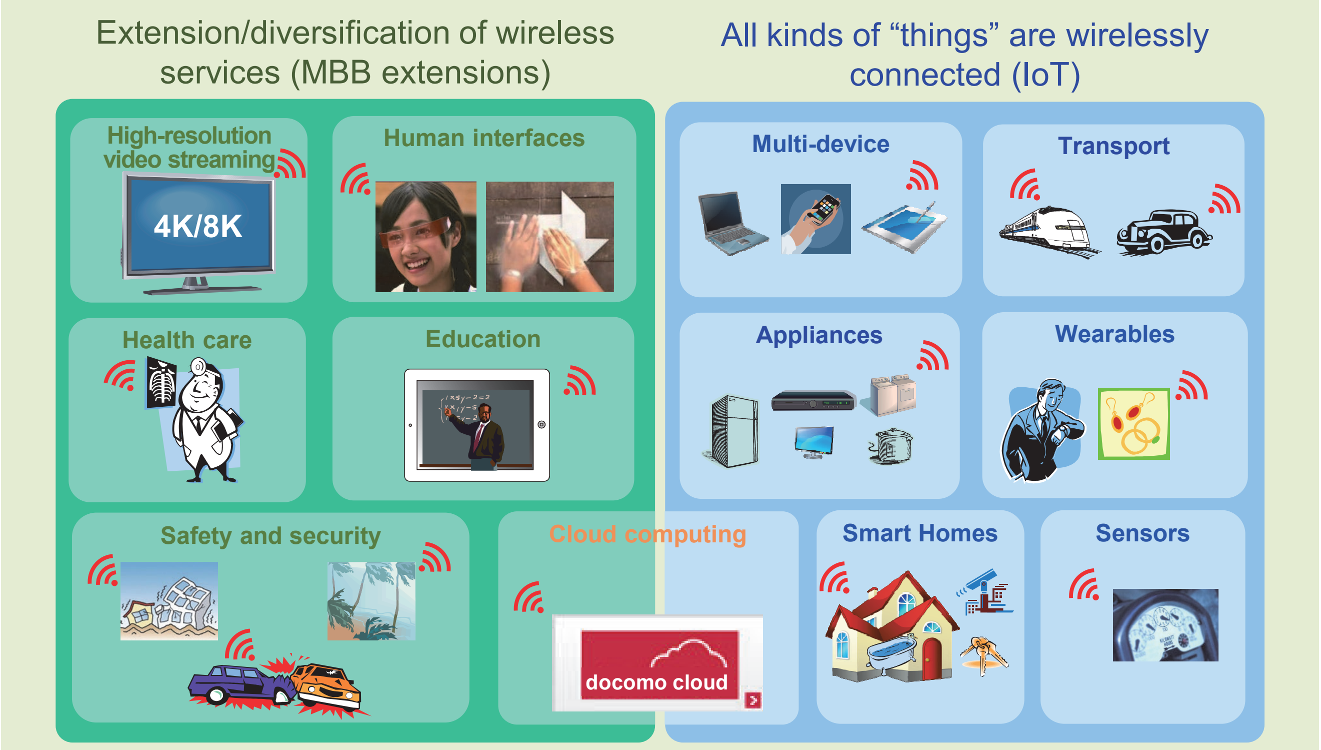


**Figure 1 Various services envisioned for 5G**

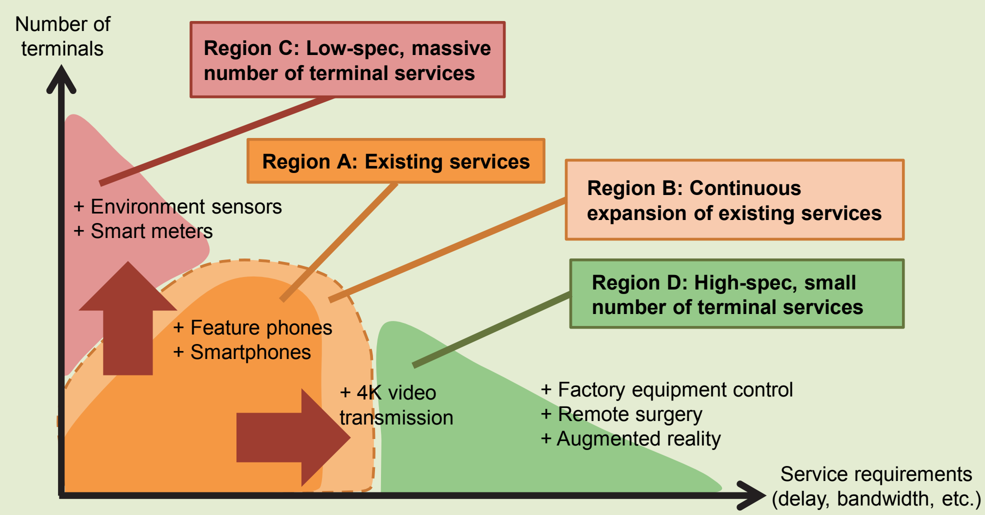


**Figure 2 Expansion in number of terminals and service requirements**

The existing Evolved Packet Core (EPC)*2 [2] network provides all services using the same network architecture and protocol control, regardless of the terminal type or services provided, but for services in region C, aspects

*2 **EPC:** An IP-based CN for LTE and other access technologies, specified by the 3GPP.

such as handover*3 are not needed at all, resulting in unnecessary overhead and inefficiencies. Furthermore, to provide services belonging to region D, measures such as bandwidth control, extensions to Quality of Service (QoS)*4, and high-level routing are required in order to satisfy stringent service requirements. These can affect all users accommodated in EPC, which would result in further increases in operating costs.

To resolve these sorts of issues and operate services with a diversity of requirements efficiently, a technology called network slicing, which creates and manages multiple virtual networks optimized according to terminal type or service requirements, and methods for selecting network slices suitable for each service are being studied.

This article first gives a vision for 5G networks and then describes a method for 5G radio access being studied to implement this vision. It gives details of network slicing technology and a control architecture using virtualization technologies. Finally, it introduces the current state of study at standardization organizations, on use cases, future service requirements and architectures.

## 2. Future Network Vision

The vision for future networks is shown in **Figure 3**. A future network will incorporate multiple radio technologies including LTE/LTE-Advanced, 5G New Radio Access Technology (RAT)*5, and Wi-Fi®*6, and be able to use them according to the characteristics of each service.

Utilizing virtualization technologies, network slices optimized for service

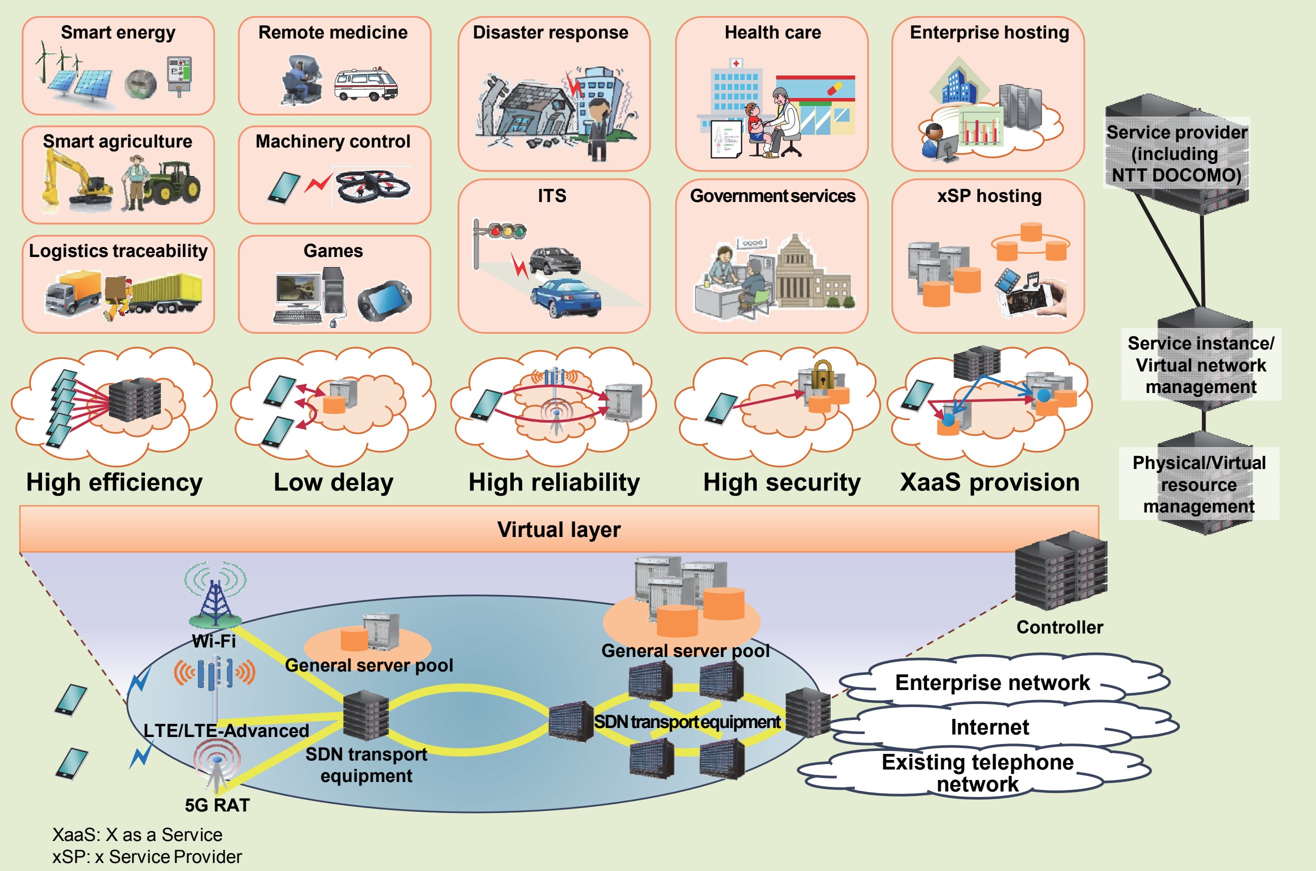


**Figure 3 Future network vision**

*3 **Handover:** A technology that enables a terminal that is communicating with a base station to switch to another base station while maintaining that communication while it moves from one to the other.

*4 **QoS:** The quality on the network, configured by service. Properties such as delay and packet drop rates are controlled by controlling bandwidth used.

*5 **RAT:** Radio access technologies such as LTE, 3G, and GSM.

*6 **Wi-Fi®:** A registered trademark of the Wi-Fi Alliance.

requirements such as high efficiency or low delay can be created. Common physical devices such as general-purpose servers and Software Defined Network (SDN)*7 transport switches will be used, and these networks will be provided to service providers. Network slices can be used either on a one service per network basis to increase network independence for originality or security, or with multiple services on one slice to increase statistical multiplexing gain and provide services more economically.

The specific functional architecture and the network topology*8 for each network slice are issues to be studied in the future, but in the case of a network slice accommodating low latency services, for example, GateWay (GW)*9 functions would need to be relatively close to radio access, service processing would be close to terminals, and routing control capable of finding the shortest route between terminals would be necessary to reduce latency. On the other hand, a network slice providing low-volume communications to large numbers of terminals, such as with smart meters, would need functionality able to transmit that sort of data efficiently, and such terminals are fixed, so the mobility function can be omitted. In this way, by providing network slices optimized according to the requirements of each service, requirements can be satisfied while still reducing operating costs.

## 3. Technical Elements for Implementation

Below, we describe elemental technologies for implementing the network vision described above, including a 5G radio access format, a slice selection technology using Dedicated Core Networks (DCN) [2]-[4], for which the Release 13 standard has almost been completed, and network slice control technologies based on virtualization technologies such as Network Function Virtualization (NFV)*10 and SDN.

### 3.1 5G Radio Access Accommodation

1) Simultaneous Connections with LTE/LTE-Advanced and New RAT

NTT DOCOMO is considering a structure for 5G radio access that combines continued development of the LTE/LTE-Advanced systems using current frequency bands with a new RAT capable of supporting higher bandwidth using higher frequencies than have been used to date [1]. In the 5G workshop at the 3rd Generation Partnership Project Technical Specification Group Radio Access Network (3GPP TSG RAN) held in September 2015, NTT DOCOMO proposed that for 5G radio access, technologies such as Carrier Aggregation (CA)*11 and Dual Connectivity (DC)*12 be used for simultaneous connections between the Radio Access Network (RAN)*13 and terminals using both LTE/LTE-Advanced and the New RAT (**Figure 4**). CA was specified in 3GPP Release 10 as the main technology in

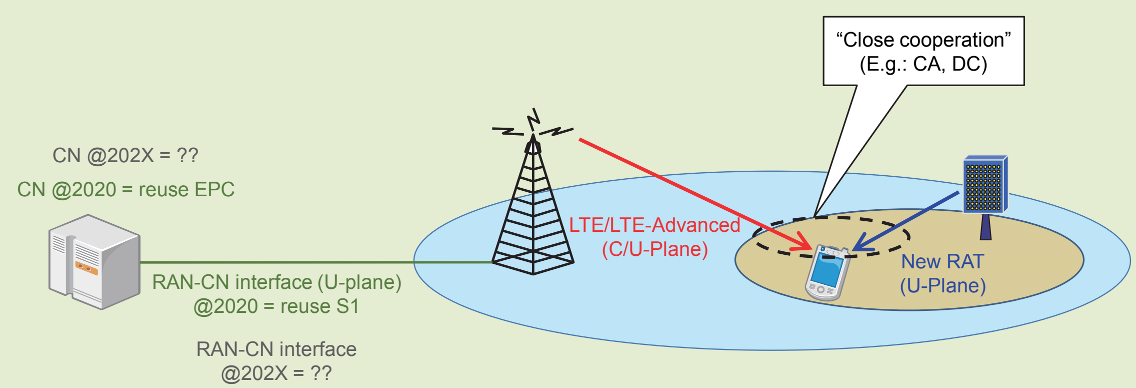


**Figure 4 NTT DOCOMO connection proposal using CA/DC**

*7 **SDN:** A technology that SDN controllers manage physical (and virtual) switches centrally, enabling high-level automation of entire networks.

*8 **Topology:** Logical relationship of devices, network configuration, etc.

*9 **GW:** A node having functions such as protocol conversion and data relaying.

*10 **NFV:** A technology that uses virtualization technologies to implement processing for communications functionality in software running on general-purpose hardware.

*11 **CA:** A technology that realizes increased bandwidth and high-speed transmission, while maintaining backward compatibility with LTE, by using multiple carriers for transmitting and receiving. It is one of the technologies used in LTE-Advanced.

*12 **DC:** A technology whereby a single terminal connects to multiple base stations using different frequency bands.

LTE-Advanced, and DC was developed to further expand LTE/LTE-Advanced and specified in Release 12. They both enable increased-bandwidth transmission using multiple frequencies at the same time [5] [6].

Realizing 5G radio access by simultaneous connections of LTE/LTE-Advanced and New RAT is expected to enable the smooth introduction of 5G radio access since it allows service levels of the stable LTE/LTE-Advanced network area quality (connection quality including coverage and mobility) to be maintained, and provides improvements in user data transmission quality (data transmission rate and latency) through introduction of the New RAT.

At the 5G workshop, many vendors and operators in addition to NTT DOCOMO proposed the close linking of LTE/LTE-Advanced and the New RAT for 5G radio access, but details will be discussed by 3GPP RAN Working groups in 5G technical studies planned to start in March 2016.

2) CN and Interface between RAN and CN

(1) Reuse of existing EPC and S1 interfaces

One possibility for the interface between the 5G RAN and the Core Network (CN)*14 that supports it would be to reuse the S1 interface*15, which is the interface between eUTRAN (the RAN for LTE/LTE-Advanced), and EPC (the existing CN accommodating eUTRAN) (Fig. 4).

The network comprising eUTRAN and EPC was originally designed to support Mobile Broad Band (MBB), and EPC and the S1 interface are suitable for implementing enhanced MBB (eMBB), which is a use case for 5G. Also, by reusing the existing EPC and S1 interface, a large number of new design items and test cases for introducing the new 5G radio access can be avoided, effectively lowering the hurdles toward introducing 5G radio access.

(2) Reconsideration of system architecture

5G is required to support diverse use cases such as IoT and low latency/highly-reliable communication in addition to eMBB, and to satisfy various operational requirements, so the existing RAN-CN structure may not necessarily always be optimal. As such, the allocation of functionality between RAN and CN needs to be studied, together with functional extensions on the CN and the accompanying extensions to the RAN-CN interface. The need to reexamine the overall system architecture has also been recognized at the 5G workshop. Specifically, discussions on the pros and cons of revisiting allocation of functions and revisions and extensions to interfaces between RAN and CN is expected to happen in coordination with the 3GPP SA (Service and System Aspects) 2 architecture studies that is mentioned later.

The 5G workshop reached a consensus to perform the 3GPP RAN 5G radio access specification in two stages, with Phase 1 providing a subset to meet market demand in 2020 and Phase 2 meeting all requirements of all use cases for 5G, but consideration for meeting market demand with flexibility and for smooth migration must also be given when studying system architecture.

## 3.2 Network Slice Selection Technology Using DCN

1) Provision Method

We have discussed provision of services according to requirements using network slices, but actually, use of multiple services with different characteristics on a single terminal such as a smartphone or in-vehicle terminal is expected. In such cases, if a network slice is created for each service, multiple network slices would have to coordinate control for a single terminal, and the resulting increased complexity is a concern. As such, it seems appropriate to allocate functions such as terminal mobility and authentication by terminal rather than by service. Thus, network slices include a terminal management slice and service slices. A terminal will be attached to a terminal management slice and one or more service slices, depending on the services being used.

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

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

*15 **S1 Interface:** The interface connecting MMEs, S-GWs and other equipment to eNBs.

2) Proposed Application of DCN

If the continuous extension of the current EPC network is considered, a technology for allocating a DCN that a terminal can access according to terminal characteristics would be desirable. Although this method is expected to be applied for selecting the terminal management slice in future CNs accommodating 5G radio, it is currently being specified as a method for selecting a CN from existing networks. Using **Figure 5**, we give an overview of the network slice selection method with the DCN allocation technology. The explanation below uses mainly LTE entity names.

3) Network Selection through SSF

Allocation to a DCN, as described above, is a method of selecting a network according to terminal characteristics, and this can be considered to be controlled mainly by the Slice Selection Function (SSF)*16 in Fig. 5. In LTE, functionality corresponding to SSF is implemented in the Mobility Management Entity (MME)*17, which initially receives the attach*18 from a terminal, but various patterns are anticipated when accommodating 5G radio access, such as placing it in the base station (eNB) or implementing it in a separate node. Note that when accommodating 5G radio access, these eNB functions may be implemented as a 5G base station (5GNB).

4) Switching Procedure

When the SSF (MME) receives an attach request from a terminal, it gets the UE Usage Type, which is a terminal identifier, from the Home Subscriber Server (HSS)*19 and uses his value to select an appropriate CN (which is the terminal management slice with network slicing) (Fig. 5 (1)-(4)). It is expected that with 5G, the basis for slice selection will be more than just UE Usage Type, and slice selection by service using new parameters will be possible. When it is determined from the UE Usage Type that a terminal must be accommodated by a suitable terminal management slice, the attach request received from the terminal by the SSF (MME) is encapsulated in a redirect request message and sent to the eNB in order to forward it to a different MME within the applicable terminal management slice (Fig. 5 (5)). By redirecting the attach request to the

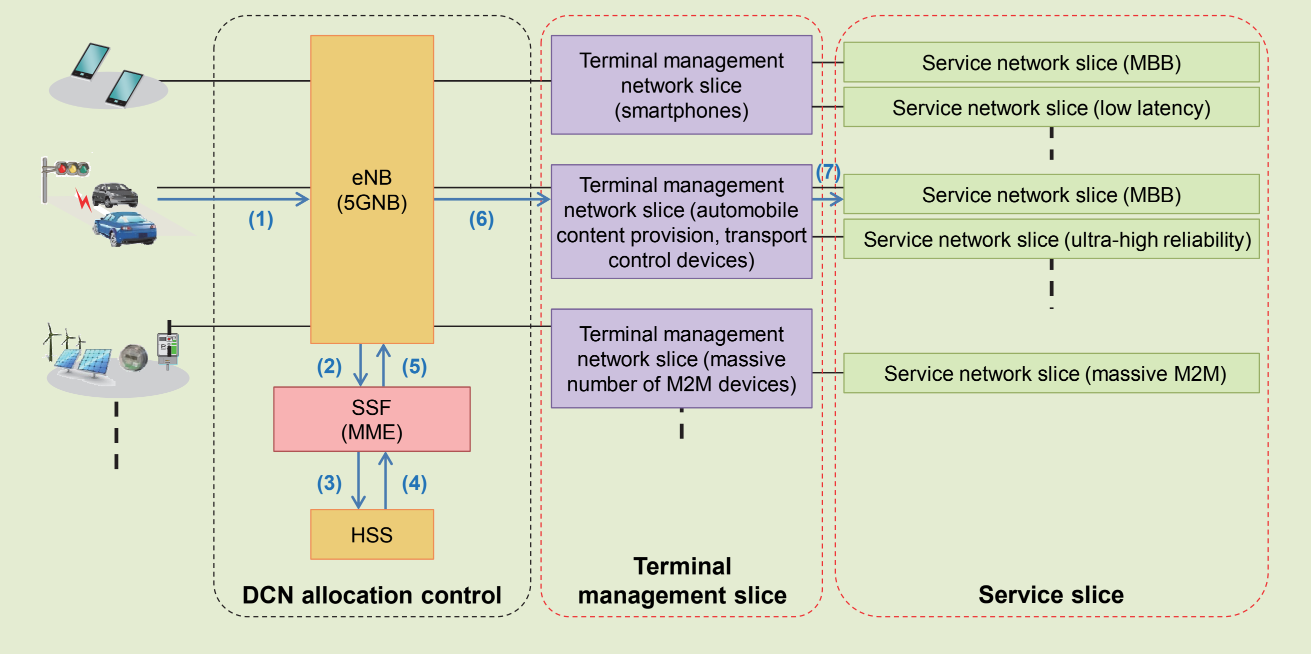


**Figure 5 Applying DCN for network slice selection**

*16 **SSF:** The function that selects the slice to which a service must connect.

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

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

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

MME in the specified desired terminal management slice, the terminal can attach to a suitable MME (Fig. 5 (6)), and thereafter services are also provided by the appropriate service slice (Fig. 5 (7)).

5) Issues with DCN Application

Since the UE Usage Type, which is a terminal identifier, is subscription data that is managed as part of the subscriber's contract, use of DCN allocation technology as the terminal management slice selection method has the benefit that operators can freely control selection of the slice that will accommodate the terminal by changing contract information, following conventional Service Order (SO)*20 procedures. This makes DCN allocation technology promising for implementing network slicing, but efficiency will need improvement and there are other issues that will need further study.

(1) The first issue is making SSF procedures more efficient. SSF equivalent functionality was provided in the MME in 3GPP Release 13 specifications, so for the desired terminal management slice to access the MME, it must first go through the MME (SSF) that is performing the terminal management slice selection. With the CN for the 5G era, the procedure can be made more efficient by, for example, placing the SSF on the RAN side, making it possible to select the desired terminal management slice MME all at once. However, in that case, a method to distribute UE Usage Types to the RAN side, or otherwise identify terminals on the RAN side would be an issue.

(2) The second issue is the implementation of the procedure to allocate service slices. With DCN allocation technology, there is no function to allocate user data transmission separately, so currently, the only way to select a connection route is based on the Access Point Name (APN)*21, but when multiple services are provided through the same APN, suitable service slices cannot be selected by this method. A service slice selection method that does not rely on just the APN needs to be considered.

(3) The third issue is deciding the node structure for each slice. Terminal management slices provide mainly C-Plane*22 functionality, while service slices provide mainly U-Plane*23 functionality, so the current allocation of functions in each entity in LTE must be reviewed, and the nodes comprising each slice must be optimized.

Concrete implementations of network slicing are still under study, so there are other improvements besides the above that need further study, and implementations other than application of DCN may also be proposed. It will be necessary to watch trends in future discussion very carefully.

### 3.3 Slice Control Technology through Virtualization

A network slice control architecture using NFV and SDN is shown in **Figure 6**. This architecture is composed of three layers: a physical/virtual resource layer, a virtual network layer, and a service instance layer.

1) Physical/Virtual Resource Layer

The physical/virtual resource layer is the lowest layer. It consists of physical and virtual resources that form networks, such as physical servers and transport switches, and these are managed as shared resources of the entire network by the Virtualized Infrastructure Manager (VIM)*24 which includes SDN Controller (SDN-C). These resources can be managed using methods studied by the European Telecommunications Standards Institute, Network Functions Virtualisation Management and Orchestration (ETSI NFV MANO)*25 [7]. Sets of resources are partitioned out as resource slices and used in the higher-level virtual network layer.

2) Virtual Network Layer

The virtual network layer is composed of network slices that contain Network Functions (NF) such as communication functions and service functions

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*20 **SO:** When changes are made to contract and other information in the customer data management system, the process of notifying and reflecting those changes from the customer data management system onto network nodes.

*21 **APN:** The name of a connection point, consisting of a string conforming to the standard 3GPP domain name format.

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

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

*24 **VIM:** A system for managing physical and virtual machines as network resources.

*25 **ETSI NFV MANO:** A general term for the virtual resource management function defined by the European Telecommunications Standards Institute.

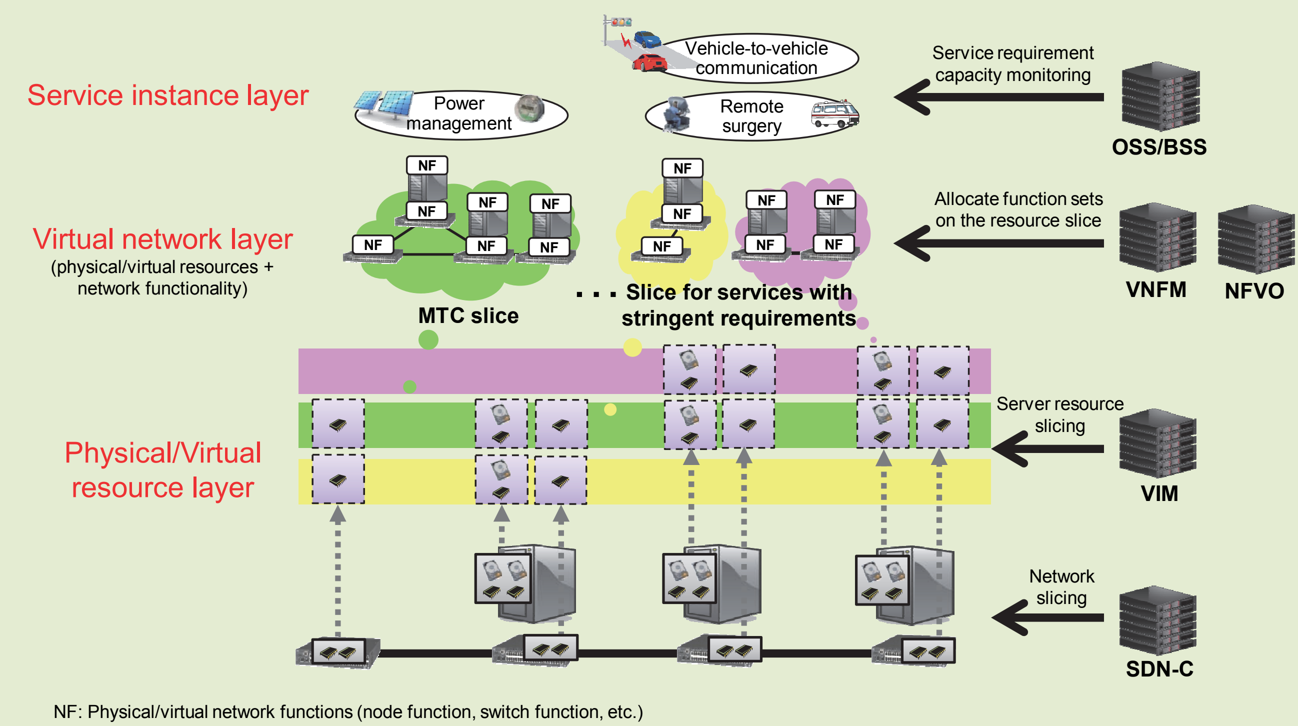


**Figure 6　Slice control architecture using NFV/SDN**

needed to implement services on top of the partitioned physical and transport protocols. The arrangement and management of this function set is performed for each network slice by the Virtual Network Function Manager (VNFM)*26 and the NFV Orchestrator (NFVO).

3)　Service Instance Layer

Various service instances provided on network slices are managed in the service instance layer, which is the highest layer. Examples are MBB services, power management, Intelligent Transport Systems (ITS)*27, and services provided to end users such as remote surgery. The Operation Support System (OSS)*28 or Business Support System (BSS)*29 constantly monitors each service instance to ensure that service requests for each service instance are being satisfied.

The services implemented on network slices are not limited to services provided on conventional feature phones and smartphones as described above. They also include IoT services and a variety of industrial and societal infrastructure services. The radio technologies and network configurations used to provide them are implemented by combining functionality freely for each network slice.

The network slice to which a service instance is attached is initially determined by the OSS, BSS or NFVO, and dynamically maintained according to service request volume and network slice loading. In this way, individual services will be managed on future CNs as service instances, based on flexible resource management technologies, and service requirements will be satisfied while providing services economically.

## 4.　Future Network Standardization Trends

The state of study at 3GPP related to technologies for implementing future networks is described below.

*26　**VNFM:** A system that manages functionality on virtual resources.

*27　**ITS:** An overall name for transportation systems using communications technology to improve vehicle management, traffic flow and other issues.

*28　**OSS:** Enterprise operational support systems. For communications operators, this can include some or all of: fault management, configuration management, charging management, performance management, and security management; for the networks and systems operating the services being provided.

*29　**BSS:** A system supporting operation for service providers.

## 4.1 Study Schedule Background

Discussion on the need to reform future network architecture and on methods of study was held in June 2014 at SA handling CN requirements and architecture. Operators in Europe have already advocated innovative developments at other organizations such as Next Generation Mobile Networks (NGMN)*30, have advocated for comprehensive review of architectures needed to introduce new services and business models, and examination of future CN requirements has been ongoing since the Release 14 SA1 meeting held in February 2015. SA2 studying architecture is also ongoing since October 2015. This study is expected to continue until the specifications are completed, with Release 15 or 16.

## 4.2 Current Study Items

The status of current study items is indicated below.

1) Use Cases

3GPP is conducting its study by incorporating appropriate elements with reference to preceding study results from regional standards organizations and industry organizations such as NGMN. Inclusion and priority of such items in the final specifications will be discussed further in the future, but as of now, the following use cases have been raised.

(1) Broadband access (immersive high-resolution 3D video, holograms, virtual reality services, etc.)

(2) IoT (Smart grid, smart city, environmental controls, health and medical related, automobile related (V2X), wearable terminals, etc.)

(3) Ultra-low-latency real-time communication (augmented reality*31, haptic communication, etc.)

(4) Highly reliable communication (industrial/factory automation, cooperative robot control, etc.)

(5) Lifeline communication (natural disaster response, police and fire communication, broadcast-type communication)

Note that provision of the above services could come in two forms; either the mobile communication providers provide services directly to users, or they create network slices according to service provider requests and the service providers provide services to users.

2) Service and Operational Requirements

Requirements will be derived from the above use cases in the future, but some of the requirements conceivable at this time are as follows.

(1) Network slices can be used.

(2) Network resources can be moved dynamically, effectively implementing an elastic core*32 concept.

(3) Services can be implemented with network edges.

(4) 5G and 4G radio access can be used simultaneously and selected according to services and applications.

(5) With 5G radio access, handover with 3G, including Circuit Switched FallBack (CSFB)*33 and Single Radio Voice Call Continuity (SRVCC)*34, will not be requested.

3) Architecture

Generally, investigation in SA2 would proceed after SA1, but this time they are proceeding in parallel while maintaining a loose connection between them. Architectural extension trends thought to be useful in the future that are already being studied in SA2 are as follows.

(1) Separation of C and U-Planes within the CN. Cost reduction of U-Plane equipment by replacing it with low-cost SDN switches.

(2) Small data transport. Efficient transport of low-volume IoT data (partially implemented in Release 13)

Issues for which companies could take differing positions in the future include the following.

- Whether to accommodate 5G radio access using the existing S1 interface or to create a new interface on the RAN side, and how to match such an interface with the existing interface of LTE/LTE-Advanced CN.
- The degree of integration of mo-

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

*31 **Augmented reality:** Technology for superposing digital information on the real-world in such a way that it appears to the user to be an actual part of the scene.

*32 **Elastic core:** A network architecture that achieves resistance to interruption by disaster and other causes by isolating state information.

*33 **CSFB:** A procedure for switching to a radio access system having a CS domain, when a terminal sends/receives a circuit switched communication such as voice while camped on an LTE network.

*34 **SRVCC:** A technology enabling seamless handover to a CS domain such as W-CDMA or GSM when in an LTE domain.

bile communication networks with fixed and Wi-Fi access.

## 5. Conclusion

This article has given an overview of elemental technologies being studied for future CN that will accommodate diverse services with varying requirements in the 5G era, and trends in standardization for future network implementation that will include these technologies. In the future, activity studying these technologies will increase at 5G-related organizations centering on 3GPP. NTT DOCOMO will continue to advance the study and standardization of technologies for future networks, as service provision infrastructure for new services and business models that could not have been provided earlier.

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# 5G Trials with Major Global Vendors

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*5G has many requirements beyond just higher speed and greater capacity, such as supporting huge numbers of devices and transmitting with even less delay. Satisfying these requirements involves many technical elements and requires supporting broad bandwidths. As such, to verify technologies efficiently, we have built relationships to collaborate on 5G trials with many influential vendors. This article gives an overview of 5G transmission trials done in collaboration with major vendors in the world, focusing on verifying multi-antenna transmission technologies for utilizing high frequency bands. It also introduces results obtained from collaborative trials done with these companies.*

## 1. Introduction

5G*1 is aiming to increase system capacity dramatically, to more than 1,000 times that of LTE. To achieve this, technical development is being done to actively use high frequency bands for mobile communications, including ultra wideband transmission exceeding 1 GHz and targeting bands up to the Extremely High Frequency (EHF)*2 band. There are also much more diverse system requirements beyond increased capacity, such as supporting connections from very large numbers of devices, and transmission with even less delay, and technical elements to implement these are diverse. Also, to implement 5G services by 2020, it will be necessary to begin practical technical verification early and accelerate technical study, so there may not be enough time for NTT DOCOMO to complete the wide range of technical validations as it has done in the past. As such, NTT DOCOMO is conducting trials in cooperation with major global vendors, to verify key elemental radio access technologies for 5G, in order to quickly establish a 5G ecosystem*3 and implement efficient and effective technical verification. As of the end of December, 2015, it had agreed on collaborative trials with 13 companies, and some vendors had started field trials as of the beginning of 2015 [1] [2].

This article gives an overview of these 5G trials and introduces the results obtained in cooperative experiments with each vendor, focusing on



*1 **5G:** A next-generation mobile communication system, the successor to 4th generation mobile communications systems.

*2 **EHF:** Radio waves in the range from 30 to 300 GHz. Also called millimeter waves.

experimental results related to multi-antenna transmission technologies for high frequency bands.

## 2. Overview of 5G Trial Collaboration

Current 5G trial efforts being conducted in cooperation with vendors can be categorized into the following topics: (1) Technologies to improve spectral efficiency that can be applied to a broad range of frequency bands, including the current cellular bands, (2) Utilization of high frequency bands including the EHF band, (3) Key devices (chipsets*4) for studying 5G terminal devices, and (4) Measurement technologies for evaluating performance of 5G radio access technologies and radio equipment in the ultra-high frequency bands (**Table 1**).

(1) Deals with validating various elemental technologies to increase system capacity in very densely arranged optical-feed

**Table 1　5G Trials overview**

| | Collaborating vendor | Trial overview |
|---|---|---|
| (1) Experiments on technology for improving spectral efficiency over a wide range of frequency bands to which it can be applied | Alcatel Lucent (France) | ・Experiments on new signal waveform candidates suitable for broadband communication and M2M communication |
| | Fujitsu (Japan) | ・Experiments on coordinated radio resource scheduling for super dense base stations using RRH |
| | Huawei (China) | ・Experiments on MU-MIMO using TDD channel reciprocity, new signal waveforms, and advanced multiple access |
| | NEC (Japan) | ・Experiments on a beamforming technology that controls directivity in the time domain using very-many-element antennas to increase system capacity per unit area in small cells |
| | Panasonic (Japan) | ・Experiments on system control technologies for efficient communication combining multiple frequencies, such as high frequency bands and wireless LAN frequency bands, and system solutions applying advanced imaging to 5G communications technology |
| (2) Experiments that focus on development of high frequency bands | Ericsson (Sweden) (Sec. 3.1) | ・Experiments on a new radio interface concept, for use with high frequency bands, and a Massive MIMO technology combining spatial multiplexing and beamforming |
| | Samsung Electronics (South Korea) (Sec. 3.2) | ・Experiments on hybrid beamforming, combining digital and analog techniques to realize stable, ultra-wideband transmission in high frequency bands as well as a beam control technology for tracking mobile stations |
| | Mitsubishi Electric (Japan) (Sec. 3.3) | ・Basic experiments on a multi-beam, multiplexing technology using virtual arrangements of massive numbers of antenna elements, which will realize ultra-high speeds in high frequency bands |
| | Nokia Networks (Finland) (Sec. 3.4) | ・Experiments on ultra-wideband radio transmission, assuming use for efficient EHF band mobile communication |
| (3) Experiments on 5G terminal devices | Intel (USA) | ・Experiments involving compact, low-power chipset prototypes for mobile terminals, such as smartphones and tablets that will realize the 5G concept of high-speed, high-capacity and high reliability. |
| | Qualcomm (USA) | ・Collaboration on study and testing for compact, low-power 5G device implementations to enable provision of mobile broadband extended to peak data rates of several Gbps |
| (4) Evaluation of performance of radio equipment for ultra-high frequency bands | Keysight Technologies (Japan) | ・Study of communication performance measurement technology for base stations and terminals, for ultra-wideband communication in high frequency bands<br>・Experiments on antenna performance measurement technology for Massive MIMO<br>・Measuring and analysis of radio propagation characteristics in high frequency bands and generation and analysis of signal waveforms |
| | Rodhe & Schwarz (Germany) | ・Study of antenna performance and evaluation technology for base station communications performance for schemes such as Massive MIMO, which use ultra-wide bandwidths in high frequency bands<br>・Measuring and analysis of radio propagation characteristics in high frequency bands, generation and analysis of signal waveforms |

*3 **Ecosystem:** A mechanism in which a number of companies partner across their specialties and include consumers and society in their business activities to stimulate each others' technologies and assets, from R&D through to sales, advertising and consumption, to enable coexistence and co-prosperity.

*4 **Chipset:** Devices that control mobile terminal software and various hardware processing. Devices such as the CPUs and control circuits are collectively referred to as "the chipset."

small cells*5 using transmission methods and signal waveforms suited to particular usage scenarios such as broadband or Machine-to-Machine (M2M)*6 communication and to further improve spectral efficiency with Multiple Input Multiple Output (MIMO)*7 transmission [3]–[7].

(2) Deals with broadband mobile communications technology with radio interfaces for effective use of frequencies higher than those currently in use, including frequencies over 6 GHz. Specific examples include ultra-high-speed, high-capacity transmission technologies using MIMO with large numbers of antennas (Massive MIMO*8) to effectively compensate for radio propagation losses in the high frequency bands, and elemental technologies that can be applied in EHF-band mobile communications.

(3) Deals with key-device prototypes for implementing compact, low-power 5G devices.

(4) Deals with elucidating radio propagation in the EHF band and evaluating radio performance of active antenna systems composed of large numbers of antennas.

## 3. 5G Experimental Trials

This section describes some of the 5G experimental trials mentioned above, emphasizing cultivation of high frequency bands in (2), which will be essential to realizing high speed and increased capacity in the medium and long term.

### 3.1 Trials of 5G Radio Access in the 15 GHz Band

An overview of verification of a 5G radio interface concept using the 15 GHz band, done in cooperation with Ericsson, is given below [8]–[10].

1) Trial Overview

The major specifications of the 15 GHz band 5G testbed are given in **Table 2**, and the base station and mobile station are shown in **Figure 1**. Four Component Carriers (CC)*9 of bandwidth of 100 MHz and of successive frequencies were combined with carrier aggregation*10, resulting in a system bandwidth of 400 MHz. Base stations and mobile stations have four antennas for transmitting and receiving and use four-stream*11 MIMO transmission. Use of high frequency bands for small cell areas is being studied for 5G, and this testbed was used in a 15 GHz band trial, to verify radio signal transmission performance in various small cell environments, in the YRP area in Yokosuka City in Kanagawa Prefecture. Experiments were done in four small cell environments: (a) a lobby (indoor), (b) a courtyard (outdoor and indoor-outdoor), (c) between buildings, and (d) a parking lot (outdoor).

2) Experimental Results

Throughput measurement results are shown together in **Figure 2**. Throughput of up to 4.3 Gbps was obtained in (a) the lobby when standing still. However, throughput dropped when in the shadow of a pillar, confirming that the direct signal is dominant at 15 GHz. In (b) the courtyard, the maximum through-

**Table 2 Test equipment basic specifications**

| | |
|---|---|
| Radio access | OFDMA |
| Duplexing | TDD (Uplink/Downlink ratio = 2 : 48) |
| Carrier frequency | 14.9 GHz |
| System bandwidth | 400 MHz |
| Output power | Base station: 2.14 W (33.3 dBm)<br>Mobile station: 2.24 W (33.5 dBm) |
| No. of transmit/receive antennas | 4 |
| No. of CCs | 4 |
| Subcarrier spacing | 75 kHz |
| Subframe length | 0.2 ms |
| Symbol duration | 13.3 μsec + CP 0.94 μsec |
| Data modulation | QPSK, 16QAM, 64QAM |

OFDMA: Orthogonal Frequency Division Multiple Access
TDD: Time Division Duplex
QPSK: Quadrature Phase Shift Keying

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

*6 **M2M:** A generic term for machine communication without intervention from a human operator.

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

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

*9 **CC:** A term used to refer to the carriers bundled together when using carrier aggregation (See *10).

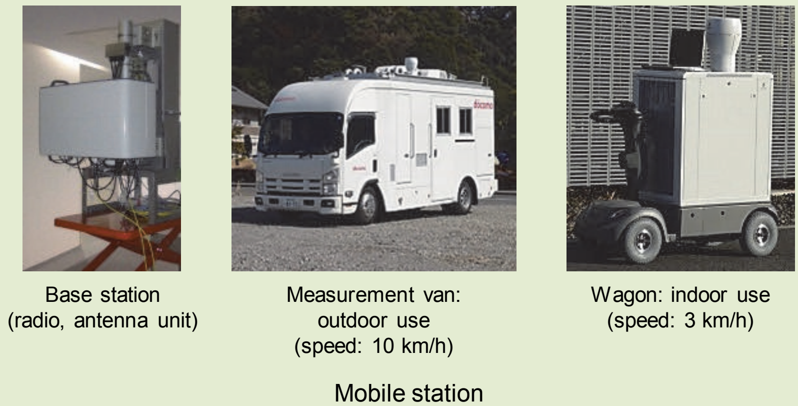



**Figure 1　5G test equipment**

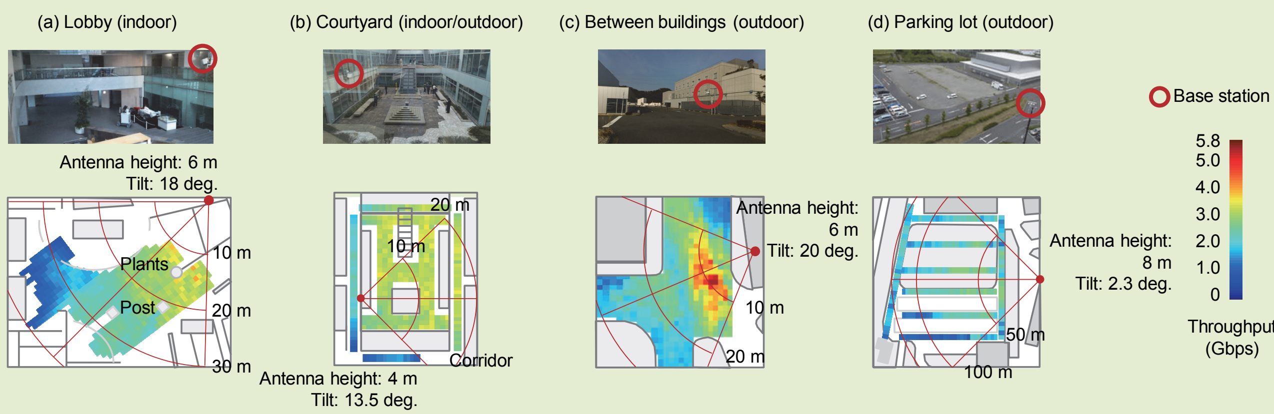



**Figure 2　Transmission test environment and throughput characteristics**

put was 3.6 Gbps, and the throughput was similar in the courtyard (outdoor) and in the corridor separated by a glass window (outdoor-indoor). In the corridor, the throughput decreases since the received signal power dropped due to the glass window separating it, while channel correlation*12 is low. On the other hand, despite the stronger received signal, the throughput decreases in both lobby and courtyard due to high channel correlation caused by the dominant direct signal path. Based on this, in measurements in (c), between buildings, throughput up to 5.5 Gbps was achieved by reducing channel correlation with increased separation between base station antenna elements, from 5 λ to 21.5 λ. Finally, (d), the parking lot, was a line-of-sight environment so channel correlation was very high, and maximum throughput was 2.8 Gbps. However, even at distances of 100 m or more from the base station, throughputs averaging 2 Gbps were achieved.

Indoor and outdoor 5G experiments were done using the 15 GHz band as above, achieving 5 Gbps by setting the outdoor base station antenna spacing to 21.5 λ. We also confirmed propagation losses and increased channel correlation due to propagation characteristics particular to high frequency bands. To resolve these issues in the future, we will validate technologies for coordinated

*10　**Carrier aggregation:** A technology for increasing bandwidth while maintaining backward compatibility with LTE, by using multiple component carriers and transmitting and receiving them simultaneously.

*11　**Stream:** A data sequence transmitted or received over a propagation channel using MIMO transmission.

*12　**Channel correlation:** An index indicating the similarity among multiple signals, with values near 1 (one) indicating similarity (correlation) and values near 0 (zero) indicating dissimilarity.

multi-point transmission*13, distributed MIMO*14, and beamforming*15.

### 3.2 Trials of 5G Radio Access in 28 GHz Band

An overview of verification of broadband transmission in the 28 GHz band, done in collaboration with Samsung Electronics, is described below [11] [12].

1) Test Overview

Various specifications of the trial test equipment are shown in **Table 3**, and the test equipment is shown in **Figure 3**. Broadband transmission was performed using a carrier frequency of 27.925 GHz and a bandwidth of 800 MHz. The base station antennas consisted of two 48-element planar array antennas*16 and the mobile station had two four-element linear array antennas. Each array antenna produced one beam, enabling beam multiplexed transmission of up to two streams. Both base station and mobile station featured beamforming capabilities, enabling them to achieve higher beam gain*17. Base station and mobile station select the combination of beams that maximize received power from among multiple beam candidates. To verify the beamforming effects of using Massive MIMO with high frequency bands, transmission field trials were conducted at Samsung Digital City in Suwon, Korea.

2) Experimental Results

**Figure 4** shows the experimental environment and results for downlink throughput. For these trials, one stream was transmitted using adaptive modulation and coding*18 with up to 16 Quadrature Amplitude Modulation (16QAM)*19, for a maximum throughput of 1.27 Gbps. The base station was located on the roof of a 23.5 m building, and throughput was measured while the mobile station moved at 3 km/h along a roadway approximately 200 m from the base station.

**Table 3 Test equipment specifications**

| Specification | Base station | Mobile station |
|---|---|---|
| Access method | OFDMA | |
| Modulation | QPSK, 16QAM, 64QAM | |
| Duplexing | TDD | |
| Carrier frequency | 27.925 GHz | |
| Bandwidth | 800 MHz | |
| No. of antenna elements per array | 8 × 6 (= 48) | 4 |
| No. of antenna arrays | 2 | |
| Array gain | 21 dBi | 7 dBi |
| Beam width | 10° | Horizontally: 20°<br>Vertically: 60° |
| MIMO configuration | Up to two-streams multiplexing | |

dBi: deciBel isotropic

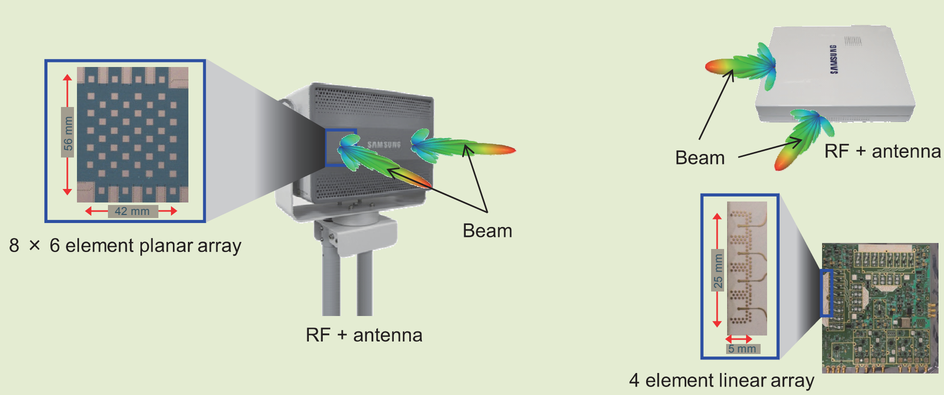



**Figure 3 Test equipment appearance**

*13 **Coordinated multi-point transmission:** Technology which sends and receives signals from multiple sectors or cells to a given UE. By coordinating transmission among multiple cells, interference from other cells can be reduced and the power of the desired signal can be increased.

*14 **Distributed MIMO:** A MIMO transmission technology that transmits different MIMO streams from multiple base stations to a single mobile station.

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

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

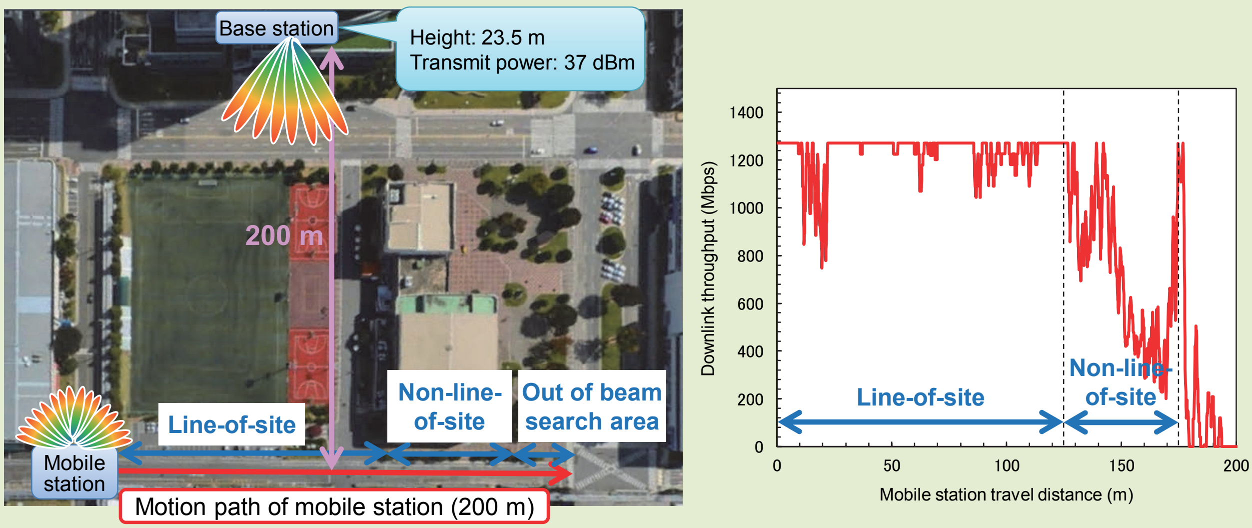



**Figure 4 Outdoor transmission tests**

Results showed that maximum throughput of almost 1.2 Gbps was possible even at points more than 200 m from the base station in line-of-sight environments, due to the effects of beamforming. On the other hand, in non-line-of-sight environments obstructed by buildings, throughput dropped due to shadowing losses*20. However, even in this sort of non-line-of-sight environment, continuous communication was possible and relatively high throughputs of around 300 Mbps were achievable. This was because even though the direct signal from the base station could not be received, beam selection enabled reception of signals reflected from the buildings.

These trials showed the potential for broadband transmission using beamforming with Massive MIMO in the 28 GHz band. Future trials will verify high-speed transmission with stream multiplexing and beam tracking performance for movement of mobile stations at high speeds.

### 3.3 Basic Trials of Multi-beam Multiplexing in 44 GHz Band

Basic trials of multi-beam multiplexing technology in the 44 GHz band, done in collaboration with Mitsubishi Electric, are described below [13]–[15]. Trials focused on multi-beam multiplexing using Massive MIMO to compensate for radio propagation losses in high frequency bands and realize dramatic increases in frequency utilization. An overview of the basic field trials and simulation studies using measured data to verify the potential of multi-beam multiplexing technology in the 44 GHz band is given.

1) APAA-MIMO

These trials examined a hybrid beamforming configuration called APAA-MIMO, which combines analog beamforming using Active Phased-Array Antennas (APAA)*21 with MIMO pre-coding using digital signal processing. To achieve the high-capacity transmission required for 5G, both the bandwidth and the frequency utilization must be increased, so MIMO spatial multiplexing of more streams using multiple beams generated by APAA is needed. With APAA-MIMO, interference generated between multiple beams can be controlled with pre-coding.

2) Trial Overview

To verify multi-beam multiplexing technology using APAA-MIMO, basic field trials were done using APAA in

*17 **Gain:** One of the radiation characteristics of an antenna. An indicator of how many times larger the radiation strength in the antenna's direction of peak radiation is, relative to a standard antenna.

*18 **Adaptive modulation and coding:** A method of modifying the modulation and coding schemes according to radio propagation path conditions. Modulation and coding schemes are modified to increase reliability when the propagation environment is poor, and to increase throughput when it is good.

*19 **16QAM:** A digital modulation method that allows transmission of 4 bits of information simultaneously by assigning one value to each of 16 different combinations of amplitude and phase.

the 44 GHz band as shown in **Figure 5**. Specifications of test equipment used are shown in **Table 4**. The APAA was a planar array of 8 × 6 (48) elements and a single beam was generated using all elements. To verify the feasibility of multi-beam multiplexing, the APAA was moved using a positioner as shown in Fig. 5, and 16-beam multiplexing performance was evaluated using a simulated array of 48 × 16 (768) elements. First, a basic trial was done in the factory of Mitsubishi Electric in Amagasaki City in Hyogo Prefecture, measuring outdoor propagation with APAA analog beamforming. These results were then used as a basis for simulating 16-user multiplexing to evaluate propagation performance.

3) Experimental Results

Experimental results are shown in **Figure 6**. High throughput was achieved, with users near the base station obtaining roughly 2 Gbps and users at 100 m from the base station obtaining roughly 1 Gbps. All users obtained a total throughput of 21.1 Gbps.

In the future, we will conduct further transmission trials and combine them with simulation to study issues including optimizations of APAA-MIMO antennas and circuit configurations, the maximum number of beams that can be multiplexed, the analog beamforming beam search interval and range, precoding optimizations, and user multiplexing control.

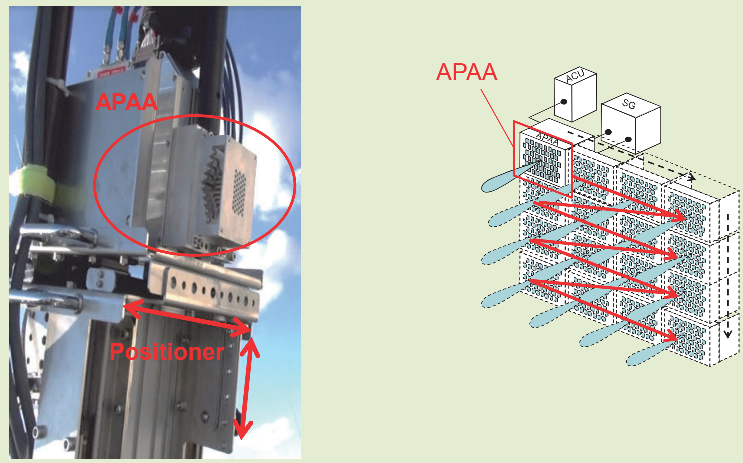



**Figure 5 APAA base station equipment and virtual beam multiplexed APAA-MIMO**

**Table 4 Test equipment specifications**

| | | |
|---|---|---|
| **Carrier frequency** | 44 GHz | |
| **Base station antenna** | APAA | |
| | No. of antenna elements | 8 × 6 (= 48) |
| | Antenna gain | 17.2 dBi |
| **Receiver antenna** | Horn antenna | |
| | Receiver antenna gain | 20.4 dBi |

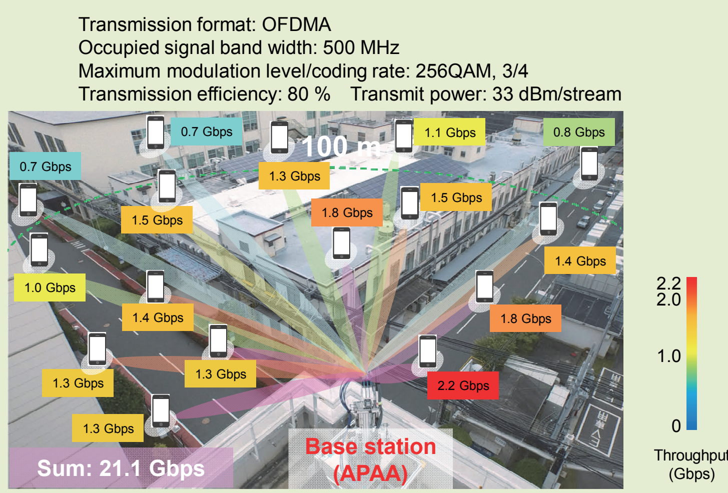



**Figure 6 Evaluation of 16-beam multiplexed-transmission characteristics by simulation based on transmission measurements**

*20 **Shadowing losses:** Shadowing refers to when reception power drops because a mobile terminal enters the shadow of a building or other object and losses refers to decreases in reception power in general.

*21 **APAA:** An array antenna with amplifiers and phase shifters for each antenna element and capable of controlling radio wave directivity (beam) electronically.

### 3.4 Trials of 5G Radio Access in the 70 GHz Millimeter-wave Band

Trials done in collaboration with Nokia Networks to verify beamforming technology for 70 GHz band millimeter wave transmission are described below [16] [17]. These trials validated beamforming technology anticipated for use in applications such as small cells and indoor hotspots*22 to improve coverage and mobility.

1) Trial Overview

Specifications of the testbed are shown in **Table 5** and the base station and mobile station are shown in **Figure 7**. The center frequency of the equipment was 73.5 GHz and the system bandwidth was 1 GHz. The base station controls a beam with half-power beam width*23 of 3° over a range of ±17.5° horizontally and ±4.0° vertically. The base station has a beam tracking mechanism that selects the beam of best mobile station signal quality from among 64 candidates (4 directions vertically and 16 directions horizontally).

Trials were conducted in various small cell environments in the YRP district in Yokosuka City, Kanagawa Prefecture, to evaluate millimeter wave propagation characteristics and beamforming. **Figure 8** shows photographs of the trial conditions. Here, we give results from testing in three environments: (a) A courtyard (outdoor, line-of-site), (b) A lobby (indoor line-of-site and non-line-of-site), and (c) An underground parking lot (indoor line-of-site and non-line-of-site). The distances from the base station to the courses in each environment were roughly 20 m in (a), 20 m and 35 m in (b), and 40 m and 60 m in (c). The mobile terminal moved at a speed of 4 km/h, assuming a walking speed. As the mobile terminal moved along the course, the best beam changed, and the base station beam followed this appropriately.

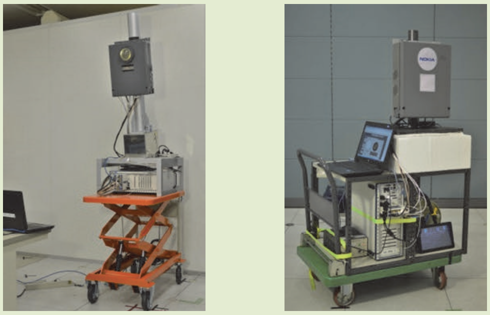
2) Experimental Results

Cumulative Distribution Functions (CDF)*24 for throughput in each of the environments are shown in **Figure 9**. The CDFs confirm the throughput distribution ratios on each course. For each of the courses, the locations where the maximum transmission throughput of

**Table 5 Testbed specifications**

| | |
|---|---|
| Radio access | NCP-SC |
| Multiplexing | TDD<br>(uplink/downlink ratio = 12 : 188) |
| Center frequency | 73.5 GHz |
| System bandwidth | 1 GHz |
| Transmitting power | 23.6 dBm (0.229 W) |
| No. of transmission/reception antennas | 1 |
| TTI length | 100 μsec |
| Data modulation | BPSK, QPSK, 16QAM |

BPSK: Binary Phase Shift Keying
NCP-SC: Null Cyclic Prefix Single Carrier



Base station equipment　　Mobile station equipment

**Figure 7 Testbed appearance**

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

*23 **Half-power beam width:** The angular range from the maximum power emitted from an antenna to the half of that value. Indicates the sharpness of the antenna pattern.

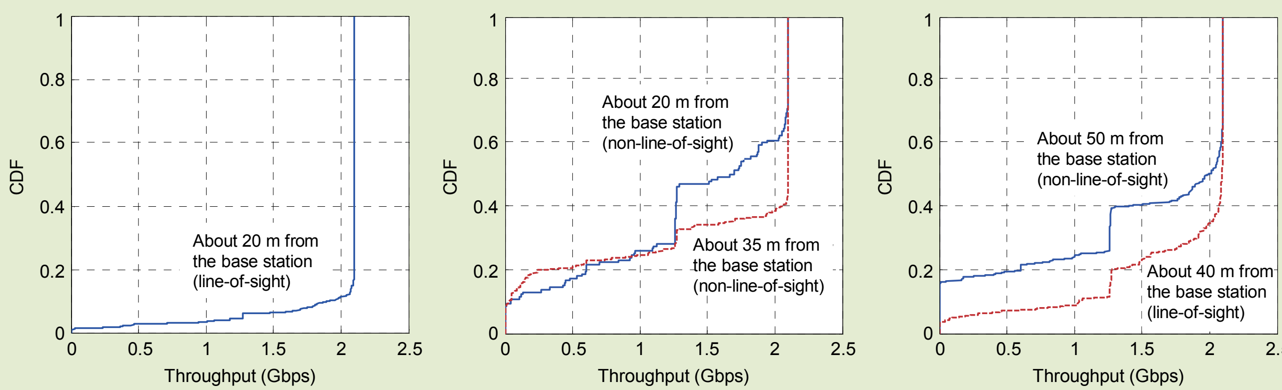
*24 **CDF:** A function that represents the probability that a random variable will take on a value less than or equal to a certain value.


(a) Courtyard: Cell radius 20 m (outdoor line-of-site)

(b) Lobby: Cell radius 35 m (indoor, line-of-site and non-line-of-site)

(c) Underground parking garage: Cell radius 60 m (Indoor, line-of-site and non-line-of-site)

**Figure 8 Trial environments**




(a) Courtyard

(b) Lobby

(c) Underground parking garage

**Figure 9 Throughput characteristics**

the equipment, which is over 2 Gbps, is achieved and the proportion of each course where this maximum throughput is achieved varies due to differences in the courses. In particular, for line-of-site environments, the maximum throughput was achieved over most of the courses.

Currently we are developing a system for visualizing beam state as shown in **Figure 10**, and explaining millimeter wave propagation characteristics. We are also conducting trials in urban environments that are closer to actual-use environments. In the future, we also plan to test multi-site transmission with multiple base stations that can reduce non-line-of-site conditions.

## 4. Conclusion

This article has given an overview of 5G trials being done by NTT DOCOMO in collaboration with major vendors and introduced experiments focused on verifying elemental technologies for utilizing high frequency bands. The test results obtained will be used as verification of the 5G concepts advocated by NTT DOCOMO and to contribute to discussion at research organizations and international conferences around the world related to 5G and in 5G standardization activities, which will begin in earnest in 2016. They will also be used in study to create more advanced technologies.

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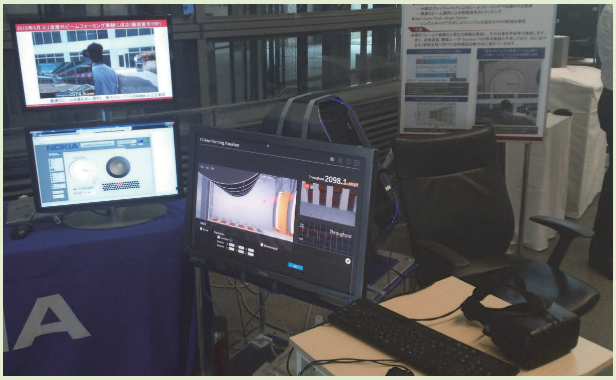

**Figure 10 Beam state visualization system**


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Local Information Extraction Technology　Twitter　Natural Language

Technology Reports

# Technology to Discover Local Events Using Twitter

*Twitter is a social networking service that enables real-time, large-scale sharing of information on a wide range of topics. This article describes technology that automatically discovers information from Twitter for local events being held throughout Japan using natural language processing technology, and introduces a "town event information" service enabled by this technology.*

Research Laboratories　*Wataru Yamada*
Service Innovation Department　*Keiichi Ochiai*
*Haruka Kikuchi*

## 1. Introduction

With the popularization of smartphones, there are now many types of location information services available. For example, Trip Advisor®*1 is a service that provides information and reviews on hotels and restaurants all over the world, while the Gurutabi®*2 service provides fine dining information for various localities in Japan. To make these location information services more attractive, it's important to provide the latest information about sightseeing spots, events, and specialties in localities.

However, it takes a lot of effort to maintain provision of up-to-date information for localities. Moreover, frequent updating is also required for information on local events to ensure the freshness of information because new events are held often, and handling these manually has its limitations.

To solve this issue, we have developed technology to automatically discover information about events being held in localities in Japan using Twitter*3. Twitter is a social networking service that enables users to post and share text messages that are up to 140 characters long (called tweets*4). Twitter enables users to share large amounts of information on various topics such as things happening in their own lives, new products, news and events. In particular, Twitter makes it easy for anyone to announce an event, not only highly public events such as fireworks displays or local festivals, but also a wide range of other events such as store fairs or indie band performances.

The technology we have developed uses natural language processing technology*5 to automatically discover event information from tweets. Not only does the technology determine whether or not there is an event, but also can extract the event name, location, and time with approximately an 80% to 90 % degree of accuracy.

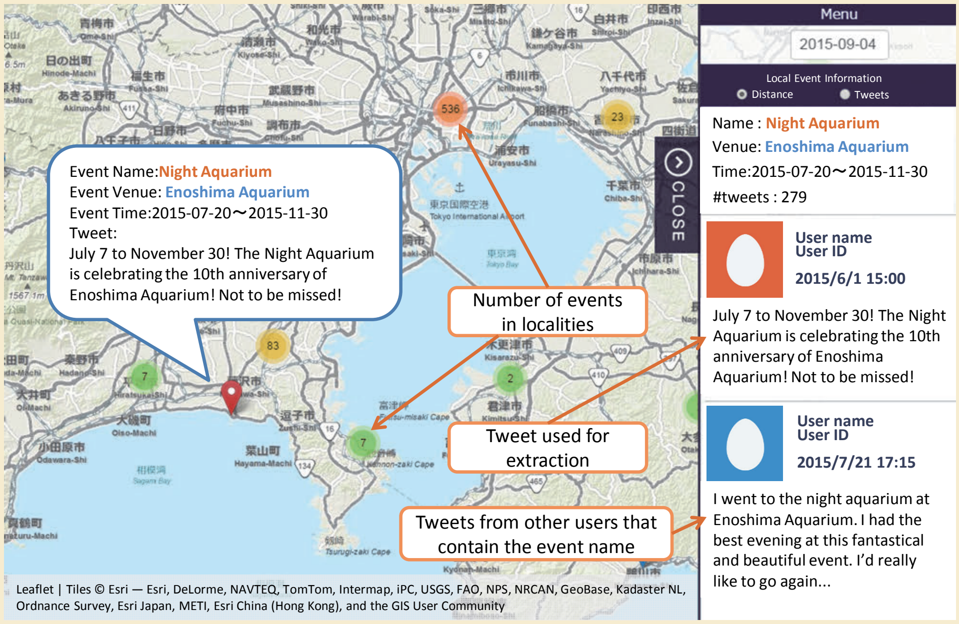
This article describes this automatic local event information discovery technology, and also describes a "town event information" service using this technology.

## 2. Overview of the Local Event Discovery Technology

The following describes an overview of the local event discovery technology. **Figure 1** shows the operations screen of the demonstration application. This application was prepared to visualize and demonstrate this technology, and displays the automatically extracted event



*1 **Trip Advisor®:** An international service that provides information on restaurants and hotels, and reviews. The trademark and registered trademark of TripAdvisor, LLC.




* These tweets are fictional examples..

**Figure 1 Image of event discovery technology prototype**

information as the time of the event and its location, which makes it easy for users to find event information in various localities. From automatically extracted local event information, Figure 1 shows events assumed to be held on Friday September 4, 2015. Information for each event contains the three pieces of information, the event name, location, and time, and also contains tweet information from which these pieces of information were extracted. For example, the balloon in Figure 1 shows three pieces of information - the event name as "Night Aquarium," the location as "Enoshima Aquarium," and the time as "July 20, 2015 to November 30, 2015." Also, users can search through tweets that contain the event name to see other users' tweets about the event. The numbers on the map in Figure 1 show the total number of events in various localities automatically extracted in a similar manner to the "Night Aquarium" event. For example, on September 4, there are 536 events being held in the Tokyo area.

The actual number of events discovered changes with seasons, with holidays and weekends, and with business days, although in general, the system can extract around 150 new events nationwide every day, or around 4,000 to 5,000 per month. This is the largest event database in the country.

Conventionally, events were extracted mainly by determining locations from a sharp rise in posts of tweets appended with location information [1] [2]. Because it's presumed that the number of tweets from around the location of the event will change in this way, this method extracts information for large-scale happenings where many tweets are posted such as earthquakes or performances by famous artists, but cannot extract small scale events that have relatively lower numbers of related tweets. Furthermore, this method cannot extract information prior to an event.

With our event discovery technology, even if there are not many tweets with location information attached, it's possible to extract event information using machine learning*6 technology that focuses on the natural language characteristics of the tweets that contain event information. Hence, even a single tweet announcing an event can be used to extract information, which makes it possible to discover not only large-scale events

*2 **Gurutabi®:** A service that introduces local specialties throughout Japan. A registered trade mark of Gurunavi, Inc.

*3 **Twitter:** A registered trademark of Twitter, Inc. in the United States and other countries.

*4 **Tweet:** A term used to refer to postings on the micro-blogging service provided by Twitter, Inc.

*5 **Natural language processing technology:** Technology to process the language ordinarily used by humans (natural language) on a computer.

*6 **Machine learning:** A mechanism allowing a computer to learn the relationship between inputs and outputs, through statistical processing of example data.

but also small-scale events held locally.

## 3. System Structure and Process Flow

The local event discovery technology consists of a location name extraction section and an event information extraction section, as shown in **Figure 2**. Processing for these sections is as follows.

### 3.1 Location Name Extraction Section

Using tweets in Japanese, the location name extraction section analyses which location the tweet is discussing, and then associates the tweet with the location. This association takes three steps - (1) to (3) shown in Figure 2. Firstly, morphological analysis*7 is performed on the Japanese language tweets (Figure 2 (1)). Next, a list of location names that includes such information as locality and facility names and flags describing ambiguity (described later) is referenced, and tweets containing nouns that match location names are extracted (Figure 2 (2)). Finally, filtering is performed for tweets that contain ambiguous location names (Figure 2 (3)). Location names that are ambiguous include names that are also used for people, or names that are used in multiple locations that cannot be uniquely determined, for example, the surname "Matsushima" and the sightseeing locality "Matsushima" in Miyagi Prefecture. An example of a location name used in more than one place is "Maruyama Park" in Kyoto and "Maruyama Park" in Hokkaido. To eliminate these ambiguities, processing with co-occurrence words and machine learning is used so that filtering is performed

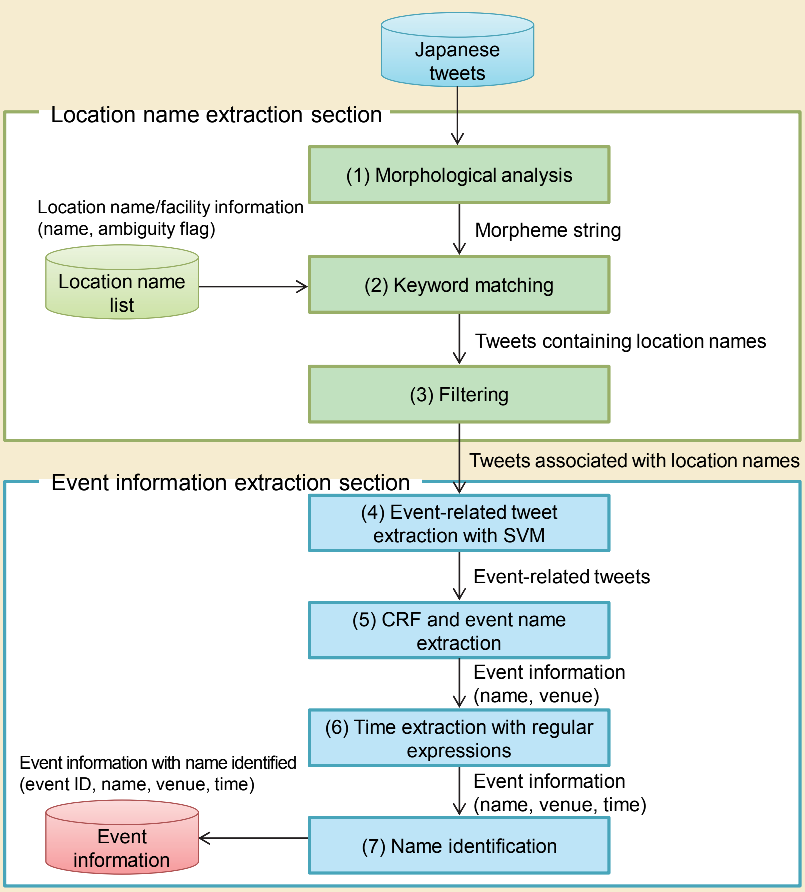



**Figure 2 Overview of entire processing for local event discovery technology**

*7 **Morphological analysis:** Technology that separates the smallest parts of words in text that have meaning, called morphemes.

correctly. See reference [3] for details of this filtering.

After the above processing, the location name extraction section outputs the Japanese language tweets associated with the location name to the event information extraction section, with ambiguity removed.

### 3.2 Event Information Extraction Section

The event information extraction section extracts the event name and time from tweets associated with location names. In general, this process consists of four steps. Firstly, event-related tweet extraction processing is performed to extract tweets from the tweets associated with location names that contain information about the event name and time (Figure 2 (4)). Secondly, event names are extracted from tweets that contain event information. Also, the location name associated with tweets used in the location name extraction section is assigned to event venue information (Figure 2 (5)). Thirdly, the event time is extracted from the tweets from which the event name was extracted (Figure 2 (6)). Fourthly, for the extracted event information, using degrees of similarity with the venue and event name, name identification processing is performed to determine whether the names are the same, then each piece of the event information is given an ID (Figure 2 (7)). The details of these processes are described below.

1) Event-related Tweet Extraction

Using machine learning, event-related tweet extraction only extracts tweets related to events from tweets already associated with location names. In this process, a classifier*8 learns characteristics of words that appear often in event-related tweets such as "hold" or "festival," and then event-related tweets are extracted from tweets associated with location names. To process large numbers of tweets quickly, an algorithm called linear Support Vector Machine (SVM) [4] is used. This algorithm is split into two phases, as shown in **Figure 3**.

(a) Firstly in the learning phase, tweets are collected, and each tweet is visually checked to see whether or not it is an event-related tweet, and either an "event-related" or "event-unrelated" la-

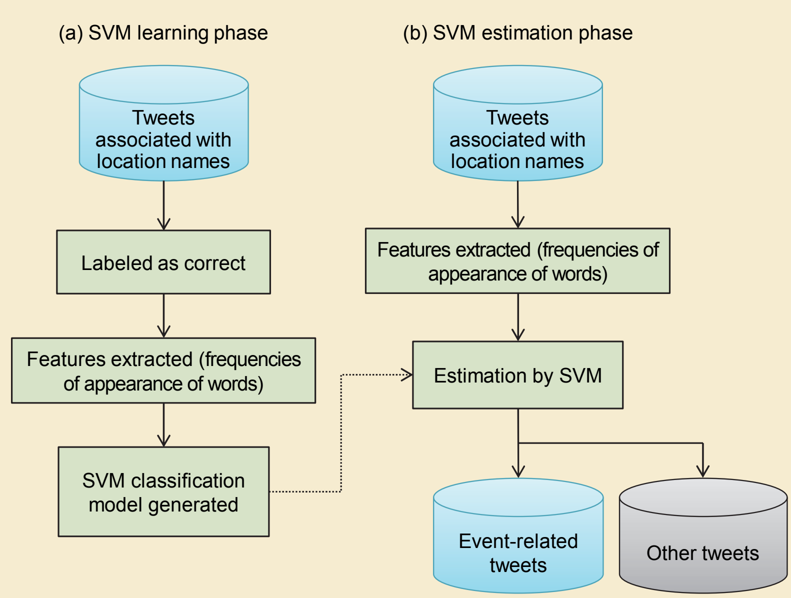



**Figure 3 Event-related tweet extraction with SVM**

*8 **Classifier:** A device that classifies inputs into a number of predetermined classifications based on their feature values.

bel is attached to each tweet. Next, features[*9] are extracted from labeled tweets. The number of times words appear is used for these features. For this reason, if there are tweets with words such as "hold" or "exhibition" that appear often in event-related tweets but not in non-event related tweets, these tweets are judged to be event-related tweets.

(b) In the estimation phase, the classifiers configured in the learning phase are used to determine whether tweets associated with location names contain information about events. Tweets which are determined to contain event information are output to event name extraction processing.

2) Event Name Extraction

Event name extraction uses SVM to extract event names from tweets judged to be event related. This process uses a machine learning algorithm called Conditional Random Fields (CRF)[*10] [5] to extract event names.

Event name extraction by CRF is also divided into two phases, as shown in **Figure 4**.

(a) In the learning phase, the sections that contain the event names and section unrelated to the event name in the event-related tweet are labeled. Then, CRF learns various characteristics such as words like "festival" that appear often in expressions and character strings such as "October fest" that appear often as event names, and then generates a classification model. Word readings and writings, parts of speech and number of characters are used as features.

(b) Using the classification model generated in the learning phase, the estimation phase determines which parts of tweets judged to be event related are related to event names. Then, tweets for which event names have been extracted are output for event time extraction.

3) Event Time Extraction

(1) Extraction using regular expressions

Regular expressions are used to extract event time from tweets. The use of regular expressions is one method of natural language processing which determines whether character strings match predetermined

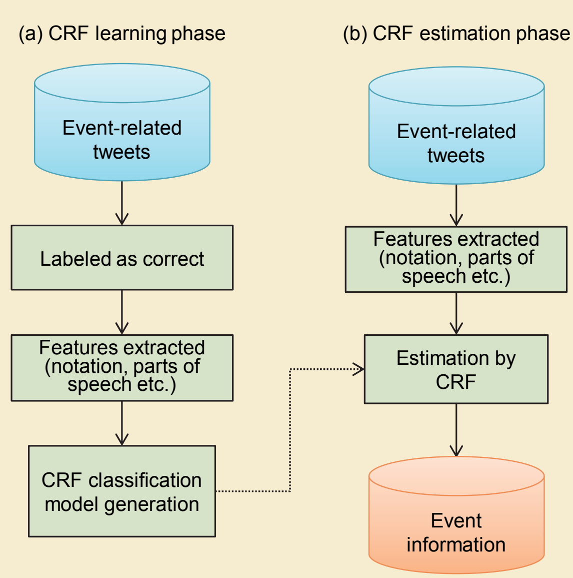



**Figure 4 Event name extraction by CRF**

*9 **Feature:** The feature values in natural language processing.

*10 **CRF:** A type of method for assigning pre-defined labels to a sequence of input entities based on the feature values of the entities.

patterns and makes it possible to extract those matching character strings from text. For example, by defining the pattern "¥d{2,4}/¥d{1,2}/¥d{1,2}" the character stings "2016/1/1" or "16/12/31" can both be extracted, since both 2 and 4 digits are defined for "year" and 1 and 2 digits are defined for month and day etc. Firstly, many date-related patterns are registered in advance for event time extraction, and then dates are extracted from text by matching those patterns.

(2) Date supplementation

Extracted dates do not necessarily contain all "year/month/day" date information, for example dates such as "1/1" or "Today." For such dates, the date that the tweet was posted is referenced and used to supplement the date so it can be read as year/month/day. Also, to handle dates that are not single dates such as "from January 1 to 3, 2016" that depict a period, the text is checked for indications of a period such as 'from,' 'to' or "-" between extracted dates. Thus, if there are indications of a period, information surrounding dates etc. is checked to extract the period for the event.

The above processes extract the three pieces of information about events - the event name and time, and the event venue assigned by the location name extraction section.

4) Name Identification Processing

Although event information up to the event time is extracted with this series of processes, there can be duplicate extractions due to the fact the multiple tweets can be posted informing of the same event.

Also, because different users might use different text characters or spelling to indicate an event name, such as "Future of the 21st Century Exhibition" or "21st Century Future Exhibition," the same events can be contained in event information with different names.

To solve this, this process uses the two pieces of event name and venue information to determine whether events are the same and then assigns the event an ID. These are numbers used for managing event information-the same ID is assigned to duplicated event information.

As shown in **Figure 5**, this process groups extracted event information by event venues. Next, all possible pairs are created from events with the same venues. Then, the event names for the events with the same venues are computed for degree of similarity, and determined to be the same event if this degree is above a certain threshold. These events names are then assigned the same event ID. The longest common subsequence ratio is used for the degree of similarity of event names. As shown in Figure 5, this process enables summarization of events with similar names that are to be held at the same venue.

## 4. The "Town Event Information" Service

Since May 12, 2015, a "town event information" service has been available in the DOCOMO d-menu real-time search corner. As shown in **Figure 6**, using this technology, this service enables users to display information to find topical events close to their location from event information collected for their current locality. Users can also search for information for events other than those in their locality by specifying locations and dates with maps and calendars, which is useful when traveling or going out.

## 5. Conclusion

This article has described an overview of technology to automatically discover local event information from tweets, and has introduced the "town event information" service provided by using this technology. In future, using this technology, we plan to produce content with nationwide event information to create services that can be used for local development. We will also research and develop local information extraction technologies for information other than events, such as information on local specialties and related reviews.

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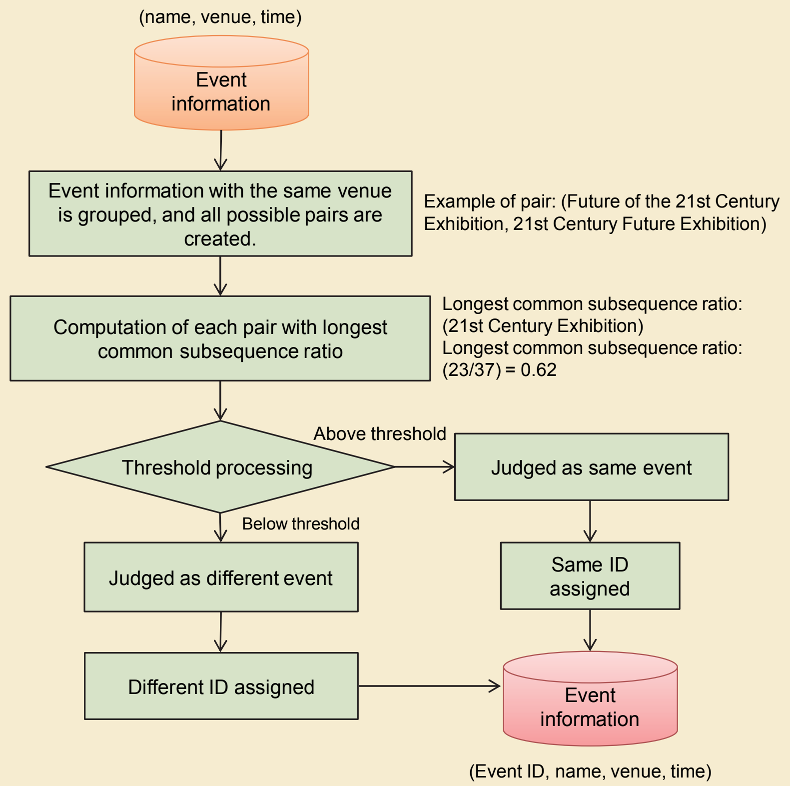


**Figure 5 Name identification of event information**

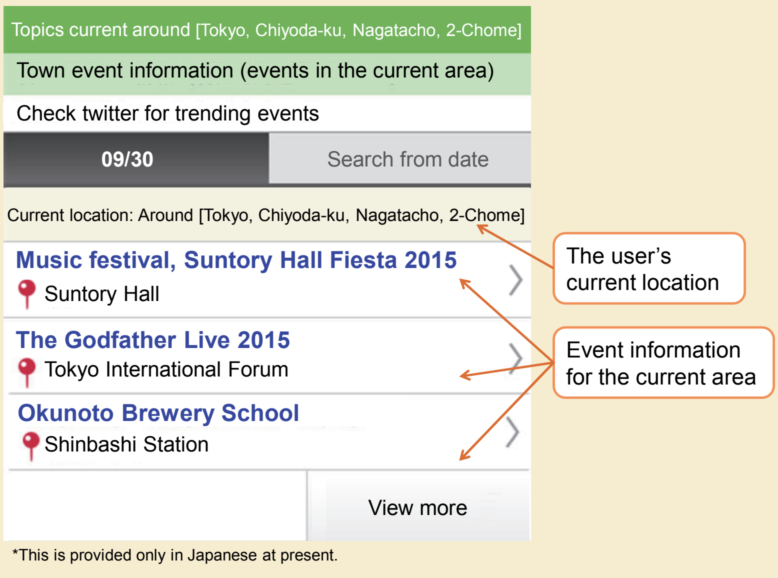


**Figure 6 Image of "Town event information" service screen**

[2] R. Lee and K. Sumiya: "Measuring geographical regularities of crowd behaviors for Twitter-based geo-social event detection," Proc. of 2nd ACM SIGSPATIAL International Workshop on Location Based Social Networks, pp.1-10, 2010.

[3] K. Ochiai et al.: "Analysis of Location-related Tweets and its Applications," NTT DOCOMO Technical Journal, Vol.16, No.2, pp.29-35, Oct. 2014.

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Traffic Isolation M2M 3GPP Release 13

Standardization

# Dedicated Core Networks to Isolate Traffic Based on Terminal Type

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*Standardized specifications for a new method of separating core networks by the terminals accessing them have been approved in 3GPP SA2. This system leverages dedicated core networks designed to handle traffic according to the characteristics of individual communications from terminals. This system eliminates the need for terminal modifications and enables terminals to be served by the desired core networks by redirecting communications from switching equipment based on terminal identification parameters held in subscription information on the core network. This system is expected to be applied to M2M communications. This article describes technical features of this system, basic call controls, trends in standardization, and the outlook for the future.*

## 1. Introduction

Since the commencement of LTE high-speed data communications services in 2010, NTT DOCOMO has also commenced services for Mobile Virtual Network Operator (MVNO)*1, international LTE data roaming [1] [2], and in 2014 commenced Voice over LTE (VoLTE) [3] to provide voice and SMS services, as smartphones have rapidly penetrated the mobile communications market. In addition, the expectation for the popularization of Machine-to-Machine (M2M)*2 devices has gradually grown since they have become inexpensive, and hence, it is predicted that the number and variety of terminals and devices connected with LTE will increase.

Going forward, to accommodate such a diverse range of terminals and devices on the network, separation of core networks*3 will enable even greater flexibility and optimal network control such as localization of network loads and efficient accommodation design to suit the characteristics of traffic and priorities. For example, in cases where network congestion*4 and failures caused by large numbers of low-priority M2M devices connected to the network could hinder high-priority smartphone user communications, separating the core networks that accommodate low-priority M2M devices would limit network congestion and failures to these core networks while these low-priority devices can be controlled without any impact on high-priority communications. Moreover, suitable reliability and cost reductions will be achievable since it is possible to design networks that can adjust the level of services



*1 **MVNO:** An operator that provides voice and data communications services etc. by renting network infrastructure from a mobile telephone carrier.

*2 **M2M:** Systems for automated communications at regular intervals or under certain condition between machines, which do not entail the involvement of humans.

to suit the traffic characteristics and priority levels of the accommodated terminals and devices.

3rd Generation Partnership Project (3GPP) has previously specified some functions for separating core networks, these, however, require functions to be implemented on terminals and devices, which is difficult to apply to terminals already in use in the wider community. Hence, as a result of NTT DOCOMO emphasizing the need for systems that do not impact on terminals, dedicated core network (hereinafter referred to as "DCN") studies on separating core networks have been endorsed as a Work Item (WI)*5 in Release 13 of 3GPP Service and System Aspects (SA) 2. In this WI (called "DECOR"), NTT DOCOMO has become the rapporteur*6 to lead these studies. Architecture standardization in 3GPP SA2 was completed in May of 2015 [4]. These functions are standardized as specifications that can be implemented with both LTE and 3G systems [5].

This article describes technical features of DCN, an overview of call control procedures related to core network rerouting and reselection, the latest trends in standardization, and the outlook for the future.

## 2. DCN Technical Features

**Figure 1** shows the DCN architecture. Here, an example of accommodating M2M devices on a DCN is given. Rerouting terminals to DCN and using DCN have the following characteristics.

- Rerouting to a DCN is possible including existing terminals already in use. The terminal identifier*7 for rerouting (UE Usage Type) is included in subscription information in the Home Subscriber Server (HSS)*8, and does not require notification to terminals.
- Rerouting to a DCN can be executed in basic call processing procedures during Attach*9 and Tracking Area Update (TAU)*10/Routing Area Update (RAU)*11. No special requests are required from terminals - everything is controlled automatically on the network. When Attach/TAU/RAU requests are sent from terminals to the conventional core network (the default core network) (Figure 1 (1)), the switching equipment (Mobility Management Entity (MME)*12/Serving General Packet Radio Service (GPRS) Support Node (SGSN)*13) firstly attempts to acquire the terminal identifier from the information held in the switching equipment in the old area (old MME/SGSN) over Identification Request/Response with Attach or Context Request/Response with TAU/RAU (Figure 1 (2), (3)). Next, if the terminal identifier cannot be acquired through this procedure, the terminal identifier included in the subscription information is acquired through the Authentication Information*14 Request/Response procedure from HSS (Figure 1 (4), (5)). The switching equipment references the acquired terminal identifier and determines whether to reroute to a DCN.
- Even if there is more than one piece of switching equipment on a DCN, control is possible with conventional technologies. When rerouting to DCN, a redirect command is issued by the switching equipment to radio equipment (eNodeB*15/Radio Network Controller (RNC)*16) to send the information from

*3 **Core network:** A network consisting of switching equipment and subscription information management equipment etc. Mobile terminals communicate with the core network via radio access networks.

*4 **Congestion:** A condition in which communications signals are concentrated in a short period of time and the processing capabilities of switching equipment are exceeded causing communications to fail.

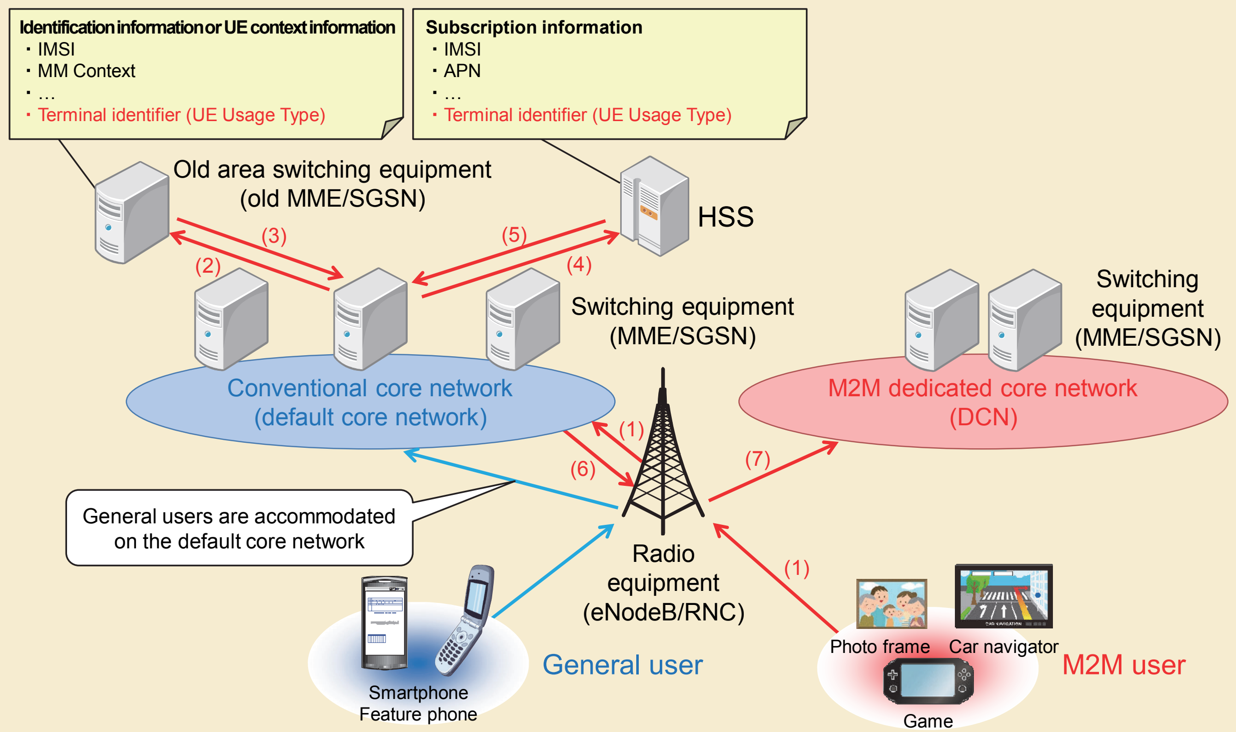
*5 **WI:** A study theme in 3GPP standardization.

*6 **Rapporteur:** The position in 3GPP that entails summarizing discussions, editing technical reports capturing the results of discussions, and managing progress on subjects of study such as individual work items on LTE etc.

*7 **Terminal identifier:** An identifier included in subscription information that indicates the type of terminal or device and its use.

*8 **HSS:** A subscription information database in a 3GPP mobile network that manages authentication and location information.

# Standardization




Legends:
(1) Attach/TAU/RAU sent
(2) Identification Request (with Attach) or Context Request (with TAU/RAU) sent
(3) Identification Response (with Attach) or Context Response (with TAU/RAU) sent*
(4) If terminal identifier cannot be acquired with (3), terminal identifier requested in Authentication Information Request
(5) Terminal identifier sent in Authentication Information Answer
(6) Attach/TAU/RAU redirected when terminal identifier determined by switching equipment
(7) Radio equipment selects switching equipment on DCN to connect using NNSF, then Attach/TAU/RAU transferred

* If the terminal has ever camped on the switching equipment in the old area, and this switching equipment supports DCN related functions, the terminal identifier is included.

**Figure 1 DCN architecture**

the terminal to the desired DCN (Figure 1 (6)). The radio equipment uses the conventional Network Node Selection Function (NNSF)*17 to select the DCN switching equipment (Figure 1 (7)).

- With LTE, Serving GateWay (S-GW)*18/Packet data network GateWay (P-GW)*19 can also be installed specifically for a DCN to enable separation of smartphone and M2M traffic. These nodes can be selected as required by configuring node information in switching equipment or by using a Domain Name System (DNS)*20 with the terminal identifier as the key.

Due to the above characteristics, it is possible to deploy a DCN that makes best use of existing call processing procedures and that does not require terminal modifications.

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*9 **Attach:** Processing to register a mobile terminal on a network when the terminal is turned on etc.

*10 **TAU:** Processing to re-register a mobile terminal on a network or update network registration equipment when the mobile terminal has moved to an LTE network.

*11 **RAU:** Processing to re-register a mobile terminal on a network or update network registration equipment when the mobile terminal has moved to a 3G network.

*12 **MME:** A logical node accommodating eNodeB (see *15) and providing mobility management and other functions.

*13 **SGSN:** A logical node accommodating RNC (see *16) and providing mobility management and other functions.

*14 **Authentication information:** Authentication and security information provided by HSS to mobile terminals.

*15 **eNodeB:** A base station for the LTE radio access system.

*16 **RNC:** 3G radio network control equipment.

## 3. Procedures for Controlling Calls to a DCN

This chapter describes the operation of this system. In this description, terminals are to be rerouted to a DCN. The first MME/SGSN is on the default core network, while the second MME/SGSN is on the DCN. Also, radio equipment (eNodeB/RNC) can connect to either MME/SGSN.

### 3.1 Rerouting Procedure

Rerouting to DCN is shown in **Figure 2**. The first MME/SGSN determines to require rerouting to DCN from the terminal identifier acquired from the HSS or the old area MME/SGSN (refer to Section 3.2) and sends Reroute NAS Message Request as a reroute request to eNodeB/RNC at Figure 2 (1). As well as the original Attach/TAU/RAU message received from the terminal, the MME Group ID (MMEGI)*21 (with LTE), or the Null Network Resource Identifier (Null NRI)*22 or the SGSN Group ID*23 (with 3G) required to identify the DCN for rerouting (hereinafter referred to as the "DCN identifier"), and under certain conditions the terminal identifier, are included in this message. As a condition of inclusion of terminal identifiers, there are cases in which the old area MME/SGSN cannot provide the first MME/SGSN with the terminal identifier, e.g. because the old area MME/SGSN does not support DCN related functions.

In Figure 2 (2), eNodeB/RNC performs NNSF based on the DCN identifier received at Figure 2 (1) to decide the second MME/SGSN to which the terminal is to connect, and then sends the original Attach/TAU/RAU message and DCN identifier at Figure 2 (3). The purpose of including the DCN identifier at Figure 2 (3) is to indicate that the forwarded Attach/TAU/RAU isn't sent directly from the terminal but is rerouted. At the same time, it is acting as a flag to prevent rerouting of the Attach/TAU/RAU message at the second MME/SGSN. With the terminal identifier included at Figure 2 (1), the same terminal identifier is included at Figure 2 (3). This enables omission of terminal identifier query processing to the HSS at the second MME/SGSN.

In consideration of the impacts of the rerouting procedure on communication conditions, rerouting is only performed for terminals that are in the idle state*24.

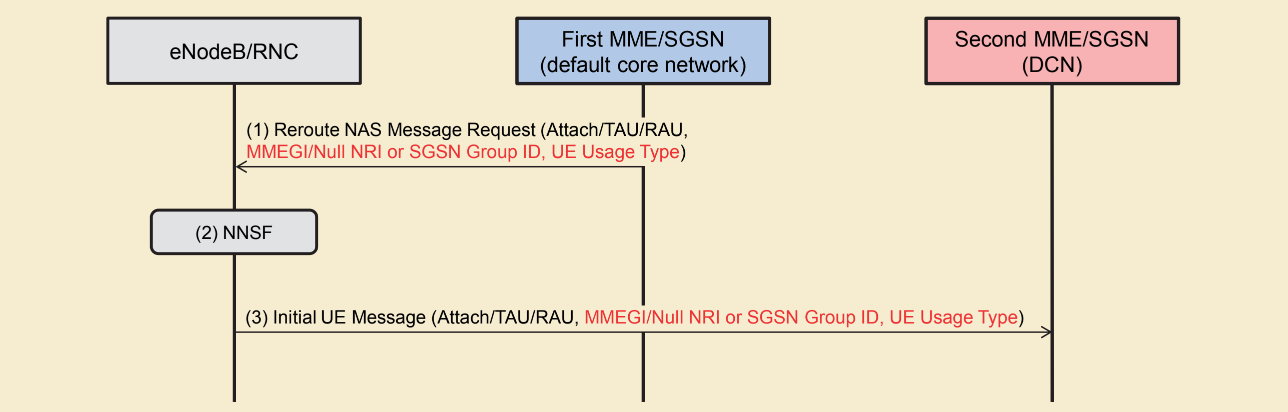


**Figure 2 Procedure for rerouting to DCN**

*17 **NNSF:** Processing facilitated by eNodeB/RNC to select a suitable node in consideration of load distribution etc. from among multiple MME/SGSN.

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

*19 **P-GW:** A gateway acting as a connection point to an external network (PDN), allocating IP addresses and transporting packets to the S-GW.

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

*21 **MMEGI:** A unique global identifier for determining the MME group (refer to *26 Pool Area).

*22 **Null NRI:** NRI is an identifier that identifies SGSN. Defined in DCN as an identifier for identifying the SGSN group (refer to *26 Pool Area).

*23 **SGSN Group ID:** A newly defined identifier instead of the Null NRI to identify the SGSN group (refer to *26 Pool Area).

### 3.2 Attach Procedure

The Attach procedure including the DCN rerouting procedure is shown in **Figure 3**. The Attach Request is sent from terminals via eNodeB/RNC to the first MME/SGSN (Figure 3 (1)). If the terminal previously camped on a different old MME/SGSN and the old MME/SGSN supports DCN-related functions, the first MME/SGSN can acquire the terminal identifier from the UE context available in the old MME/SGSN (Figure 3 (2), (3)).

If the first MME/SGSN cannot acquire the terminal identifier from the old MME/SGSN because the terminal has never camped on an old MME/SGSN, or the old MME/SGSN does not support DCN-related functions, the first MME/SGSN sends an Authentication Information Request (AIR) to acquire the terminal identifier with an Authentication Information Answer (AIA) from the HSS (Figure 3 (4), (5)). In this case, authentication information can be acquired in addition to the terminal identifier if necessary.

The first MME/SGSN determines whether to reroute to a DCN from the terminal identifier at Figure 3 (6), and if rerouting is required, the DCN rerouting procedure described in Section 3.1 is performed at Figure 3 (7). If rerouting is not required, the terminal camps on the conventional core network or Attach is rejected, in accordance with operator policies.

After DCN rerouting is performed,

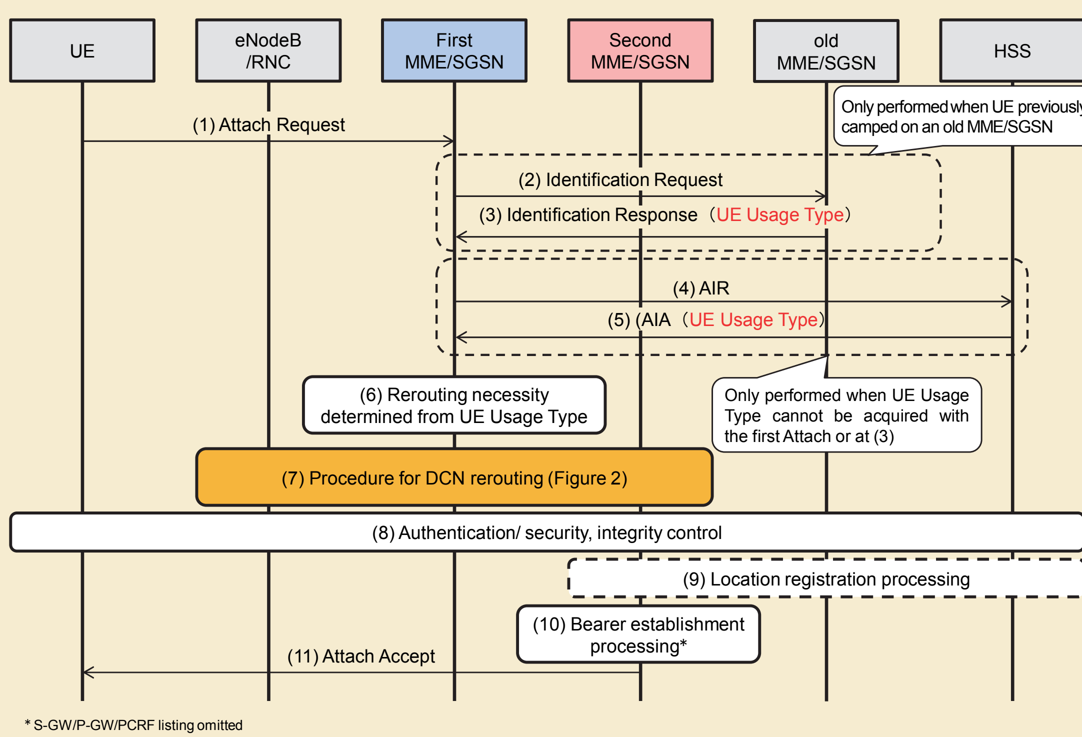


**Figure 3 Attach procedure including DCN rerouting**

***24 Idle state:** A state in which resources between the mobile terminal and the radio network are released.

the same Attach procedure as the conventional is performed for the second MME/SGSN. After the procedure to Attach to the second MME/SGSN is complete, the terminal camps on the DCN (Figure 3 (8) to (11)).

### 3.3 TAU/RAU Procedure

The TAU/RAU procedure also supports DCN rerouting described in Section 3.1. This procedure is shown in **Figure 4**.

The TAU/RAU Request is sent from terminals via eNodeB/RNC to the first MME/SGSN (Figure 4 (1)). The first MME/SGSN attempts to acquire the terminal identifier from the old MME/SGSN with the UE context*25 acquisition procedure (Context Request/Response) to determine whether DCN rerouting is required (Figure 4 (2), (3)). If the identifier is acquired with this procedure, the first MME/SGSN temporarily sends the Context Acknowledge message to the old MME/SGSN with a code indicating that the UE context acquisition failed. This fail code instructs the old MME/SGSN to hold UE context without erasing it (Figure 4 (4)), because in subsequent processing, the UE context containing the terminal identifier must be acquired through the UE context acquisition procedure by also accessing the old MME/SGSN from the second MME/SGSN to which rerouting is to be performed (Figure 4 (9)).

If the terminal identifier could not be acquired by the UE context acqui-

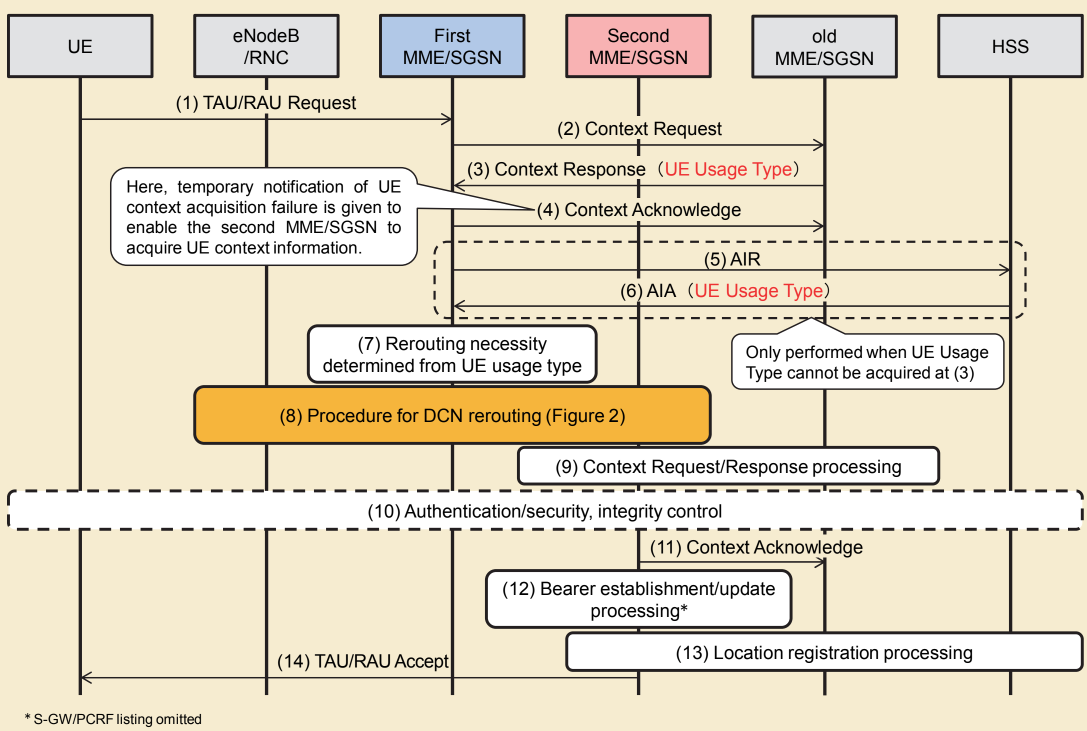


**Figure 4 TAU/RAU procedure including DCN rerouting**

*25 **UE context:** Information about mobile terminal authentication and security etc. retained in switching equipment.

sition procedure, the terminal identifier is acquired from the HSS by the AIR/AIA procedure (Figure 4 (5), (6)), similar to the Attach procedure. After determining whether DCN rerouting is required (Figure 4 (7)) from the terminal identifier in the first MME/SGSN and the DCN rerouting procedure (Figure 4 (8)), processing between the terminal and the second MME/SGSN is the same as the existing TAU/RAU processing (Figure 4 (9) to (14)).

If the terminal moves across the MME/SGSN Pool Area*26, the MME/SGSN must be reselected (TAU/RAU), however, it is possible that an MME/SGSN other than the desired DCN will be selected by eNodeB/RNC NNSF at this time. **Figure 5** shows an image of the method of preventing rerouting processing in this case (the figure only applies to LTE). Regarding the home MME/SGSN Pool Area and

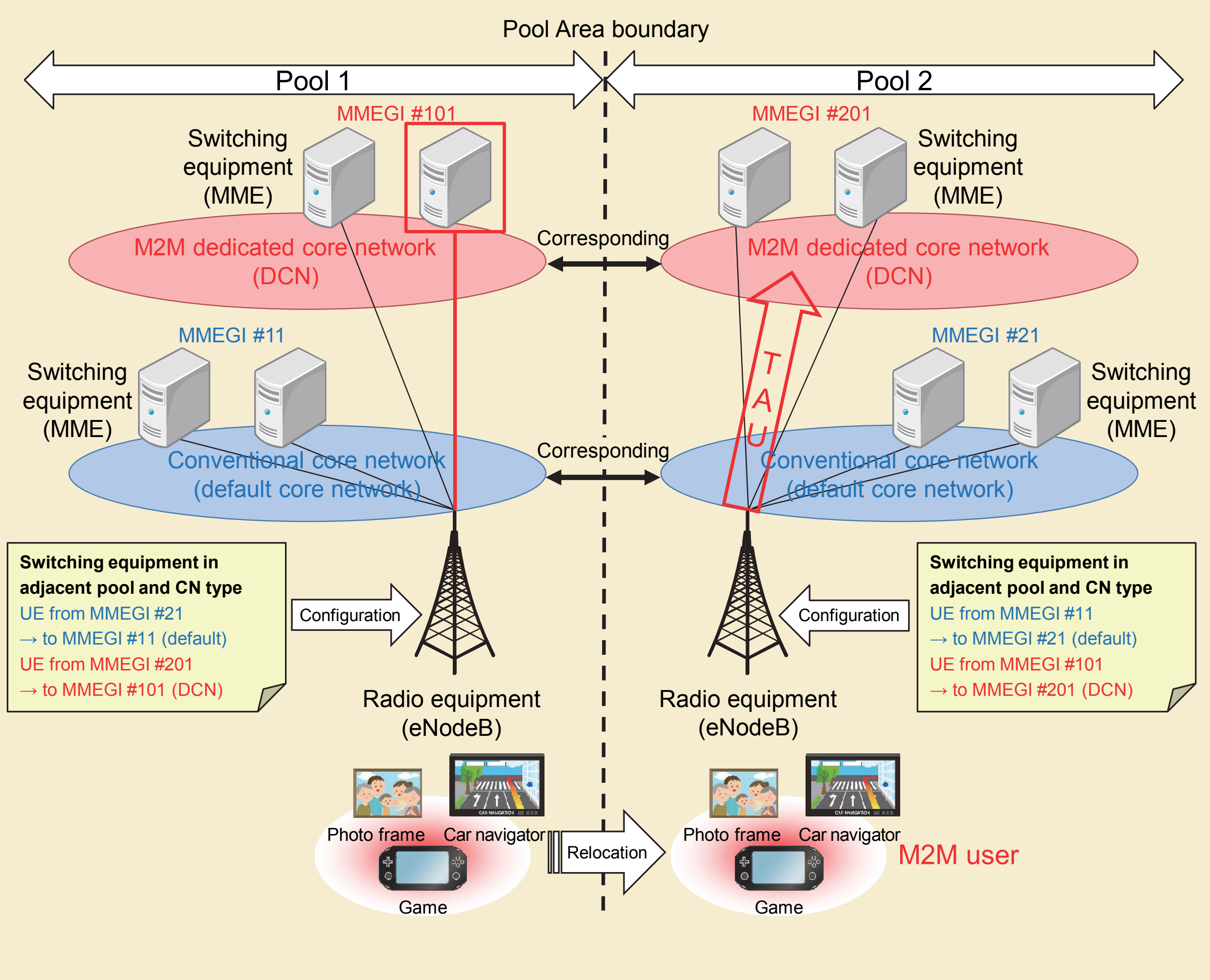


**Figure 5 Image of prevention of DCN rerouting procedure when moving across Pool Area (with LTE)**

*26 **Pool Area:** A full mesh connection area between MME and eNodeB or between SGSN and RNC (all sections connected like the mesh of a net).

each adjacent MME/SGSN Pool Area MMEGI (with LTE), or Null NRI or SGSN Group ID (with 3G), the configuration of DCN correspondences and non-DCN correspondences is set in advance in eNodeB/RNC. This configuration raises the possibility that the terminal will move between corresponding DCNs during TAU/RAU, in other words, it reduces the frequency of occurrence of rerouting procedures.

### 3.4 DCN Reselection Procedure

**Figure 6** describes the procedure when the value for the terminal identifier set in subscription information in the HSS is updated and then the DCN onto which the terminal should camp is changed while a terminal is camping on a network.

If the terminal identifier in subscription information managed by the HSS is updated, the HSS sends a request (Insert Subscriber Data Request) to change the subscription information to the second MME/SGSN on which the terminal is camping, and the second MME/SGSN provides a subscription information change response (Insert Subscriber Data Answer) (Figure 6 (1), (2)).

If it is necessary to reroute a terminal to another DCN immediately, and the terminal is in the idle state, it is necessary to make the terminal go to the connected state*27 by second MME/SGSN paging*28 (Figure 6 (3), (4)). If the terminal is in the connected state, with LTE, a process called Globally Unique Temporary UE Identity (GUTI)*29 Reallocation is performed from the second MME to assign non-

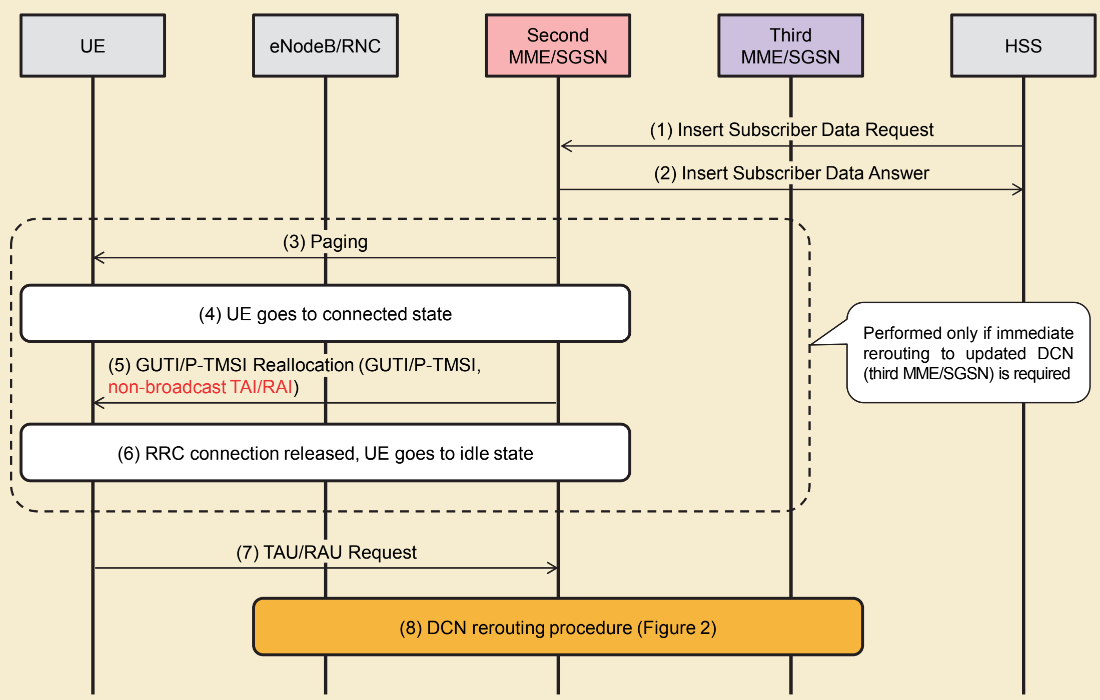


**Figure 6 DCN reselection procedure if the terminal identifier value is updated**

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*27 **Connected state:** A state in which resources are allocated between a mobile terminal and a radio network.

*28 **Paging:** Calling all mobile terminals at once when there is an incoming call.

*29 **GUTI:** Information consisting of a Globally Unique MME Identifier (GUMMEI) and TMSI (see *31). This is a temporary ID used to uniquely identify a mobile terminal instead of using the permanent mobile terminal or user (USIM) ID.

broadcast Tracking Area ID (TAI)*30 to the terminal, or with 3G, Packet-Temporary Mobile Subscriber Identity (P-TMSI)*31 Reallocation is performed from the second SGSN to assign non-broadcast Routing Area ID (RAI)*32 to the terminal. After that, the Radio Resource Control (RRC)*33 connection is released and the terminal goes back to the idle state again (Figure 6 (5), (6)). Although dependent on the terminal implementation, TAU or RAU is performed by the terminal right after non-broadcast TAI/RAI is allocated (Figure 6 (7)).

If it is not necessary to reroute a terminal to another DCN immediately, and the terminal is in the connected state, the second MME/SGSN can wait until the terminal spontaneously goes to the idle state and Figure 6 (7) is performed.

With TAU/RAU procedure in Figure 6 (7), the rerouting procedure described in Section 3.3 is performed by the second MME/SGSN to redirect the UE to the third MME/SGSN, which belongs to another DCN (Figure 6 (8)).

## 4. Standardization Trends

After DCN architecture specifications were completed in 3GPP SA2, discussion on detailed specifications for new signals and parameters began in the RAN3 and Core network and Terminals (CT) 4 meetings in August of 2015 based on those specifications.

Regarding the S1 Application Protocol (S1AP)*34/Radio Access Network Application Part (RANAP)*35 interface between radio and switching equipment, creating specifications for the new Reroute NAS Message Request signals and updating specifications for the existing Initial UE message*36 signals are ongoing in RAN3 meetings.

Meanwhile, in CT4 meetings, discussions are in progress about details of terminal identifier values, ways to convey terminal identifiers in each interface, and standard specifications for DNS procedures for selecting suitable serving nodes such as S-GW/P-GW with terminal identifiers as keys with LTE.

Both RAN3 and CT4 plan to finish DCN specifications by March of 2016, which is the planned completion date for the Release 13 studies.

## 5. Conclusion

This article has described technological characteristics of DCN to separate core networks on which terminals should camp based on their type, basic call control procedures and trends in standardization.

In the role of rapporteur, NTT DOCOMO has taken a proactive lead in discussions about these functions which are being studied in 3GPP SA2, and has finished their architecture standardization. Also, in the RAN3 and CT4 groups, NTT DOCOMO is making significant contributions to the creation of specifications for the main technological elements.

Looking ahead to the 5G*37 era, discussions are currently underway in various associations including 3GPP about the next generation of core networks. For example, Next Generation Mobile Networks (NGMN)*38 have revealed in their 5G white paper the concept of network slicing*39 as a future vision [6]. DCN could be one of the fundamental technologies that will achieve that concept. Please refer to this publication's 5G special article for more on this item [7]. Using the strengths of these technologies, NTT DOCOMO will continue to further contribute to standardization of the next generation of core networks.

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*30 **Non-broadcast TAI:** TAI is a unique location registration area ID on an LTE network. A non-broadcast TAI is a TAI that has an exceptional value and is not assigned to any area.

*31 **P-TMSI:** A number assigned temporarily for each user on the network using mobile communications, and stored in the User Identity Module (UIM).

*32 **Non-broadcast RAI:** RAI is a unique location registration area ID on a 3G network. A non-broadcast RAI is an RAI that has an exceptional value and is not assigned to any area.

*33 **RRC:** Layer 3 protocol for controlling the radio resources.

*34 **S1AP:** The name of the interface between eNodeB and MME.

*35 **RANAP:** The name of the interface between RNC and SGSN.

*36 **Initial UE message:** A message sent from eNodeB or RNC to MME or SGSN to establish an S1 connection between eNodeB and MME, or an Iu connection between RNC and SGSN.

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*37 **5G:** The next-generation mobile communications system to succeed the 4th-generation system.

*38 **NGMN:** A working group formed of global vendors and operators to study the next generation of networks in the 5G era.

*39 **Network slicing:** One system of achieving the next-generation of networks in the 5G era, studied by NGMN. Optimized architecture that entails splitting core networks by services such as usage cases or business models.



Standardization

# USSI for NW Service Menu Configurations in LTE

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Unstructured Supplementary Service Data using Internet protocol Multimedia Subsystem (USSD using IMS*1), or USSI is technology to enable menu configuration for network (NW) services on LTE, such as voice mail and call waiting (Catch Phone®*2) services. Required functions have been specified by the 3GPP standardization association [1].

Since June 2014, NTT DOCOMO has been providing Voice over LTE (VoLTE) [2] services to enable voice communications on LTE. However, menu configurations have been provided using the existing 3G USSD system, which means that transitioning to 3G using Circuit Switched FallBack (CSFB)*3 is required. This raises the following three issues:

- It takes more time to complete menu configurations.
- Data throughput during menu configuration falls back to the 3G level.
- To prevent calls being cancelled by CSFB, user equipment (UE) needs to disable menu configuration during VoLTE communications.

Thus, to improve user convenience, NTT DOCOMO made a decision to support USSI on the NW and from Winter 2015 UE models. After that, USSI solved the aforementioned issues and enabled menu configurations when UE is camping on LTE cells. Regarding differences in menu configurations in LTE cells, **Figure 1** shows the user interface on UE, while **Figure 2** shows the NW connection system.

1) USSI Architecture on 3GPP Standard

USSI uses Session Initiation Protocol (SIP)*4, the same as VoLTE call control (**Figure 3**).

When a user performs a menu configuration (Figure 3 (1)), the UE sends SIP_INVITE*5 with USSI message for NW service settings/updates to the Proxy Call Session Control Function (P-CSCF)*6. P-CSCF sends SIP_INVITE to the Application Server (AS)*7 via Serving Call Session Control Function (S-CSCF)*8 (Figure 3 (2)). AS sets/updates the service status according to the USSI message in SIP_INVITE (Figure 3 (3)), and stores a result response in SIP_BYE, which is returned to the UE



*1 **IMS:** A communication system architecture standardized by 3GPP. IMS integrates IP technologies and the SIP (see *4) used for Internet telephony to implement multimedia services on fixed telephone and mobile communication NWs.

*2 **Catch Phone®:** A registered trade mark of Nippon Telegraph and Telephone Corporation.

*3 **CSFB:** A procedure for switching to a radio access system having a CS domain such as W-CDMA/GSM, when a UE uses a circuit switching service such as voice while camped on an LTE NW.

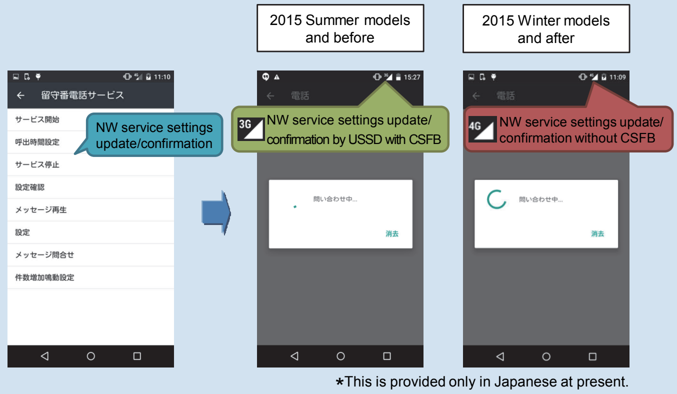


**Figure 1　Menu configurations in LTE cells (screen transitions)**

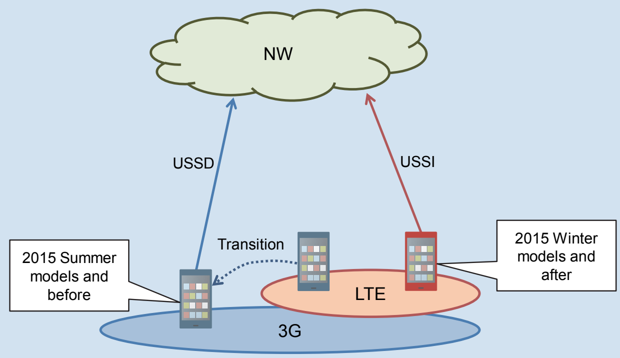


**Figure 2　Menu configurations in LTE cells (NW connection systems)**

(Figure 3 (4)).

2) USSI on the DOCOMO NW

Because NW service configurations are retained in AS in standard specifications, the system also terminates the USSI message in AS. However, due to design policies on the DOCOMO NW, some service configurations are retained in Front end Service Control Point (F-SCP)/Database SCP (D-SCP), which manages subscriptions. For this reason, it is necessary to send NW service settings information to a F-SCP/D-SCP. The flow of menu configuration control on the DOCOMO NW is shown in **Figure 4**.

The USSI development was achieved by devising a way to use the existing USSD interface (IF) between F-SCP/D-SCP and the Application Serving Node (ASN), which is equivalent to AS in standard specifications.

Specifically, the ASN analyzes the USSI message received, and if it is a service which settings are retained in F-SCP/D-SCP, protocol is converted to the IF similar to the existing USSD (SIP to MAP conver-

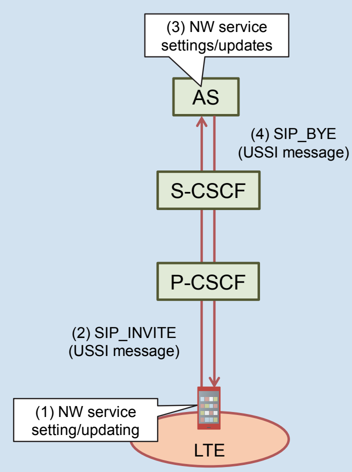


**Figure 3　USSI control in standard specifications**

*4　**SIP:** One of the communications control protocols standardized by the Internet Engineering Task Force (IETF) used with IP telephony etc.

*5　**Invite:** A SIP signal that requests a connection.

*6　**P-CSCF:** A function deployed at the connection point with EPC and at the UE connection point with S-CSCF and I-CSCF. It links with EPC to initiate QoS control and relays SIP signals between the UE, S-CSCF and I-CSCF.

*7　**AS:** A server that executes an application to provide a service.

*8　**S-CSCF:** A SIP server performing terminal session control and user authentication.

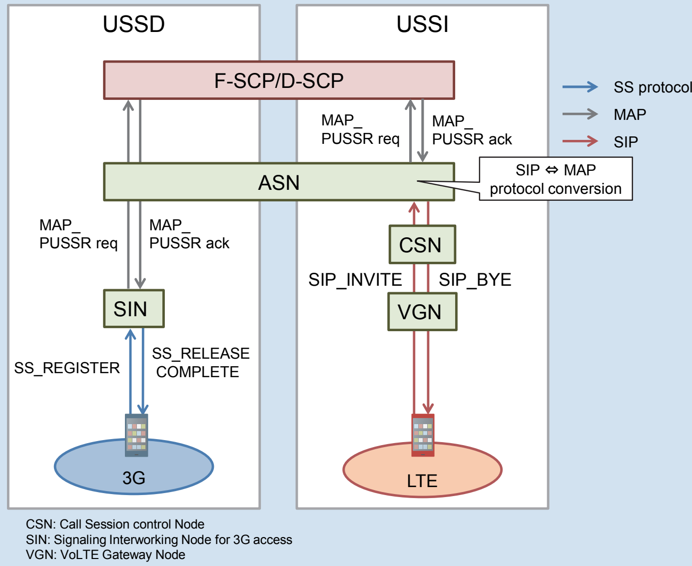


**Figure 4 Menu configurations control on the DOCOMO NW**

sion), and F-SCP/D-SCP is notified. Also, conversion from the existing IF to USSI (MAP to SIP conversion) is performed for the results response from F-SCP/D-SCP. This enables USSI without developing F-SCP/D-SCP.

This article has described USSI enabled on LTE for menu configurations for NW service settings/update. Supporting USSI in this way has solved the issues discussed at the beginning of this article, and improved user convenience. Also, providing NW service menu configurations when camped on an LTE cell will also assist with the future transition to the LTE-only NW from 3G.

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**NTT DOCOMO**
**Technical Journal Vol.17 No.4**

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

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