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Seeking Evolution of Networks to Satisfy Customers

Akihiro Maebara

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"Anytime, anywhere, with anyone" . . . I was taught this phrase as keywords summarizing the target qualities of mobile communication systems by my superiors and senior co-workers about 20 years ago when I joined NTT. Soon after I entered the company, 2.4-kbps circuit-switched data communication service using the PDC standard began. At that time, the service was called "non-telephone communication," indicating the fact that voice calls directly between customers made up almost all mobile communication. "With anyone" was expressed vividly by that trend then. How the times have changed. Afterwards, 28.8-kbps packet communication service appeared in the form of the PDC-P protocol in 1997, and services utilizing data communication in mobile environments grew. The standards then proceeded to W-CDMA and HSPA and LTE. We began PREMIUM 4G™*1 in March this year as an LTE Advanced service, ushering in the era of speeds greater than 225 Mbps.

With the realization of high-speed data communication, services dealing with high-volume contents, such as high-resolution video distribution and cloud services, have grown. At the same time, real-time message communication services are also expanding. Furthermore, as represented by the VoLTE service, launched last year, and the flat-rate system for voice calls, one can sense that even the conception of service for voice communication, the original point of mobile communication, is coming under review. So that customers can use such evolving and diversifying services with convenience and peace of mind, what is critical is not just improving data communication's speed and capacity. Also important is ensuring the basic quality of mobile communication systems with criteria such as "connection" and "without interruption," especially for message and voice communication. Our mission as mobile communication system developers is to respond to these demands by incessantly advancing the sophistication of networks.

We are now in the era of LTE. Together with the advent of this standard, high-speed technologies such as MIMO and carrier aggregation and various interference-reduction technologies have been developed as devices have evolved. Mobile communication networks have dramatically progressed. Technologies have also advanced to allow customers to securely use mobile phones. Examples include traffic control technologies so that more customers can communicate even during extremely crowded conditions, such as during a disaster and in an event space. However, even as such new technologies are being created, it is also effective to create new value by making ingenious use of current technologies and combining multiple technologies to improve the efficiency of network performance. An example is NTT DOCOMO's proposal of advanced C-RAN for the deployment of LTE-Advanced, which it then developed. This system combines two technologies – carrier aggregation and heterogeneous networks – to provide high-speed and high-quality network services. NTT DOCOMO is able to pioneer this system precisely because it intimately understands communication systems from its experience in network operations and standardization activities. We wish to continue to leverage this know-how and thoroughly exploit such existing knowledge going forward.

We have strengthened networks to meet the proliferation of services and terminals such as i-mode and smartphones. These technologies have brought about major changes to mobile communication traffic. In the coming Internet of Things (IoT) era, communication traffic different in character from those of today's mobile communication networks will be produced by the arrival of terminals with even more diverse forms of communication. To flexibly adapt to these changes and demonstrate high performance, we must respond with a fine balance of "developing new technologies" and "taking advantage of existing technologies." We also wish to maximize our utilization of the wireless spectrum, a limited resource, and continue to build robust yet flexible networks so that our customers can conveniently use mobile systems "anytime and anywhere."

*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.

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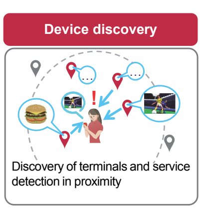

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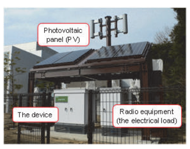

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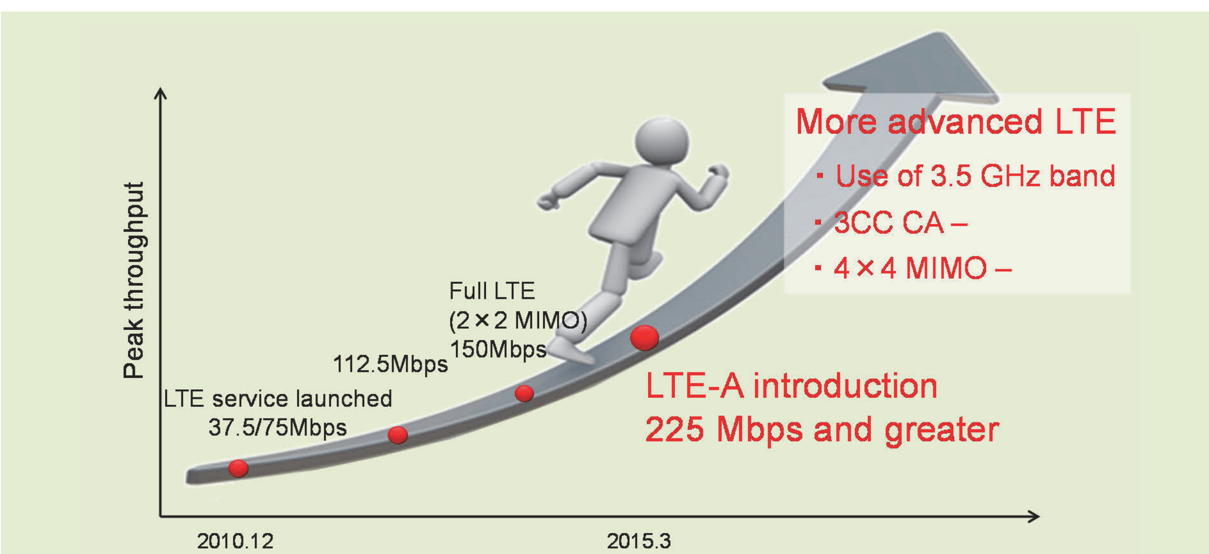

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Toward more advanced LTE

Technology Reports

LTE-Advanced | CA | Advanced C-RAN

Special Articles on PREMIUM 4G—Introduction of LTE-Advanced—

LTE-Advanced as Further Evolution of LTE for Smart Life

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*LTE-Advanced, which was launched in March 2015 as PREMIUM 4G™*1, is an LTE-based mobile system with even higher bit rates and system capacity. NTT DOCOMO has developed Advanced C-RAN and terminals supporting LTE-Advanced to make the most of LTE-Advanced features and improve transmission data rates and radio capacity. Advanced C-RAN provides stable high-speed communications even in areas with particularly high traffic such as train stations and large commercial complexes thereby supporting an effective rollout of the LTE-Advanced system.*

1. Introduction

Mobile data traffic is increasing at a dramatic rate driven by the popularity of smartphones and new ways of using the mobile network as represented by social networking and video streaming. According to a report issued by the Ministry of Internal Affairs and Communications (MIC) [1], mobile traffic in Japan increased by approximately 1.5 times in a recent one-year period generating a problem that must be addressed in common by Japan's mobile communications operators.

In December 2010, NTT DOCOMO introduced LTE featuring "high-speed," "large-capacity," and "low-delay" to improve the customer experience, increase transmission data rates to open up new possibilities in services, and support the continuously increasing volumes of mobile traffic. The introduction of LTE enabled data rates to be increased by approximately ten times, capacity to be expanded by approximately three times, and delay to be reduced to approximately one-fourth the existing levels compared to the High Speed Packet Access (HSPA)*2 specification in use at that time. These improvements significantly enhanced the convenience of using smartphones and other smart devices.

As of March 2015, LTE was operating in approximately 150 countries by more than 300 operators—it had been introduced at an extremely fast pace around the world compared to any other standardized mobile system to date. The en-

*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.
*2 **HSPA:** A specification for increasing packet-data rates in W-CDMA, and a general term encompassing High Speed Downlink Packet Access (HSDPA), which increases the speed from the base station to the mobile terminal, and High Speed Uplink Packet Access (HSUPA), which increases speed from the terminal to the base station.

hanced form of LTE is LTE-Advanced, which holds promise of being a vitally important and influential technology in society.

NTT DOCOMO launched LTE-Advanced as a commercial service under the name "PREMIUM 4G" in March 2015. In this article, we present an overview of LTE-Advanced technologies and of our newly developed Advanced Centralized Radio Access Network (C-RAN), which enables Carrier Aggregation (CA) between cells, improves throughput while maintaining mobility characteristics, and increases capacity. Other special articles in this issue provide details on control schemes and equipment in Advanced C-RAN and on mobile terminal technologies supporting LTE-Advanced [2]–[4].

2. LTE-Advanced Requirements

A specifications study for LTE-Advanced as an enhancement of LTE began in June 2008 and LTE-Advanced requirements were subsequently compiled in a 3GPP Technical Report [5]. In addition to coexistence with LTE, migration scenario from LTE, and improved performance, a reduction in power and operating costs was also included as one of the requirements. Main requirements for LTE-Advanced are described below.

1) Coexistence with LTE

LTE-Advanced is, of course, expected to surpass LTE in system performance, but it must also enable a smooth migration from existing LTE. In short, backward and forward compatibility with LTE is a key requirement.

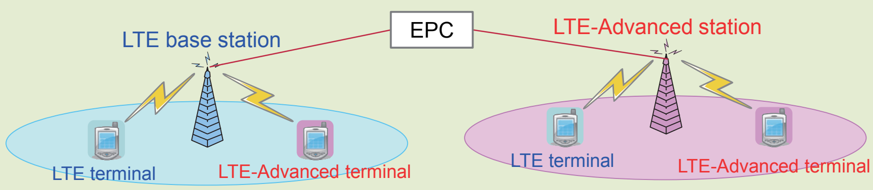
Here, we define backward and forward compatibility in terms of terminal capabilities as shown in **Figure 1**. First, LTE terminals must naturally be able to connect to the LTE-Advanced network, and second, LTE-Advanced terminals must exhibit a significant improvement in performance when connected to the LTE-Advanced network while being able to connect to the LTE network as well.

2) Improvement in Peak Data Rate, Spectral Efficiency, and Cell Edge User Throughput

LTE-Advanced must provide a dramatic improvement in basic system performance over LTE. The requirement for peak data rate is 1 Gbps in the downlink and 500 Mbps in the uplink.

Additionally, LTE-Advanced is required to improve spectral efficiency by approximately 1.5 times over LTE. Considering that LTE-Advanced requirements were established right after the approval of LTE itself, this requirement for improved spectral efficiency was a very challenging target.

Cell edge user throughput was also taken up as an important performance index. This is because throughput at cell



LTE and LTE-Advanced compatibility

	LTE base station	LTE-Advanced station
LTE base station	LTE	LTE
LTE-Advanced terminal	LTE	LTE-Advanced

EPC : Evolved Packet Core

Figure 1 LTE-Advanced compatibility

edge is an important factor in providing a sufficiently satisfactory service to a cell-edge user whose received quality is low due to a weak radio signal and interference from other cells. In LTE, as well, cell edge user throughput is an important index, but in LTE-Advanced, technologies that could improve throughput especially in such a cell-edge environment were a focus of study.

3. Main Technologies of LTE-Advanced

To satisfy the requirements described above for LTE-Advanced, further advancements in radio interface technologies were proposed as described below.

3.1 CA

For a maximum bandwidth of 20 MHz, LTE achieves a peak data rate of 300 Mbps in the downlink by supporting 4×4 Multiple Input Multiple Output (MIMO)*3 technology. In contrast, a peak data rate of 1 Gbps in the downlink and 500 Mbps in the uplink has been specified as a requirement for LTE-Advanced, so the provision of even broader bandwidths is needed. LTE-Advanced, however, must also ensure backward compatibility with LTE. For this reason, CA was proposed as a means of bandwidth extension achieved by combining multiple frequency blocks, each of which is called a Component Carrier (CC) having a bandwidth supported by LTE [6]. The use of CA enables higher data rates to be achieved while maintaining backward compatibility with existing LTE. It also enables instantaneous load balancing*4 between frequency bands to improve spectral efficiency.

3.2 Advanced Multi-antenna Technology

LTE supports single-user MIMO*5 multiplexing for up to 4 layers*6 in the downlink but supports no MIMO multiplexing in the uplink. In contrast, LTE-Advanced supports single-user MIMO multiplexing for up to 8 layers in the downlink and up to 4 layers in the uplink to satisfy requirements for peak spectral efficiency*7. In addition, multi-user MIMO*8 has been enhanced in LTE-Advanced to improve system capacity. Furthermore, to improve cell edge user throughput, Coordinated Multiple Point transmission and reception (CoMP) technology has been proposed as a means of performing transmission and reception via multiple cells working in cooperation [6].

3.3 Base Station Coordination in HetNet

In LTE-Advanced, lowering the cost of the Radio Access Network (RAN)*9 is also an important requirement. In addition to the conventional deployment of macro cell*10 base stations, implementation of a Heterogeneous Network (HetNet) is also attracting attention. HetNet appropriately deploys and coordinates base stations of various form factors and power levels including the small cell*11 with the aim of lowering costs. Radio interfaces that can efficiently support inter-frequency coordination in conjunction with CA, enhanced Inter-Cell Interference Coordination (eICIC) that mitigates intra-frequency interference, and such have been specified for HetNet.

4. Features of Advanced C-RAN Architecture

Although further advancements in data rates can be achieved using CA as one of the main technologies of LTE-Advanced, technology than can increase capacity for the environments with exceptionally large volumes of traffic, such as the neighborhood surrounding a major train station, is particularly important. Such an environment requires not only the use of more frequencies to accommodate traffic but also an increase in an area capacity by deploying small cells, as part of HetNet. However, user movement in such an environment increases HandOver (HO)*12 occurrences either between small cells or between a macro cell and small cell, which may cause higher probability of call drop.

Moreover, while higher transmission data rates and improved user throughput by load balancing between frequency blocks can be expected with introduction

*3 **MIMO:** A technology for achieving high-speed transmission by simultaneously transmitting different signals from multiple antennas.

*4 **Load balancing:** The process of reducing load between frequencies or cells by moving users accordingly.

*5 **Single-user MIMO:** Technology that uses MIMO transmission over the same time and frequency for a single user.

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

*7 **Peak spectral efficiency:** Maximum spectral efficiency that can be achieved according to specifications. Maximum rate efficiency.

*8 **Multi-user MIMO:** Technology that uses MIMO transmission over the same time and frequency for multiple users.

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

*10 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

*11 **Small cell:** Generic name for a cell covering a small area and having low transmission power relative to a macro cell.

of CA, at the base station with high traffic frequency resources to perform CA are likely to be completely utilized, which makes it difficult to achieve a significant improvement in spectral efficiency.

In light of the above, NTT DOCOMO proposed Advanced C-RAN architecture (**Figure 2**) in March 2012 [7] and commenced its development in 2013. Advanced C-RAN architecture adds a number of small cells on top of a macro cell (hereinafter referred to as "add-on cells") and coordinates the add-on cells and the macro cell through CA.

Advanced C-RAN architecture has the following features achieved by utilizing CA and HetNet features.

(1) High-speed transmission through CA

Increases transmission data rates in a flexible manner depending on the current traffic environment by CA between macro cells and between macro cell and multiple add-on cells.

(2) Comparable mobility characteristics as a conventional macro cell

Maintains the same rate of HO occurrence as in a conventional configuration with only macro cells by adding or deleting add-on cells while maintaining macro-cell connection. This scheme achieves conventional mobility performance even in an environment with add-on cells.

(3) Greater capacity through add-on cells

Improves user throughput in both macro cells and small cells by arranging add-on cells effectively in areas with high traffic and offloading traffic as needed thereby increasing capacity over the entire area.

5. Rollout Scenario

Since 2009, NTT DOCOMO has been deploying an centralized RAN (C-RAN) architecture for LTE in which baseband*13 processing is performed in central node, and radio units may be distributed in different location connect-

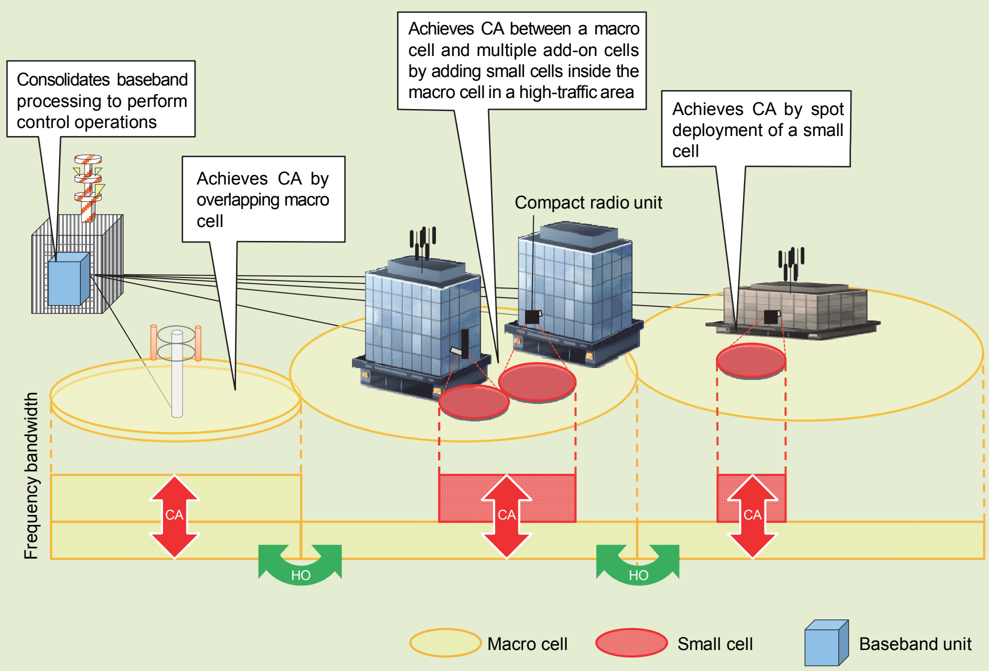


Figure 2 Advanced C-RAN architecture

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

*13 **Baseband:** The circuits or functional blocks that perform digital signal processing.

ed to the baseband unit via optical fiber [8]. This made it easy to construct a network that can make the most of the features described above by simply replacing the baseband processing unit with new equipment supporting Advanced C-RAN without touching the existing radio units.

We have also been developing radio equipment for add-on cells that is far lighter and smaller than existing equipment [3]. Specifically, we have been able to reduce the size of this equipment to 1/5 that of existing units, which has the effect of relaxing installation conditions for these radio units and broadening their scope of application.

NTT DOCOMO had already been operating LTE on four carriers, and these frequencies have to be used effectively. In Advanced C-RAN architecture, each radio unit operates on one of these carriers, and since these radio units are independent of their common baseband unit, it is relatively easy to combine any of these carriers. At the time of LTE-Advanced introduction, a total bandwidth greater than 30 MHz could be achieved by combining the 800 MHz and 1.7 GHz carriers or the 2 GHz and 1.5 GHz carriers making for a maximum throughput greater than 225 Mbps.

Going forward, the plan is to use a combination of three component carriers (3CC) in conjunction with Time Division Duplex (TDD)*14 on the newly allocated 3.5 GHz carrier and to apply advances in MIMO technology to achieve even higher transmission data rates and greater capacities. The ultimate goal here is to improve the user's quality of experience (**Figure 3**).

6. Conclusion

This article presented an overview of LTE-Advanced technologies reflecting the ongoing evolution of LTE and introduced Advanced C-RAN as network architecture for making the most of LTE-Advanced features. Approximately five years after the introduction of LTE, NTT DOCOMO launched LTE-Advanced services under the banner of PREMIUM 4G in March 2015 to improve the user experience even further. Looking to the future, NTT DOCOMO aims to contribute to society by expanding the service area and enhancing its lineup of mobile devices, and by providing a new and fertile social infrastructure as a Smart Life Partner.

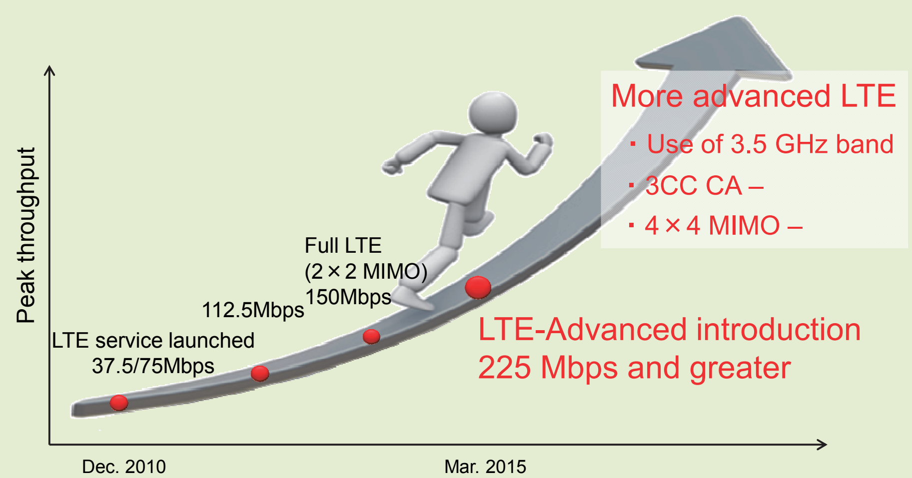


Figure 3 Toward more advanced LTE

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

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LTE-Advanced | CA | Advanced C-RAN

Technology Reports

Special Articles on PREMIUM 4G—Introduction of LTE-Advanced—

Commercial Development of LTE-Advanced Applying Advanced C-RAN Architecture —Expanded Capacity by Add-on Cells and Stable Communications by Advanced Inter-Cell Coordination—

In March 2015, NTT DOCOMO launched the PREMIUM 4G™[*1] service in Japan using LTE-Advanced as an evolved form of the LTE mobile communications system. This deployment includes the introduction of Advanced C-RAN architecture that combines macro cells and small cells through CA to increase transmission speeds, expand capacity, and provide stable communications for a more satisfying user experience. In this article, we overview the features, effects, and control procedures of Advanced C-RAN architecture.*

Radio Access Network Development Department

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1. Introduction

Recent years have seen a dramatic increase in network traffic thanks to the expanded use of smartphones and the popularity of large-capacity content such as images and video. The need has therefore been felt for even higher communication speeds and greater capacities in the radio network. The 3rd Generation Partnership Project (3GPP) began work in 2008 on formulating specifications for the LTE-Advanced[*2] system to improve the speed and capacity performance of LTE and extend LTE functions. As a result of these efforts, standardization of LTE-Advanced was completed in 2011 [1].

To achieve an effective rollout of the LTE-Advanced system, NTT DOCOMO proposed Advanced Centralized Radio Access Network (C-RAN) architecture and commenced development of base station equipment supporting this architecture in February 2013 toward commercialization [2]. Then, in March 2015, NTT DOCOMO introduced LTE-Advanced using Advanced C-RAN architecture and began the commercial provision of high-speed transmission in the downlink at a maximum data rate of 225 Mbps under the name of PREMIUM 4G. Advanced C-RAN architecture achieves high-speed and large-capacity communications by combining two key technologies of LTE-Advanced: Carrier Ag-

*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.
*2 **LTE-Advanced:** Name of IMT-Advanced in 3GPP. IMT-Advanced is the successor to the IMT-2000 third-generation mobile communications system.

gregation (CA) and Heterogeneous Network (HetNet)*3. Advanced C-RAN is also being studied as a basic architecture for the next-generation 5G*4 mobile communications system now attracting attention throughout the world [3]. In this article, we overview the features, effects, and control procedures of LTE-Advanced based on Advanced C-RAN architecture.

2. Advanced C-RAN Architecture

As stated above, CA is a key technology of LTE-Advanced enabling a terminal to simultaneously connect to multiple LTE carriers (component carriers) operating on different frequencies. Achieving bandwidth extension in this way makes for higher communication speeds [4]. Furthermore, in addition to increasing the data rate, NTT DOCOMO also uses CA to expand radio capacity and improve communications stability by enabling a terminal to simultaneously connect to a macro cell*5 and small cell*6 added to that area (hereinafter referred to as an "add-on cell"). CA requires coordination between cells that a terminal is to be simultaneously connected to, and as a result, specifications dictate that the same base station be used to control those cells. Consequently, to increase capacity and improve stability through add-on cells, macro cells and add-on cells installed at different points must be controlled by the same eNodeB (eNB)*7.

To this end, while base station equipment normally consists of a baseband*8 processing unit and radio unit, NTT DOCOMO separates the baseband processing unit from the base station leaving only the radio unit to be installed at the base station site*9. C-RAN architecture consolidates multiple baseband processing units in high-density baseband processing equipment thereby reducing the space needed for installing base station equipment and decreasing facility investment. NTT DOCOMO has been operating C-RAN architecture since 2003 [5]. Furthermore, by leveraging the features of this C-RAN architecture and adopting a new architecture that accommodates a macro cell and multiple add-on cells in the same baseband processing unit, flexible coordination between a macro cell and add-on cells through CA has become possible. This new architecture is called Advanced C-RAN architecture (**Figure 1**), which is facilitating a smooth rollout of LTE-Advanced and an expansion of radio capacity.

We consider the use of Advanced C-RAN architecture to have the following three effects, each of which are described below.

- Higher transmission speeds and improved spectral efficiency by CA
- Expanded capacity by add-on cells

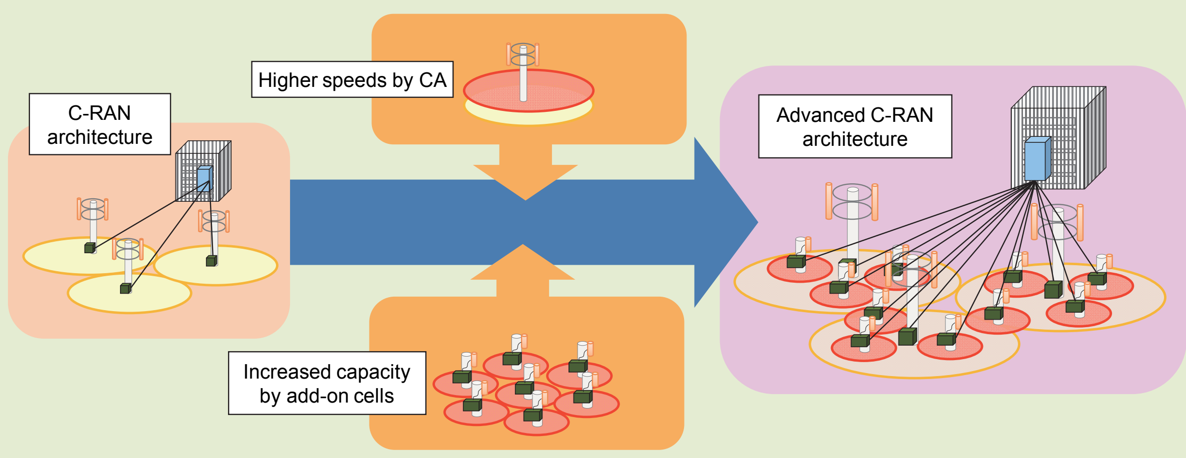

Figure 1 Overview of Advanced C-RAN architecture

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*3 **HetNet:** A network configuration that overlays nodes of different power. A network that mixes, links, and integrates base stations of relatively low transmission power.

*4 **5G:** A next-generation mobile communications system succeeding the 4G mobile communications system.

*5 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

*6 **Small cell:** Generic name for a cell covering a small area and having low transmission power relative to a macro cell.

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

*8 **Baseband:** The circuits or functional blocks that perform digital signal processing.

• Improved stability in communications

Additionally, while CA is assumed between a macro cell and add-on cell as described above, Advanced C-RAN also supports CA using two macro cells. For example, in a suburban area having no need of extending radio capacity by installing add-on cells, the goal may be to provide users with higher transmission speeds by CA using macro cells. Advanced C-RAN can be applied in a flexible manner according to area conditions.

2.1 Higher Transmission Speeds and Improved Spectral Efficiency by CA

1) Simultaneous Connection to Multiple Carriers

Since the launch of NTT DOCOMO's LTE-Advanced service in March 2015, CA has been achieved by simultaneous connection to two LTE carriers. Maximum transmission speed in the downlink is determined by the total frequency bandwidth of these simultaneously connected LTE carriers (**Table 1**). In this regard, 3GPP specifications call for a maximum downlink speed of 300 Mbps by simultaneous connection to two LTE carriers, but this specification is for a total frequency bandwidth of 40 MHz. NTT DOCOMO, however, uses either of two combinations of carriers to achieve a total frequency bandwidth of 30 MHz, that is, the 2 GHz (15 MHz bandwidth) + 1.5 GHz (15 MHz bandwidth) bands or the 800 MHz (10 MHz bandwidth) + 1.7 GHz (20 MHz bandwidth) bands. The standard calls for a maximum downlink speed of 225 Mbps in this case. NTT DOCOMO has also been conducting field trials in an outdoor commercial environment using a total frequency bandwidth of 35 MHz through a combination of the 800 MHz (15 MHz bandwidth) + 1.7 GHz (20 MHz bandwidth) bands. In those trials, it was found that a maximum downlink speed of 240 Mbps could be achieved (**Figure 2**).

In addition, LTE-Advanced speci-

Table 1 Improved throughput by CA

Total frequency bandwidth (MHz)	Maximum downlink speed (Mbps)
5	37.5
10	75
15	112.5
20	150
25	187.5
30	225
35	262.5
40	300

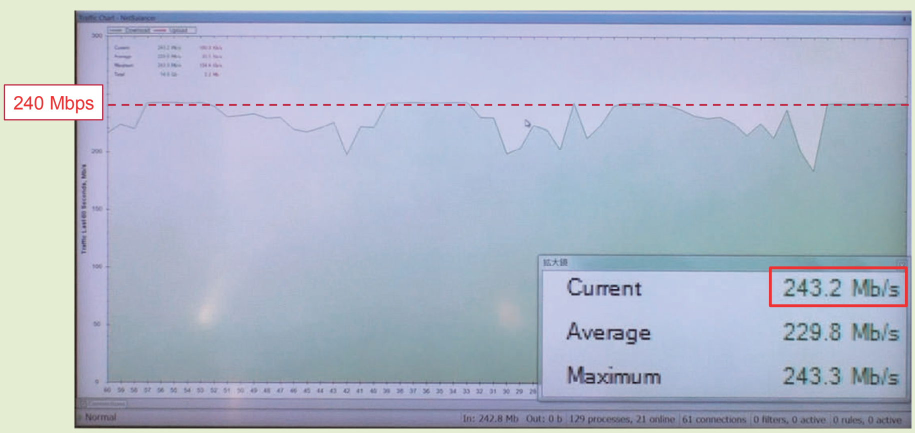

Figure 2 Achieving 240 Mbps in a commercial environment

*9 **Site:** The location installing base station antennas.

fications prescribe CA for a maximum of five LTE carriers (total bandwidth of 100 MHz). Our plan is to extend CA to three or more LTE carriers toward even higher transmission speeds. Advanced C-RAN architecture, which is capable of accommodating and controlling many cells with a single baseband processing unit, has a configuration that makes such CA extension relatively easy to achieve.

2) Load Balancing Between Cells

CA is effective not only for increasing transmission speeds but also for achieving load balancing*10 between cells. In a commercial environment, the distribution of users, imbalance in frequency bands supported by mobile terminals, difference in radio propagation characteristics among frequency bands, etc. can result in a bias in the degree of congestion among frequency carriers. Accordingly, terminals that support multiple frequency bands should be controlled so as to connect as much as possible to an LTE carrier with a low level of congestion. However, in conventional LTE, a HandOver (HO)*11 procedure is needed to switch cells, so if the degree of congestion fluctuates in short time periods, switching that can keep up with such rapid fluctuation becomes difficult. In contrast, the use of CA means that the terminal is already connected to multiple carriers, which means that an LTE carrier can be instantaneously selected according to carrier-congestion conditions even if those conditions are changing rapidly. An improvement in spectral efficiency can therefore be expected (**Figure 3**).

2.2 Expanded Capacity by Add-on Cells

HetNet technology is attracting attention throughout the world as a means of increasing the radio capacity of a system [6]. This is accomplished by offloading traffic within a macro cell to low-power add-on cells installed at spots where traffic concentrates within that macro-cell area. To link macro cells and add-on cells by CA in a HetNet, NTT DOCOMO uses separate frequency bands for a "coverage band" that covers a macro-cell area and a "capacity band" for increasing radio capacity using an add-on cell. For example, the 2 GHz or 800 MHz band may be used as a coverage band and the 1.5 GHz or 1.7 GHz band as a capacity band.

1) Evaluation by Simulation

We here explain the results of computer simulations of the capacity-expansion effect of add-on cells. In this evaluation, coverage bands were arranged only as macro cells, and capacity bands

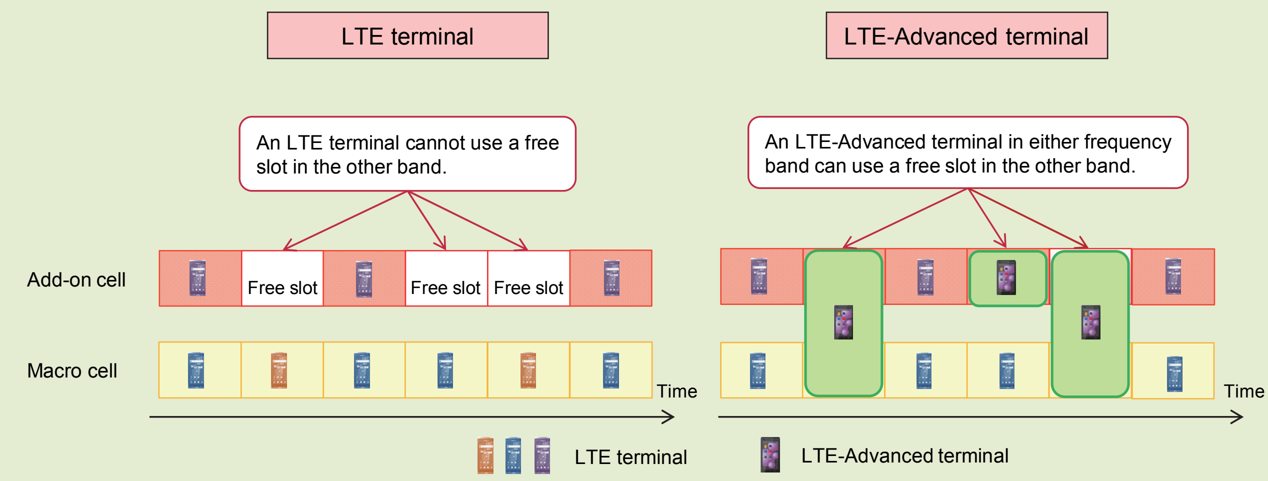

Figure 3　Load balancing by CA

*10 **Load balancing:** The process of distributing traffic load among cells.

*11 **HO:** The process of switching the base station connected to the UE.

were installed either as macro cells in the same manner as coverage bands (Case 1 in **Figure 4**) or as add-on cells (Case 2 in the figure). We compared the results of these two cases. In both cases, the area covered by a single macro base station was divided into three sectors and the frequency bandwidth of either a coverage band or a capacity band was 10 MHz.

Furthermore, in case 2, multiple add-on cells were positioned within a single macro cell and users were located in the vicinity of those add-on cells. In short, this evaluation was performed assuming that such add-on cells could be installed exactly in areas where users would concentrate.

2) Evaluation Results

Evaluation results are shown in **Figures 5** and **6**. First, sector capacity (total of capacity of coverage-band cell and capacity of all capacity-band cells within that sector) for Case 1 and Case 2 is shown in Fig. 5. In the figure, sector capacities are normalized against that of Case 1 to reflect the capacity-expansion effect of add-on cells. For Case 2, a capacity-expansion effect of approximately 2.5 times was obtained for an installation of four add-on cells showing that increasing the number of add-on cells could increase capacity. Next, capacity per add-on cell for Case 2 is shown in Fig. 6. These results show that capacity per add-on cell decreases as the number of add-on cells increases. This is because interference between add-on cells increases as more add-on cells are installed. As a consequence, the capacity-expansion effect and cost-effectiveness per add-on cell decreases if too many add-on cells are installed.

Given the conditions of this evaluation, four or six add-on cells per sector could be taken to be an optimal number. This value, however, could change depending on the antenna configuration of the add-on cells (beam width, installation height, etc.), macro cell radius, and other conditions.

2.3 Improved Stability in Communications

As described above, cell capacity increases by simply adding add-on cells, but installing multiple add-on cells within an area also means an increase in the number of cell edges. In such an environment, a moving user will frequently straddle two add-on cells at their edges, and if these add-on cells are installed without using CA, the user will experience a drop in communications quality at this time owing to interference between those cells and HO processing. In contrast, Advanced C-RAN architecture enables a terminal to be simultaneously connected to an add-on cell and macro cell through CA, which means that stable communications can be ensured via the macro cell and noticeable degradation in quality while moving can be suppressed.

We here explain in detail the above stability effect in communications using

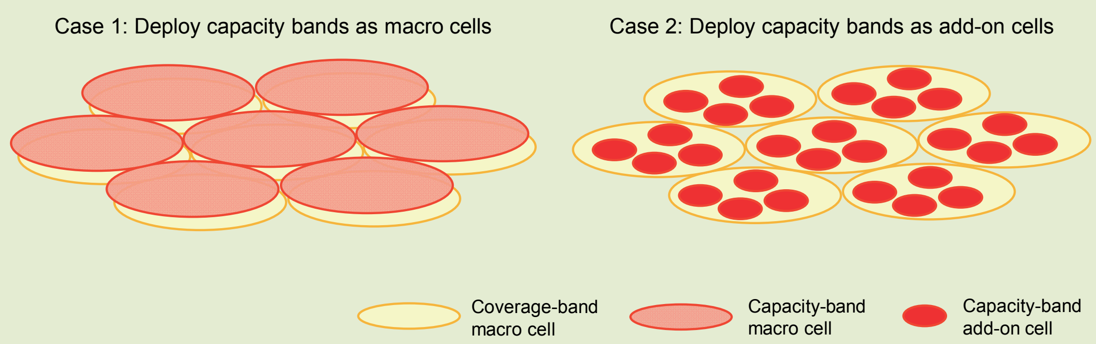

Figure 4 Simulation scenarios

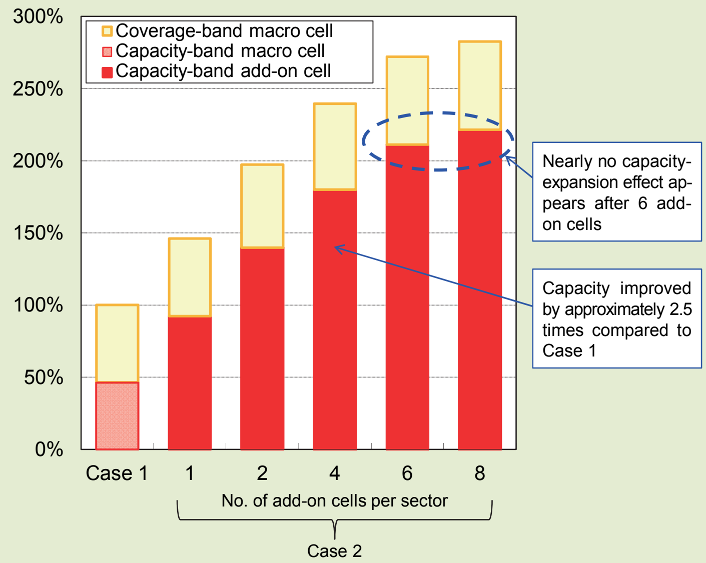

Figure 5　Capacity-expansion effect of add-on cells

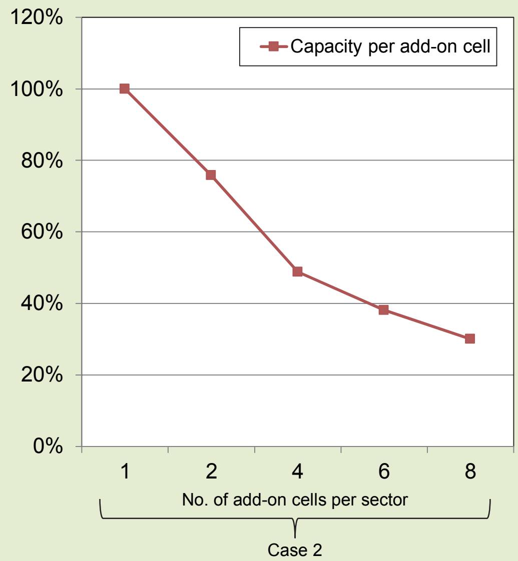

Figure 6　Capacity per add-on cell

Figure 7. At point 1 in the figure, an LTE terminal connects to add-on cell A and achieves the throughput provided by LTE. An LTE-Advanced terminal, in contrast, lies in both a macro cell and add-on cell A, which means that it can achieve higher throughput than the LTE terminal by simultaneously connecting to those cells through CA. Now, on moving to point 2 at the edge of add-on cells A and B, the LTE terminal experiences a drop in throughput due to interference between the add-on cells and HO processing. The LTE-Advanced terminal, however, though also switching between add-on cells A and B, is simultaneously connected to the macro cell, which prevents a dramatic deterioration in throughput and enables a certain level of communications quality to be maintained. In short, Advanced C-RAN architecture enables flexible switching between add-on cells while keeping an LTE-Advanced terminal connected to a macro cell thereby achieving high-speed and stable communications. This effect has been verified by tests performed in an outdoor commercial environment (**Figure 8**).

3. SCell Control in Advanced C-RAN

In CA whereby a mobile terminal connects to multiple LTE carriers simultaneously, the primary carrier is called the Primary Component Carrier (PCC) while the secondary carrier is called the Secondary Component Carrier (SCC). In addition, the cells connected to the terminal via PCC and SCC are called the PCell and SCell, respectively [7].

Since multiple add-on cells can exist within a macro cell in Advanced C-RAN architecture, a control process is needed to select which of those add-on cells is to be set as a SCell for a mobile terminal connected to the macro cell according to that terminal's position.

Furthermore, since the optimum add-on cell will change as the mobile terminal moves, the terminal will switch to another add-on cell to be set as the SCell at such a time. Moreover, if no add-on cell can offer a sufficient level of quality making it useless for a mobile terminal to connect to a SCell, the SCell setting will be deleted for the sake of battery savings on the mobile terminal. NTT DOCOMO achieves the above controls by "SCell add," "SCell change," and "SCell delete" procedures using mobile-terminal radio quality measurements and measurement reports to eNB as prescribed in 3GPP specifications [8]. These procedures are described below.

3.1 SCell Add

For a mobile terminal in a state connected only to a macro cell (non-CA state), the control procedure for adding a SCell is shown in **Figure 9** (1). First, the eNB commands the mobile terminal to make measurements to ascertain whether an add-on cell exists in the neighborhood. If a neighboring add-on cell does exist, the mobile terminal returns a report to the eNB on the radio quality of that add-on cell. Now, if the reported radio quality satisfies certain conditions, the eNB commands the mobile terminal to add that add-on cell as a SCell. On doing

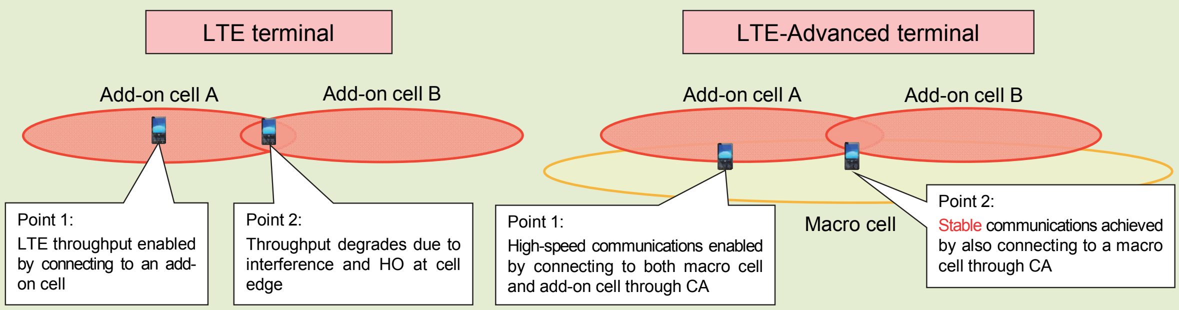

Figure 7 Communications by Advanced C-RAN architecture

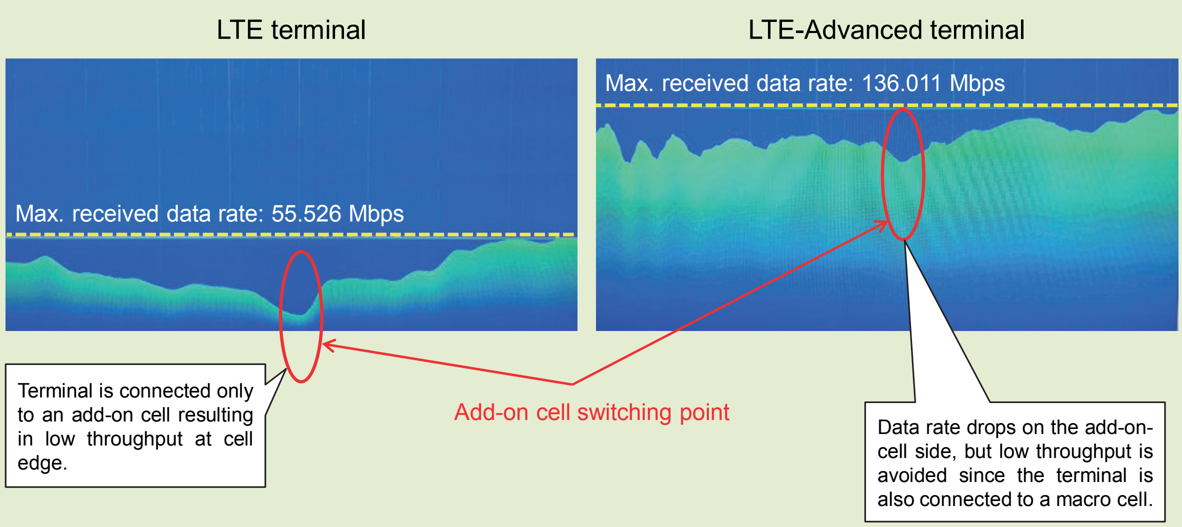

Figure 8 Comparison between LTE/LTE-Advanced terminals moving between add-on cells in a commercial environment

so, the mobile terminal enters the CA state, which enables it to be simultaneously connected to a macro cell and add-on cell. In this way, the most optimum add-on cell can be set as a SCell according to the position of the mobile terminal.

3.2 SCell Change

Next, for a mobile terminal connected to both a macro cell and add-on cell (CA state), the control procedure for changing the SCell if the mobile terminal should move into the area of another add-on cell is shown in Fig. 9 (2). At the time of "SCell add" as described in section 3.1, the eNB commands the mobile terminal to make measurements (event A6 measurements) so that an eNB report can be made if a cell of the same frequency as the existing SCell and with better radio quality comes to exist. Now, when the mobile terminal currently connected to the macro cell and add-on cell #1 moves into the boundary area between add-on cell #1 and add-on cell #2, the radio quality of the SCell (add-on cell #1) deteriorates while the radio quality of neighboring add-on cell #2 improves. The mobile terminal now reports the radio quality of add-on cell #2 to eNB based on event A6 measurements as described above. On the basis of this report, eNB commands the mobile terminal to change to add-on cell #2 having better radio quality than the current SCell. The above procedure makes it possible to keep up with the movement of the mobile terminal and set the most optimum add-on cell as the SCell.

3.3 SCell Delete

Finally, for a mobile terminal in CA state moving out of an add-on cell area, the control procedure for deleting the SCell is shown in Fig. 9 (3). At the time of "SCell add" as described in section

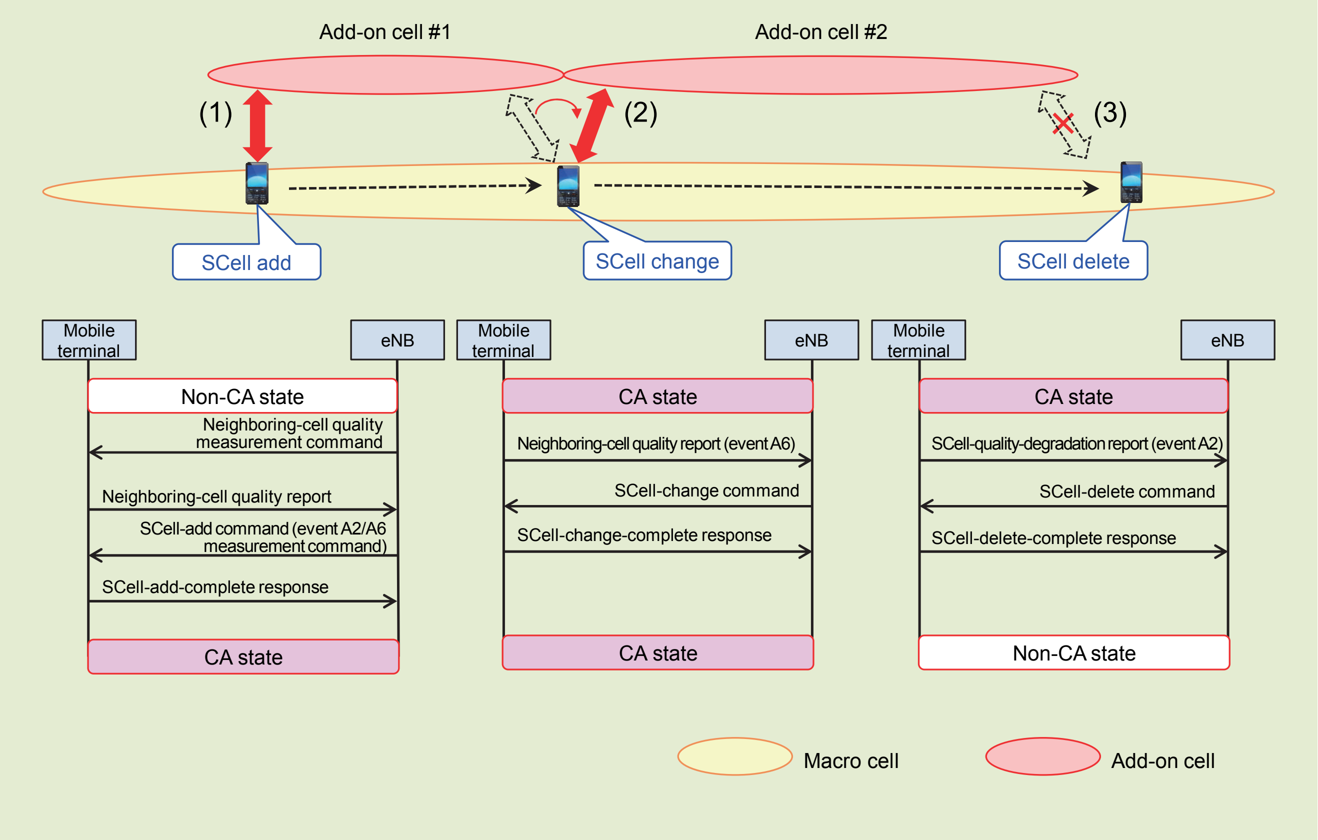

Figure 9 SCell control in Advanced C-RAN

3.1, the eNB commands the mobile terminal to make measurements (event A2 measurements) so that an eNB report can be made if the radio quality of the existing SCell should deteriorate below a specific threshold. These event A2 measurements are to be continued even if SCell should change. Now, if the mobile terminal currently connected to the macro cell and add-on cell #2 moves out of the area of add-on cell #2, radio quality will deteriorate. The mobile terminal therefore reports to eNB that the radio quality of add-on cell #2 has deteriorated based on event A2 measurements described above. On the basis of this report, eNB commands the mobile terminal to delete that SCell. The CA state is therefore cancelled and the mobile terminal enters a conventional LTE communications state (non-CA state). Cancelling the CA state in this way when appropriate can reduce the use of eNB resources and save battery power on the mobile terminal.

4. Conclusion

In this article, we described LTE-Advanced features with a focus on Advanced C-RAN architecture, presented capacity expansion effects on the basis of simulations, and overviewed control procedures. Advanced C-RAN architecture can increase radio capacity through the use of add-on cells while maintaining high-speed and stable communications befitting an LTE-Advanced system. The net result is an improved user experience. Going forward, we plan to study means of achieving even higher transmission speeds and improving radio spectral efficiency.

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High-density BDE | SRE | Small Cell Antenna

Technology Reports

Special Articles on PREMIUM 4G—Introduction of LTE-Advanced—

Radio Equipment and Antennas for Advanced C-RAN Architecture

*NTT DOCOMO began providing LTE-Advanced mobile communication services under the name PREMIUM 4G™ *1 in March 2015 as an evolved form of LTE. In this article, we overview newly developed high-density BDE, SRE, and antennas for constructing small cells, all with the aim of achieving and commercializing Advanced C-RAN architecture toward a full-scale rollout of LTE-Advanced.*

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1. Introduction

In March 2015, NTT DOCOMO launched "PREMIUM 4G" mobile communication services using LTE-Advanced, a communication system that achieves even higher transmission speeds and capacity than LTE. PREMIUM 4G applies Carrier Aggregation (CA)*2, a key technology of LTE-Advanced, to achieve a maximum downlink bit rate of 225 Mbps (reaching 262.5 Mbps in some areas) at the time of service launch, becoming the maximum transmission speed in Japan. The plan is to increase this bit rate to 300 Mbps within fiscal year 2015. To achieve PREMIUM 4G and support an effective rollout of LTE-Advanced, NTT DOCOMO has adopted Advanced Centralized Radio Access Network (Advanced C-RAN)*3 architecture [1].

As in the case of conventional C-RAN architecture, which was introduced for the rollouts of the W-CDMA [2] and LTE [3] mobile communication services, Advanced C-RAN consists of a Base-Band (BB)*4 unit having signal processing functions and Radio Equipment (RE)*5 having radio-signal transmitting/receiving functions. In this architecture, the BB unit connects to RE via optical fiber in a configuration where multiple RE units can be centrally controlled by a single BB unit. This "optical remote radio" configuration makes RE installation flexible and therefore speeds up the rollout of new services even in urban areas with limited installation space at the cell site. In addition, CA and mobile control through such centralized control enables advanced coordination between cells.

To effectively implement Advanced C-RAN architecture, NTT DOCOMO developed new high-density Base station Digital processing Equipment (BDE) as a BB unit, low power Small optical remote Radio Equipment (SRE) as RE for

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*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.
*2 **CA:** A technology that achieves high-speed communications through wider bandwidth while maintaining backward compatibility with existing LTE by performing simultaneous transmission and reception using multiple component carriers.

small cell*6 use, and base-station antennas likewise for small cells. An image of service area rollout by Advanced C-RAN architecture using the above equipment is shown in **Figure 1**. In this article, we provide an overview of high-density BDE, SRE, and base-station antennas for small cells.

2. High-density BDE

High-density BDE corresponds to the BB unit in an Advanced C-RAN optical-remote-radio configuration. It is capable of operating in LTE and LTE-Advanced simultaneously (**Photo 1**). This equipment has the features showed in **Table 1**.

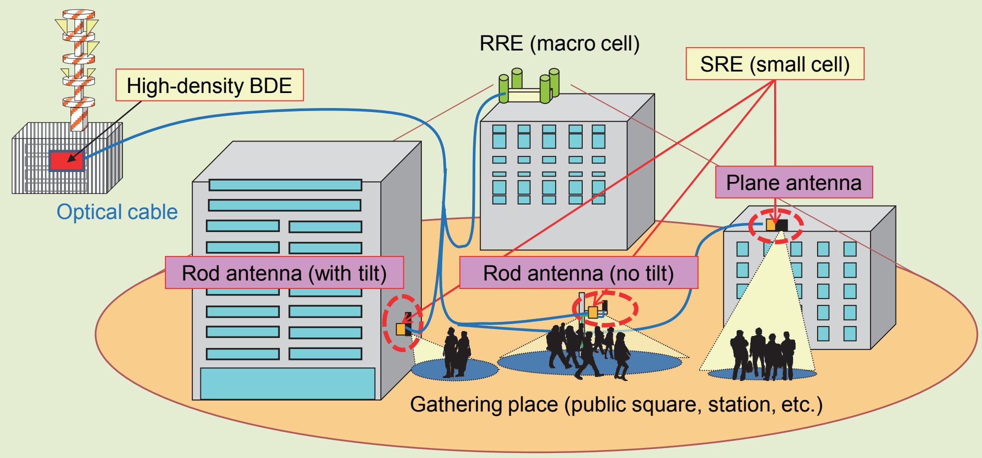

Figure 1 Service area rollout by Advanced C-RAN architecture

Photo 1 Appearance of high-density BDE

*3 **Advanced C-RAN:** Network architecture promoted by NTT DOCOMO using CA technology to enable cooperation between macro cells and small cells.

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

*5 **RE:** Radio equipment that connects to BDE via CPRI.

*6 **Small cell:** Generic name for a cell covering a small area and having low transmission power relative to a macro cell.

2.1 Increase in Number of Accommodated Cells and Advanced Inter-cell Coordination

One unit of high-density BDE can accommodate a maximum of 48 optical fiber connections each over a Common Public Radio Interface (CPRI) link*7, which means a maximum of 48 cells or eight times that of existing BDE [4]. Centralized control of a large number of cells enables more flexible inter-cell coordination and cell combinations for CA. In addition, this equipment can connect to SRE for small cells as well as existing Remote RE (RRE)*8 used in macro cells, and thus realize CA with any combination of cells without restrictions on frequency bands or RE types.

To achieve higher peak speeds by CA in a stable manner, receive timing difference between Component Carriers (CCs)*9 in the mobile terminal must be kept to within a certain range for either macro cells or small cells [5]. The high-density BDE is equipped with a function for adjusting and synchronizing the transmission timing of all connected RE (RRE and SRE). This makes it possible to perform CA even between REs installed at different locations or REs having different optical cable lengths for connecting to the high-density BDE.

2.2 Greater Ease of Installation and Longer Optical Connections

High-density BDE makes the installation of equipment easier by significantly reducing the installation space and power needed per cell (installation space and power consumption approximately one-half and 40%, respectively, that of existing BDE). The optical-connection length between the BB unit and RE has also been extended by approximately 1.5 times that of existing equipment for more flexible area expansion and cell accommodation.

2.3 Future Extendibility

This high-density BDE also supports 3G and Time Division Duplex (TDD)*10 systems. Here, TDD support requires the synchronization of transmission timing among all adjacent RE units. High-density BDE supports GPS and Precision Time Protocol (PTP)*11 as time synchronization methods, and synchronization between high-density BDE units can be achieved through synchronization with GPS either directly or via a PTP network. This ability to synchronize via a PTP transmission path facilitates service expansion by TDD even in an environment in which GPS antennas—which are ordinarily used for TDD time synchronization—are difficult to install, such as underground complexes. In addition, high-density BDE supports TDD- Frequency Division Duplex (FDD)*12 CA [6] with existing FDD bands and 3CC-or-greater CA as further extensions of CA. It also supports extension to higher order Multiple Input Multiple Output (MIMO)*13 toward the realization of advanced designated base stations in the 3.5 GHz band [7].

Table 1 Basic specifications of high-density BDE

	High-density BDE	Existing BDE
Supported systems	LTE/LTE-Advanced	LTE
No. of CPRI links	Max. 48	Max. 6
Length of optical connection	Approx. 1.5 times existing BDE	—
Max. downlink speed (per cell)	225 Mbps (30 MHz bandwidth) - 3 Gbps (future support)	50 Mbps (20 MHz bandwidth)
Power consumption	125 W (per cell)	200 W (per cell)
Size	Approx. 1/2 existing BDE (per cell)	—

*7 **CPRI link:** Circuit between BDE and RE conforming to CPRI internal interface specifications for standard radio base stations. High-density BDE can operate a maximum of 48 CPRI links enabling a maximum of 48 RE connections.

*8 **RRE:** eNB antenna equipment installed at some distance from an eNB using optical fiber or other means.

*9 **CCs:** Bundled carriers used for achieving CA.

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

*11 **PTP:** A protocol for achieving high-accuracy time synchronization among equipment connected to a network. In this protocol, equipment that delivers time information (Master Clock) synchronizes with GPS, so by having high-density BDE synchronize with the Master Clock, synchronization between high-density BDE units based on GPS time can be performed.

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

*13 **MIMO:** Wireless communications technology for expanding transmission capacity by using multiple transmit/receive antennas.

3. SRE

SRE corresponds to compact, low-output, optical-RRE for small cells of the one-LTE-carrier, one-sector type using a dual-antenna system. It comes in two types: equipment supporting the 1.5 GHz band as a capacity band[*14] and equipment supporting the 1.7 GHz band (**Photo 2**).

Similar to existing RRE, SRE consists of a Transmitter and Receiver-INter-Face (TRX-INF)[*15] functional component, Transmitter and Receiver (TRX)[*16] functional component, Transmission-Power Amplifier (T-PA)[*17], Low Noise Amplifier (LNA)[*18], and DUPlexer (DUP)[*19]. SRE features are summarized below (**Table 2**).

3.1 Compact, Light, and Low-power Configuration

SRE is smaller and lighter than existing RRE while consuming less power making it more advantageous for installation. Having a small cell radius and low output power, SRE is conducive to high-density arrangements and installation on low-rise buildings relative to RRE and can therefore be used to increase radio capacity. Furthermore, as the maximum transmit power of SRE is less than that of existing RRE, the degree of contribution of the TRX functional component to overall power consumption is relatively larger than that of the T-PA functional

RRH: Remote Radio Head

Photo 2　Appearance of SRE (left: macro cell RRE; right: SRE (3 models))

Table 2　Basic specifications of SRE

	1.5 GHz SRE	1.7 GHz SRE	(Reference) Existing 2 GHz RRE
Max. transmit power	2 W / 15 MHz / branch	2 W / 20 MHz / branch	20 W / 20 MHz / branch
No. of branches	2		2
Size	Under 3 ℓ		Under 13 ℓ
Equipment weight	Under 3 kg		Under 11.5 kg
Power consumption	Under 30 W		Under 220 W
Power supply	AC 100 V/200 V		DC −48 V

*14 **Capacity band:** A band used mainly for increasing radio capacity.

*15 **TRX-INF:** Functional component that converts IQ signals and maintenance and monitoring signals between BB and TRX to CPRI format for transmission along optical fiber.

*16 **TRX:** Functional component having a function for converting input BB transmit signals into RF transmit signals through orthogonal modulation and a function for performing A/D conversion on RF receive signals and converting result to BB receive signals.

*17 **T-PA:** Functional component that amplifies RF transmit signals from TRX to prescribed power levels.

*18 **LNA:** Device that performs initial amplification of signals received from an antenna. The noise level applied at amplification is low and resulting distortion is also low even for a weak received signal.

*19 **DUP:** Device that separates and multiplexes RF transmit signals and RF receive signals and connects to T-PA and LNA. Includes a function for filtering frequency components other than RF transmit components and RF receive components.

component. The TRX functional component includes a distortion compensation circuit for suppressing the distortion components generated during amplification by T-PA, so adopting simpler implementations applicable to SRE maximum transmit power for the distortion compensation circuit can reduce power consumption. Moreover, while existing RRE adopts a DC power supply, SRE adopts an AC power supply that can generally be provided by a commercial utility to simplify installation in an installation infrastructure different than the existing one. Reducing power consumption in SRE means less heat dissipation compared to existing equipment, so in addition to conventional vertical mounting (on a front or side surface), horizontal mounting can also be considered since heat will still be able to dissipate. These mounting options contribute to ease of installation.

3.2 Optimization of Transmitting and Receiving Performance

There are also cases of operating small cells in the same frequency band in an area that overlaps a macro cell. In such a case, SRE transmit power can be increased to maintain each cell's required radius. Additionally, since the installation height of SRE antennas is lower than that of existing RRE, the propagation loss between a mobile terminal and the base station is less than that of macro equipment. Thus, while there may be times that SRE receives much interference from mobile terminals connected to the macro cell, SRE still satisfies the required receive dynamic range*20 enabling high-quality reception.

4. Base-station Antennas for Small Cells

Specifications for base-station antennas for use with small cells developed by NTT DOCOMO are overviewed in **Table 3**.

These antennas feature dual polarization*21 and can be shared among the 1.5 GHz and 1.7 GHz frequency bands. A separately developed compact duplexer is installed between the SRE and antenna to separate and combine signals of these frequency bands. The compact configuration of these antennas simplifies their installation.

When planning a service area by placing small cells next to each other, deterioration in signal quality due to interference between small cells is an issue of concern. To resolve this issue, downward tilting*22 in the vertical plane is effective to reduce the interference caused by that antenna's signals on adjacent cells while also to raise the receive level within the antenna's own cell. The end result is improved throughput [9]. The following summarizes the features of three types of antennas developed by NTT DOCOMO taking interference reduction and diverse installation environments into account.

1) Rod Antenna (Two Types)

Having an omnidirectional radiation pattern*23 in the horizontal plane, this type of antenna is installed on the wall or ceiling of a building to form a service area in its periphery. Two types of rod antennas have been developed: one with tilting for an interference-reduction effect and the other with no tilting for a compact configuration. The rod antenna with tilting consists of multiple vertically aligned antenna elements, the amplitude and phase of each of which is adjusted to produce an electrical tilt. The tilt angle, however, is predetermined.

2) Plane Antenna

This type of antenna has high gain*24 while having a unidirectional radiation pattern making it applicable to installation on high places like building roofs to form a service area in a spot-like manner. A plane antenna can be given a mechanical tilt with a metal fixture to reduce interference.

5. Conclusion

In this article, we overviewed high-density BDE, SRE, and base-station antennas for small cells all newly developed by NTT DOCOMO for implementing Advanced C-RAN. Looking to the future, we are committed to raising customer satisfaction even further by increasing transmission speeds and capacity in the radio network, such as

*20 **Dynamic range:** The range of input/output signal that can be processed without distortion.

*21 **Polarization:** Direction of electric-field vibration. Vibration of the electric field in the vertical plane relative to the ground is called vertical polarization and that in the horizontal plane is called horizontal polarization.

*22 **Tilting:** Inclination of an antenna's main beam direction in the vertical plane. There are mechanical tilt systems that physically tilt the antenna and electrical tilt systems that control the amplitude and phase of antenna array elements.

*23 **Radiation pattern:** Expresses the strength of radio waves radiated in different directions.

*24 **Gain:** Relative signal power in the direction of maximum radiation.

Table 3 Overview of base-station antenna specifications

Antenna type	Rod antenna with titling	Rod antenna with no tilting	Plane antenna	(Reference) Macro cell antenna [8]
Appearance				
Frequency band	1.5/1.7 GHz bands			0.7/0.8/1.5/1.7/2 GHz bands
Horizontal-plane directivity	Omnidirectional	Omnidirectional	Unidirectional	Unidirectional
Tilt type	Electrical tilt (no remote control support)	No tilt	Mechanical tilt (no remote control support)	Electrical tilt (remote control support)
Size (mm)	Under ϕ55×340	Under ϕ55×150	Under 200×200×60	Under ϕ200×2,700

through the development of 3.5 GHz, TDD-compatible equipment, and by improving the overall quality of communications.

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LTE-Advanced | CA | Category 6

Technology Reports

Special Articles on PREMIUM 4G—Introduction of LTE-Advanced—

Router-type Mobile Terminals for LTE-Advanced Category 6 Carrier Aggregation

The growing popularity of data-intensive content is driving the demand for even greater throughput in mobile communications. Studies have been performed on CA—a key technology of LTE-Advanced—as a means of increasing throughput by enabling the simultaneous use of multiple frequency bands. NTT DOCOMO has developed router-type mobile terminals in two models to support the rollout of LTE-Advanced in March 2015. With a maximum throughput of 300 Mbps on the downlink, these terminals support LTE Category 6 CA.

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1. Introduction

The proliferation of data-intensive content such as movies and video clips in recent years has raised expectations for LTE-Advanced, which can deliver higher transmission speeds and greater capacity while maintaining compatibility with the existing LTE system.

NTT DOCOMO has adopted LTE Category 6 achieving a maximum data rate twice that of existing LTE Category 4 and has been providing LTE-Advanced services featuring maximum throughput on the downlink of 225 Mbps since March 2015 under the name PREMIUM 4G™*1. It has also developed new terminals to support LTE-Advanced for this launch.

In this article, we first give an overview of LTE Category 6 features and router-type mobile terminals supporting LTE Category 6 Carrier Aggregation (CA) (hereinafter referred to as "LTE-Advanced mobile terminals"). We then describe the Radio Frequency (RF)*2 configurations for achieving three combinations of 2 DownLink CA (2DL CA)*3 and present the throughput characteristics we obtained through laboratory and field tests.

We note here that the value of maximum throughput in the downlink varies according to the bandwidths that can be applied for CA. The LTE-Advanced mobile terminals introduced in this article can achieve a maximum throughput of 300 Mbps using the 40 MHz bandwidth of LTE Category 6. However, at the time of launching the LTE-Advanced service, NTT DOCOMO operations allowed for bandwidth allocation up to 30 MHz only, so throughput at that time was 225 Mbps.

2. Definition of Mobile Terminal Categories

The 3rd Generation Partnership Project (3GPP) defines categories of combined transmit/receive capability in LTE

† Currently of Network Department.

*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.
*2 **RF:** The radio frequency circuit.
*3 **2DL CA:** An LTE-Advanced technology enabling high-speed communications by bundling two frequency bands on the downlink (from base station to mobile terminal).

mobile terminals [1]. Category 4 LTE mobile terminals and Category 6 LTE-Advanced mobile terminals are compared in **Table 1**.

Existing Category 4 mobile terminals support a maximum transmit/receive bandwidth of 20 MHz. In contrast, Category 6 mobile terminals can support downlink bandwidths in excess of 20 MHz up to 40 MHz by using two frequency bands simultaneously. This bandwidth extension achieves a throughput of 300 Mbps, which is twice that of Category 4 mobile terminals. However, using only a single frequency band at the time of transmission results in a maximum throughput of 50 Mbps, the same as existing LTE mobile terminals.

The above description pertains to Category 6 in general. But as a specific implementation, NTT DOCOMO uses three combinations of frequency bands, namely, 2 GHz + 800 MHz *4, 2 GHz + 1.5 GHz, and 1.7 GHz + 800 MHz. The 2 GHz + 800 MHz and 2 GHz + 1.5 GHz combinations are implemented throughout Japan while the 1.7 GHz + 800 MHz combination is currently being used in the Tokyo, Nagoya, and Osaka regions. Since the maximum operating bandwidth at the time of LTE-Advanced service launch in March 2015 was 30 MHz, maximum throughput on the downlink was 225 Mbps at that time. 3GPP specifications define a maximum bandwidth of 35 MHz for the frequency-band combinations described above [2], so NTT DOCOMO foresees an eventual data rate of 262.5 Mbps.

3. Overview of LTE-Advanced Mobile Terminals

The LTE-Advanced mobile terminals developed by NTT DOCOMO are shown in **Figure 1** and their basic specifications are listed in **Table 2**. These mobile terminals boast high-speed packet communications based on LTE-Advanced and feature stable communications. They are mobile Wi-Fi routers compatible with quad-band LTE*5. To make full use of the high-speed features offered by LTE-Advanced, wireless LAN communications between the mobile terminal and Wi-Fi client adopt the Wi-Fi IEEE 802.11ac*6 standard, which makes it relatively difficult for the client to be affected by Wi-Fi signal interference while enabling high-speed communications of 876 Mbps. The idea here was to make high-speed communications noticeable not only on the WAN side but on the LAN side as well.

In developing the two models of LTE-Advanced mobile terminals shown here (HW-02G and L-01G), NTT DOCOMO

Table 1 Comparison of Category 4 and Category 6 mobile terminals (Mbps)

		Total Bandwidth (MHz)				
		20	25	30	35	40
Throughput (theoretical value)	Terminal category 4	150	—	—	—	—
	Terminal category 6	150	187.5	225	262.5	300

Figure 1 LTE-Advanced Wi-Fi routers

*4 **2 GHz + 800 MHz:** Notation for CA using the 2 GHz and 800 MHz frequency bands in which the "+" symbol is used to indicate that combination. Likewise, "2 GHz + 1.5 GHz" indicates CA using the 2 GHz and 1.5 GHz frequency bands and "1.7 GHz + 800 MHz" that using the 1.7 GHz and 800 MHz frequency bands.

*5 **Quad-band LTE:** An LTE service using four frequency bands: 2 GHz, 800 MHz, 1.5 GHz, and 1.7 GHz.

*6 **Wi-Fi IEEE802.11ac:** A wireless LAN standard using the 5 GHz frequency band that can achieve high-speed data communications of 433 Mbps – 6.93 Gbps through a maximum bandwidth of 160 MHz, a multi-value modulation signal (256-QAM), and a MIMO system extension (8×8 MIMO).

Table 2 Basic specifications of HW-02G/L-01G terminals

		HW-02G	L-01G
Frequency	LTE-Advanced	2 GHz+1.5 GHz/1.7 GHz+800 MHz/ 2 GHz+800 MHz[*1]	2 GHz+1.5 GHz/1.7 GHz+800 MHz/ 2 GHz+800 MHz[*1]
	LTE	800 MHz/1.5 GHz/1.7 GHz[*2]/2 GHz[*2]	800 MHz/1.5 GHz/1.7 GHz[*2]/2 GHz[*2]/ 2.6 GHz[*2, 3]
	W-CDMA	800 MHz/850 MHz[*2]/2 GHz[*2]	800 MHz/850 MHz[*2]/2 GHz[*2]
	GPRS[*2]	—	850 MHz/900 MHz/1,800 MHz/1,900 MHz
Max. data rate (UE category)	LTE-Advanced	DL : 262.5 Mbps (Category 6) UL : 50 Mbps (Category 6)	DL : 262.5 Mbps (Category 6) UL : 50 Mbps (Category 6)
	LTE	DL : 150 Mbps (Category 4) UL : 50 Mbps (Category 4)	DL : 150 Mbps (Category 4) UL : 50 Mbps (Category 4)
	HSDPA/ HSUPA	DL : 14.4 Mbps (Category 10) UL : 5.7 Mbps (Category 6)	DL : 14.4 Mbps (Category 10) UL : 5.7 Mbps (Category 6)
Dimensions		Approx. 90 mm (H) × 35 mm (W) × 12.9 mm (D)	Approx. 115 mm (H) × 34 mm (W) × 5.0 mm (D) (Max. depth: approx. 10.0 mm)
Weight		Approx. 110 g	Approx. 187 g
Wi-Fi (LAN side)[*4]		802.11a/b/g/n (2.4 GHz/5 GHz) /ac	802.11a/b/g/n (2.4 GHz/5 GHz) /ac
Battery capacity		2,400 mAh	4,880 mAh
Ethernet connection (when using supplied cradle)		802.3ab (1000Base-T)	—

*1 Function addition by software update
*2 Roaming support
*3 TD-LTE support
*4 Only 2.4 GHz Wi-Fi provided when placing in cradle (802.11b, 802.11g, 802.11n)

took into account the environments where users would tend to use each model to determine what functions to give to each, as discussed below.

1) HW-02G

The concept of the HW-02G Wi-Fi router focuses on users whose indoor use is relatively heavy. The design keeps the terminal small so that it can easily be placed on a desk in a study, on a telephone stand in a living room, etc. thereby enabling Wi-Fi to be used just about anywhere in the house. To this end, Wi-Fi functions were enhanced in this model so that it could be used even in places where Wi-Fi signals are difficult to propagate, such as spacious single-family homes or condominiums in which Wi-Fi clients may be located at a distance from the router or behind signal obstructions such as doors, walls, and furniture. Specifically, the cradle supplied with the HW-02G model is equipped with a chip for producing high-power Wi-Fi signals in the 2.4 GHz band. When placing the HW-02G unit in the cradle, the HW-02G built-in Wi-Fi chip is shut down and a switch is made to the Wi-Fi chip on the cradle side. Making an indoor Wi-Fi connection in this way enables high-power signals to be transmitted compared to what could be provided by the Wi-Fi router itself making it possible to use LTE-Advanced even in spacious indoor areas.

2) L-01G

The concept of the L-01G Wi-Fi router focuses on users whose outside use is relatively heavy. Here, the design enables long-term use even if battery charging cannot be performed while on the go. The unit is equipped with a 4,880-mAh large-capacity battery to enable extended use when out and a function enabling it to serve as an auxiliary battery. As a result, the L-01G Wi-Fi router can be used not only for data communications but also as a mobile battery in the event that the user's smartphone or tablet runs out of power. It also supports 3G, General Packet Radio Service (GPRS)*7, Frequency Division Duplex (FDD)-LTE*8 for overseas roaming as well as Time Division Duplex (TDD)-LTE*9 (2.6 GHz). As such, the L-01G Wi-Fi router is a product that meets the needs of overseas travelers for high-speed data communications.

4. Overview of RF Configurations for Three Combinations of 2DL CA

4.1 Two Methods of Frequency Separation

NTT DOCOMO implements three combinations of 2DL CA in one mobile terminal. Typical RF configurations for implementing CA are shown in **Figure 2**. To achieve CA, two frequency bands must be separated and simultaneous communication by those bands must be enabled. There are two methods for doing so. The first method uses a DIPlexer (DIP)*10 situated directly under an antenna as a filter for separating two frequency bands with low loss (Fig. 2 (a) and (b)). The other method uses two antennas for separate and simultaneous communication in two frequency bands (Fig. 2(c)). In the method using DIP, the technical problem is how to suppress insertion loss and prevent drops in signal power, while in the antenna-separation method, the problem is how to minimize the antenna installation space.

4.2 RF Configurations

The RF configuration for achieving 2DL CA for global use (Fig. 2 (a)) differs from the RF configurations for the LTE-Advanced mobile terminals developed by NTT DOCOMO (Fig. 2 (b) and (c)). The global configuration generally places the DIP directly under the antenna to separate low-band frequencies (1 GHz and lower) from high-band frequencies (1.7 GHz and higher) and achieves CA by a low-band and high-band combination. However, to achieve the three types of CA combinations adopted by NTT DOCOMO, the 1.5 GHz band used only in Japan presents a problem. This is because, when applying the DIP used in the global configuration described above, the 1.5 GHz band corresponds to a stopband owing to DIP filter characteristics with the result that filtering loss becomes excessively large. For this reason, NTT DOCOMO has standardized in 3GPP a specification that extends the passband on the high-frequency side of the DIP directly under the antenna to the 1.5 GHz band as shown in Fig. 2 (b) [2]. Consequently, by applying a configuration that couples this DIP with another lower DIP for separating the 1.5 GHz and 2 GHz bands, or a configuration that

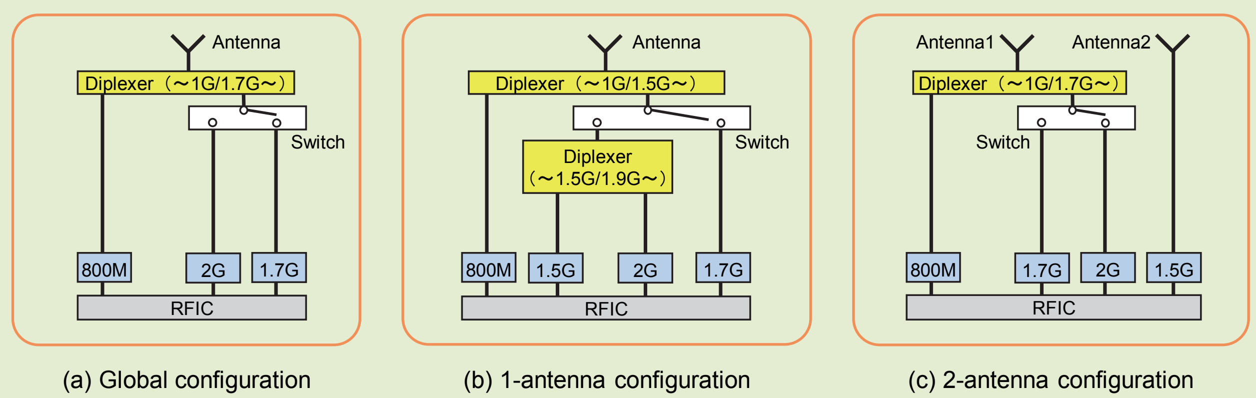

Figure 2 Examples of RF configurations in mobile terminal

*7 **GPRS:** A packet switching service available on GSM network.

*8 **FDD-LTE:** An LTE system applying FDD technology.

*9 **TDD-LTE:** An LTE system applying TDD technology.

*10 **DIP:** A filter for separating two frequency bands at low loss. It consists of a low pass filter (that treats the low-frequency side as the passband and the high-frequency side as the attenuation band) and a high pass filter (that treats the high-frequency side as the passband and the low-frequency side as the attenuation band).

uses a separate antenna to transmit and receive signals only in the 1.5 GHz band as shown in Fig. 2 (c), it becomes possible to achieve 2DL CA through a middle-band and high-band combination (2 GHz + 1.5 GHz). This is in addition to the 2 GHz + 800 MHz and 1.7 GHz + 800 MHz combinations achievable by the global configuration that separates low and high bands.

4.3 Problems and Countermeasures

A multi-level DIP configuration as shown in Fig. 2 (b) results in a decrease in terminal usage time, an increase in generated heat, and a drop in receive sensitivity owing to an increase in insertion loss. Achieving low-loss DIPs was therefore considered. In contrast, separating frequency bands through the use of two antennas and performing simultaneous communications accordingly as shown in Fig. 2 (c) does not generate the loss associated with the above multi-level DIP configuration. However, a terminal having the configuration of Fig. 2 (c) separates frequency bands using different antennas while supporting a 2×2 Multiple Input Multiple Output (MIMO)[*11] configuration on the downlink, which requires a total of four antennas within the same housing. Antenna performance may therefore drop as a result of size limitations and mutual coupling between antennas. To deal with these problems, measures have been taken in the LTE-Advanced mobile terminals that have been developed to enhance antenna structure and optimize the arrangement between transmit/receive antennas and the arrangement of receive antennas.

5. Test Results for Downlink Data Rates in LTE-Advanced Mobile Terminals

We performed maximum throughput tests of LTE-Advanced mobile terminals using actual base station equipment in both laboratory and field test environments. For the laboratory test environment, the base station and mobile terminal were connected by cable thereby creating an ideal environment having no interference or fading in radio quality. In the test, data was transferred from a file server to the mobile terminal and throughput on the Medium Access Control (MAC) layer[*12] [3] [4] was measured. Results are listed in **Table 3**. For a 35 MHz bandwidth, a throughput of 241 Mbps was measured. This figure agrees with the theoretical value obtained by subtracting the radio control signal needed for our operation.

We next performed a similar test in an field test environment, in which we made measurements in a static state at a location near the base station having a small amount of interference from other base stations and mobile terminals. For a 35 MHz bandwidth, a throughput of 238 Mbps was measured, which shows that a throughput nearly the same as that of the laboratory test environment could be achieved.

In an actual commercial environment, the base station varies transmission speed adaptively based on the number of connected mobile terminals, the amount of interference, distance from the base station, and radio quality. Thus, while data rates will differ depending on the usage environment, the results of these tests demonstrate that both the LTE-Advanced mobile terminal and base station exhibit sufficient performance.

6. Conclusion

In this article, we overviewed the specifications and features of the NTT DOCOMO HW-02G and L-01G

Table 3 Theoretical values and test results for downlink data rate (Mbps)

		Total bandwidth (MHz)				
		20	25	30	35	40
Theoretical value		150	187.5	225	262.5	300
Measured value	Laboratory test environment	135	166	205	241	—
	Field test environment	—	—	199	238	—

*11 **MIMO:** A wireless communication technique that utilizes multiple paths between multiple antennas at the transmitting and receiving ends to exploit spatial propagation properties, causing the capacity of wireless links to increase in proportion with the number of antennas.

*12 **MAC layer:** A radio-interference protocol in LTE and LTE-Advanced. As a sub-layer of Layer 2, it allocates radio resources, performs data mapping, and controls retransmission.

Wi-Fi routers developed as LTE-Advanced mobile terminals for the LTE-Advanced (PREMIUM 4G) service launched in March 2015. We also described the RF configurations for achieving three combinations of 2DL CA adopted by NTT DOCOMO, explained the definitions of mobile terminal categories, clarified throughput characteristics in both laboratory and field test environments, and showed that throughput could be obtained in line with theoretical values.

Going forward, we will conduct more laboratory/field evaluations in multi-user environments, heavy-interference environments, etc. toward improved performance. We also plan to develop mobile terminals capable of 3DL CA (Category 9*) that uses three frequency bands simultaneously to increase throughput even further. Our goal here is to achieve a throughput of 300 Mbps at an operating bandwidth of 40 MHz.

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* Specifications call for an upper performance limit of 450 Mbps at a bandwidth of 60 MHz.

3GPP | Release 12 | LTE/LTE-Advanced

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

LTE-Advanced Release 12 Standardization Technology Overview

The international standards organization, 3GPP, specified the Release 10 specification for the LTE-Advanced standard, which introduces advanced technologies of LTE. 3GPP has continued to study technologies to further advance the functionality of LTE/LTE-Advanced, and has recently completed the Release 12 specification. In this article, we describe the main functionalities decided in Release 12.

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1. Introduction

The 3rd Generation Partnership Project (3GPP), which developed the specifications for W-CDMA*1 and HSPA*2, published the Release 8 specification for the LTE standard in 2008, to introduce a more competitive mobile communications system able to meet the expanding needs of smartphone users. Then, 3GPP expanded and extended LTE to meet the market need for higher performance and service diversification, publishing the Release 10 specification for LTE-Advanced*3 in 2011. Later, to further extend functionality and increase performance of LTE-Advanced, 3GPP published the Release 11 specification in 2012, and Release 12 in March 2015. In this article, we describe background considerations and the main new functionalities introduced in Release 12, the latest specification for the LTE-Advanced standard.

2. Release 12 Specification Background Consideration

Release 10, the first release of the LTE-Advanced standard, introduced technologies to deal with increasing mobile traffic while maintaining backward compatibility with LTE, including Carrier Aggregation (CA)*4, which enables extending transmission and reception bandwidth up to 100 MHz, and advanced multi-antenna technologies, supporting up to eight transmissions on the downlink and four transmissions on the uplink [1]. Also, for Heterogeneous Networks (HetNet)*5, which deploy smaller cells in urban and other areas with more traffic, a technology called Inter-Cell Interference Coordination (ICIC)*6 was introduced. Release 11 also introduced a technology called Coordinated Multi-Point (CoMP)*7 transmission and reception

*1 **W-CDMA:** Wideband Code Division Multiple Access.

*2 **HSPA:** Standard that enables the high speed packet data transmission in W-CDMA; collective term for High Speed Downlink Packet Access (HSDPA) that speeds up the downlink (from base station to mobile terminal) and High Speed Uplink Packet Access (HSUPA) that speeds up uplink (from mobile terminal to base station).

between cells on HetNet. Solutions for Machine-to-Machine (M2M) services such as smart meters (electricity and gas meters) incorporating LTE communications modules were also supported in Release 11 [2].

3GPP has been fulfilling the market demands in these ways, based on recent diversifying trends and requirements in the mobile communications market. The main functionalities in the recent Release 12 specification can be classified into three main categories, which are: (1) New technologies increasing user throughput*8 and capacity, (2) New technologies for expanding service areas, and (3) Enhanced functionality based on network operations experience.

3. New Functionality in Release 12

The standard technologies mentioned above were actively discussed with great interest by the various companies participating in the 3GPP, and an overview of the functionalities included in Release 12 of the standard is shown in **Figure 1**. Functions in each of the categories are described in more detail below.

3.1 New Technologies for Increasing User Throughput and Capacity

This study area focused on HetNet scenarios based on CA, deploying a large number of small cells using different frequencies than the existing macro cells*9 in high-traffic areas. One reason for this is that with many operators using LTE with multiple frequencies, it is a way to use high frequencies (e.g., the 3.5 GHz band) efficiently, by using CA to establish communication with macro cells and small cells simultaneously. The following six technologies for HetNet scenarios using different frequencies

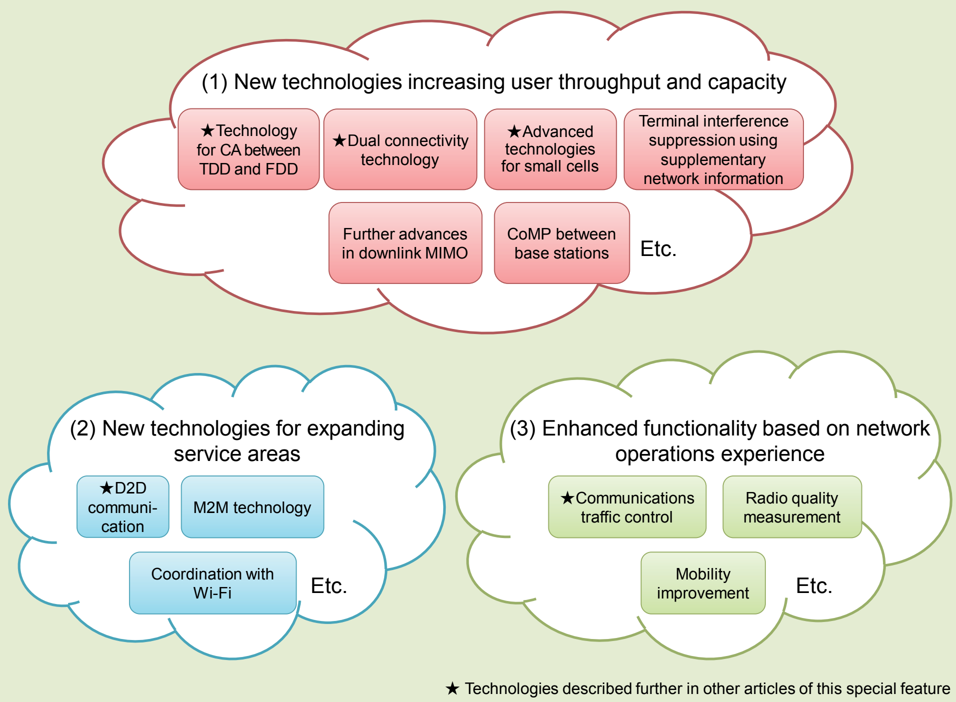

Figure 1 Main functionality decided in Release 12 specifications

*3 **LTE-Advanced:** Name of IMT-Advanced in 3GPP. IMT-Advanced is the successor to the IMT-2000 third-generation mobile communications system.

*4 **CA:** Technology to simultaneously transmit and receive signals from 1 user using multiple carrier waves to enable wider bandwidths while maintaining back compatibility with existing LTE, and achieve faster transmission speed.

*5 **HetNet:** A network configuration that overlays nodes of different power. It typically includes picocell, femtocell, Wi-Fi and other base stations of lower power than conventional base stations, mixing, linking and integrating multiple technologies.

*6 **ICIC:** A technology that reduces the effects of inter-cell interference by semi-statically allocating different time/frequency radio resources between cells.

*7 **CoMP:** 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.

*8 **User throughput:** The amount of data that one user can transmit without error per unit time.

attracted much interest at the 3GPP, and specifications were decided for them.

1) CA between TDD and FDD

CA was introduced from Release 10, for increasing user throughput, but was limited to LTE carriers that use the same duplex scheme, either Frequency Division Duplex (FDD)*10 or Time Division Duplex (TDD)*11. Considering that frequency bands that can be used with the LTE TDD scheme are increasing and there was demand from operators in Japan, the United States, and Europe that have already adopted the LTE FDD scheme, CA between FDD and TDD frequencies was introduced in Release 12. This will enable user throughput to be increased further by making it possible for operators to cooperate across different duplex schemes in various frequency bands through CA.

2) Dual Connectivity

In the operation of CA, backhaul*12 delay was assumed to be negligible when transmitting multiple LTE carriers simultaneously, such as when transmitting them from the same base station, or if transmitted from different base stations (e.g., a macro base station and Remote Radio Equipment (RRE)*13), that they are connected by optical fiber. However, in many countries and regions, base stations are usually connected by a backhaul that permits delay, because the equipment is relatively less expensive. Thus, due to strong demand from operators in various countries, a new technology called Dual Connectivity was specified, which enables user throughput to be increased using the multiple LTE carriers provided by different base stations. Dual Connectivity enables simultaneous communication on LTE carriers between any two base stations that are connected by an X2*14 interface. This will enable operators to implement improved user throughput in a variety of base station deployment scenarios.

3) Advanced Technologies for Small Cells

In studying small cell deployment scenarios, various technologies were adopted for densely arranged small-cell environments, under the name, Small Cell Enhancements (SCE). Advanced technologies for small cells include (1) higher order modulation using 256QAM on the downlink, and (2) technologies for small cell on/off switching and small cell discovery during CA, to reduce interference between densely deployed small cells when they are configured as Secondary Cells (SCells). Using these technologies in small cell environments is expected to increase user throughput and capacity.

4) Terminal Interference Suppression Using Supplementary Network Information

Release 11 specified interference suppression that only uses information obtainable on the terminal. With Release 12, user throughput and capacity can be further increased using neighboring cell and other supplementary information provided by the base station.

5) Further Advances in Downlink MIMO

Downlink Multiple Input Multiple Output (MIMO)*15 technology, which increases user throughput and capacity, has been further advanced. Release 12 assumes multi-user MIMO*16 transmission using four orthogonal polarized antennas on the base station transmission, and specifies a codebook*17 able to realize higher resolutions than Release 8. It also specifies new feedback modes, providing feedback information such as Channel Quality Indicators (CQI)*18 from terminals to the base station in sub-band units that partition the system bandwidth.

6) CoMP between Base Stations

CoMP in Release 11 assumed an active CoMP transmission and reception technology coordinating between macro base stations and RRE that are connected by a channel such as optical fiber, for which transmission delay can be ignored. In contrast, Release 12 assumed CoMP transmission and reception between base stations that are connected by a back haul that permits delay, and defines back haul signaling for its operation. This makes semi-static interference control for interference between cells possible, allowing increased throughput, for users at the cell edge in particular.

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*9 **Macro cell:** Cellular communication area with a cell radius of several hundred meters to several tens of kilometers mainly covering outdoors. Antennas are usually installed on towers or on roofs of buildings.

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

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

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

*13 **RRE:** eNB antenna equipment installed at some distance from an eNB using optical fiber or other means.

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

*15 **MIMO:** A wireless communication technique that utilizes multiple paths between multiple antennas at the transmitting and receiving ends to exploit spatial propagation properties, causing the capacity of wireless links to increase in proportion with the number of antennas.

*16 **Multi-User MIMO:** A technology that improves spectral efficiency by applying MIMO multiplexed transmission to the signals for multiple users.

3.2 New Technologies for Expanding Service Areas

In addition to basic performance increases in the typical mobile telephone system as indicated in Section 3.1, interest in Device-to-Device (D2D) communication between terminals, M2M communication for terminals such as smart meters, and coordination with Wi-Fi®*19 communications is increasing rapidly.

1) D2D Communication

One application anticipated for D2D communication is for a public safety radio system. Direct communication between terminals co-existing with the LTE network was supported, so that a means of communication could be provided even if base stations were down due to large-scale disaster, or when in the mountains or other areas outside of base-station coverage. Another application of D2D is for commercial D2D proximity services, and a device-discovery technology was also introduced for receiving such services.

2) M2M Technology

Migration of smart meters and other services using W-CDMA/HSPA or GSM*20 M2M terminals to LTE is being widely considered. However, LTE modules for M2M terminals are currently expensive compared to W-CDMA/HSPA and GSM modules, so specifications for a low-cost module were desirable. As such, Release 12 supports a new category of terminal for M2M with features including (1) maximum data rates of 1 Mbps, (2) FDD half-duplex, and (3) reception with one antenna. New Power Saving Modes (PSM) for M2M terminals were also specified, along with functionality that considers communication traffic and frequency of handover*21 when setting the time for maintaining communication state.

3) Coordination with Wi-Fi

Wi-Fi is accommodated by Evolved Packet Core (EPC)*22, which are the core nodes of an LTE network, and technology to off-load some traffic to Wi-Fi has been included since Release 8. However, till now, traffic off-loading has been controlled using only information obtainable on the core network, such as traffic type and preconfigured priorities for LTE and Wi-Fi. Release 12 specifies a technology to control off-loading between LTE and Wi-Fi, taking radio quality for both LTE and Wi-Fi and the state of Wi-Fi congestion*23 into consideration.

3.3 Improved Functionality Based on Network Operations Experience

Functional improvements based on the experience of operators of LTE and LTE-Advanced networks were also introduced. Examples of these include a traffic control technology that considers Voice over LTE (VoLTE)*24, a radio quality measurement technology, and mobility improvement technologies.

1) Communications Traffic Control Technology

NTT DOCOMO began providing VoLTE services within Japan early, in June 2014, and operators outside of Japan are also introducing VoLTE commercially. With the spread of VoLTE, the ability to implement flexible access control*25 of data and voice traffic is becoming important for operation of LTE and LTE-Advanced networks.

Considering this, Release 12 specifies new technologies including (1) Smart Congestion Mitigation, which controls voice (VoLTE) and packet traffic independently, and (2) SSAC in connected, a control technology that can regulate voice (VoLTE) call initiation even when the user terminal is already communicating.

2) Radio Quality Measurement Technology

Mobile operators are operating more frequency bands for LTE in order to handle the increasing mobile traffic. Because of this, it is becoming increasingly important among operators for terminals to measure as many LTE frequencies as possible and control operation so that the best quality frequencies are always being used. As such, Release 12 includes specifications enabling terminals to measure more carrier frequencies at the same time.

It also includes specifications for a scheme to increase the accuracy of Ref-

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*17 **Codebook:** A set of predetermined precoding-weight matrix candidates.

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

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

*20 **GSM:** A Second-Generation mobile communication system used for digital mobile phones.

*21 **Handover:** The technique of switching from one base station to another without interrupting communication when a terminal moves between base stations.

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

*23 **Congestion:** Impediments to communications services due to communications requests being concentrated in a short period of time and exceeding the processing capabilities of the service control server.

*24 **VoLTE:** A function to provide voice services over LTE using packet switching technologies.

*25 **Access control:** The restricting of location-registration and calling operations in mobile stations to effect an early recovery from a state of congestion caused by a processing anomaly or failure in Satellite-Base station Equipment (S-BE) owing to an accident, disaster, or popular event.

erence Signal Received Quality (RSRQ) measurements.

3) Mobility Improvement Technologies

To improve the success rates for handover in HetNet environments using the same frequency, functionality to adjust parameters related to handover for individual cells was specified. A mechanism was also specified for terminals in a standby state to notify base stations of their speed of motion (high/med/low) and a list of cells on which the UE has recently camped together with how long the UE was camped on the cells, for use in adjusting mobility-related parameters.

4. Conclusion

In this article, we have described background study and the main new functions introduced in Release 12 of LTE-Advanced. Of the main functions introduced here, "CA between TDD and FDD" in Section 3.1 1) [3], "Dual connectivity technology" in Section 3.1 2) [3], "Advanced technology for small cells" in Section 3.1 3) [4], "Terminal interference suppression using supplementary network information" in Section 3.1 4) [4], "D2D communication" in Section 3.2 1) [5], and "Communications traffic control technology" in Section 3.3 1) [6] are described in more detail in other articles in this special feature.

Initiatives to create Release 13 are also in progress, to further extend functionality of LTE-Advanced.

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LTE-Advanced CA DC

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

Carrier Aggregation Enhancement and Dual Connectivity Promising Higher Throughput and Capacity

In 3GPP Release 10 of LTE-Advanced, CA was introduced as a promising way to increase user throughput and it is being introduced commercially around the world. In Release 12, new functionalities were specified to further increase user throughput and capacity and to realize more flexible deployment: CA between LTE carriers using different duplex modes, RF requirements for CA with more LTE carriers, and DC, which enables a UE to connect with multiple base stations simultaneously.

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1. Introduction

As smartphones have spread, traffic on wireless networks has increased. To increase the capacity of wireless networks and handle this increase, the 3GPP has been studying Heterogeneous Networks (HetNets)*1, which offload macro cell*2 radio traffic to small cells*3 with relatively low transmission power. NTT DOCOMO has been proposing a technology for and planning the deployment of "add-on cell" operation, which applies Carrier Aggregation (CA)*4 on HetNets, as specified in the Release 10 specification, to realize increased radio capacity using small cells while maintaining stable communication [1]. NTT DOCOMO is actively studying how to expand the regions where add-on operation is used, and other companies in the 3rd Generation Partnership Project (3GPP) are also actively studying how to achieve higher throughput using multiple LTE carriers and more-flexible operation. Based on this background, the Release 12 standard specifies TDD-FDD CA which aggregates LTE carriers using different duplex modes, Frequency Division Duplex (FDD)*5 and Time Division Duplex (TDD)*6, and the Radio frequency (RF) requirements for CA using more LTE carriers. It also specifies a new technology called Dual Connectivity (DC), with which UE is connected to multiple evolved NodeBs (eNBs)*7 using multiple LTE carriers. This article describes these technologies.

2. CA Extensions

2.1 CA between LTE Carriers with Different Duplex Modes

Release 12 specifies a TDD-FDD CA for CA between LTE carriers with different duplex modes, FDD and TDD, so

*1 **HetNet:** A network deployment that overlays nodes of different power. It typically mixes-in, links and integrates base stations of lower transmission power than conventional base stations.

*2 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

that a wider variety of frequency bands can be aggregated by CA. The FDD and TDD specifications are mostly compatible, but some control signaling procedures specifying transmission/reception timing are designed differently, such that they fit with their respective frame structures. It is difficult to perform CA with both FDD and TDD carriers utilizing such duplex-mode specific operation, since CA requires coordination between Component Carriers (CCs)*8, so a new control signaling procedure was specified for TDD-FDD CA.

The control schemes for both FDD and TDD in LTE, as well as TDD-FDD CA are described below.

1) FDD and TDD

A conceptual diagram of FDD and TDD in LTE is shown in **Figure 1**. With FDD, different frequencies are used for the UpLink (UL) and DownLink (DL) (pair band). Conversely, with TDD, the UL and DL use the same frequency, but transmitting and receiving switches in time, between the DL and the UL. Note that when switching from DL to UL, a Special subframe*9 is inserted, incorporating a DL reception period Downlink Pilot Time Slot (DwPTS), a Guard Period (GP), and an UL transmitting period Uplink Pilot Time Slot (UpPTS). In LTE, seven UL/DL configurations with different subframe up-down ratios and different UL/DL switching periods are specified (**Table 1**).

As mentioned earlier, the frame structures for FDD and TDD are different, with FDD allowing transmission and reception at any time, while TDD has constraints on such timing. For this reason, differences arise with control signalling procedure that requires specific timing, such as Hybrid Automatic Retransmission reQuest (HARQ)*10. With HARQ control, the User Equipment (UE) attempts to receive data on the Physical Downlink Shared CHannel (PDSCH)*11 allocated to itself, and transmits the decoding result (ACKnowledgement (ACK)*12 or NACK) as a HARQ feedback signal in a prescribed UL subframe. In CA aggregating multiple LTE carriers, the HARQ feedback signals for data received on a Primary Cell (PCell)*13 and Secondary Cell (SCell)*14 in the DL are sent together on the Physical Up-

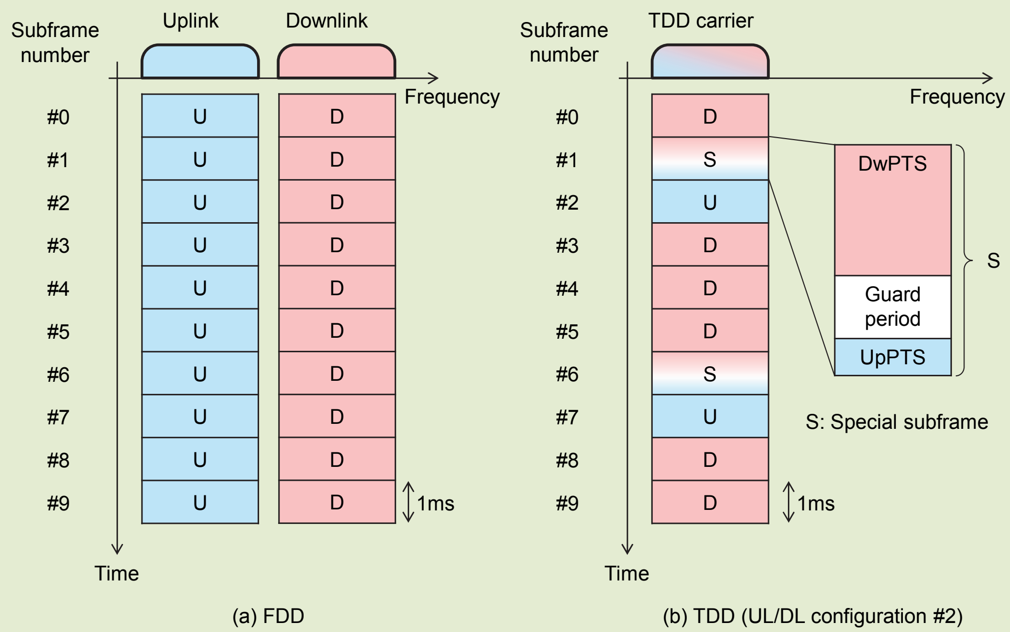

Figure 1 Frame structures for FDD and TDD

*3 **Small cell:** A general term for cells that transmit with power that is low compared to that of a macro cell transmitting at higher power.

*4 **CA:** A technology that achieves high-speed communications through wider bandwidth while maintaining backward compatibility with existing LTE by performing simultaneous transmission and reception using multiple component carriers.

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

*6 **TDD:** A scheme for transmitting signals using the same carrier frequencies and bands in the uplink and downlink. It switches time slots for uplink and downlink.

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

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

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

link Control CHannel (PUCCH)*15 of the PCell. With an FDD carrier (or CA among FDD carriers), the HARQ feedback signal for data received on the DL is sent uniformly 4 ms later in the PCell UL subframe (**Figure 2**(a)). In contrast, with a TDD carrier (or CA among TDD carriers), the HARQ feedback timing depends on the DL subframe in which the data was received, since only certain subframes can be used for UL in the PCell. Specifically, as illustrated in Fig. 2(b), one or more HARQ feedback signals are sent in a particular PCell UL subframe at least 4 ms after the DL data is received.

Thus, the HARQ feedback timing is uniquely determined based on the respective FDD and TDD frame structures.

2) TDD-FDD CA

The timing of the HARQ feedback signal specified for TDD-FDD CA is described using an example below.

(1) PCell is FDD carrier

In the case that the PCell is an FDD carrier (FDD PCell) and conventional TDD HARQ feedback timing applies for a TDD carrier added as an SCell (TDD SCell), HARQ feedback delay will be the same as for conventional TDD, even though

Table 1 TDD UL/DL configurations specified in LTE

Uplink-downlink configuration	Downlink-to-Uplink switch-point periodicity	Subframe #									
		0	1	2	3	4	5	6	7	8	9
0	5ms	D	S	U	U	U	D	S	U	U	U
1	5ms	D	S	U	U	D	D	S	U	U	D
2	5ms	D	S	U	D	D	D	S	U	D	D
3	10ms	D	S	U	U	U	D	D	D	D	D
4	10ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5ms	D	S	U	U	U	D	S	U	U	D

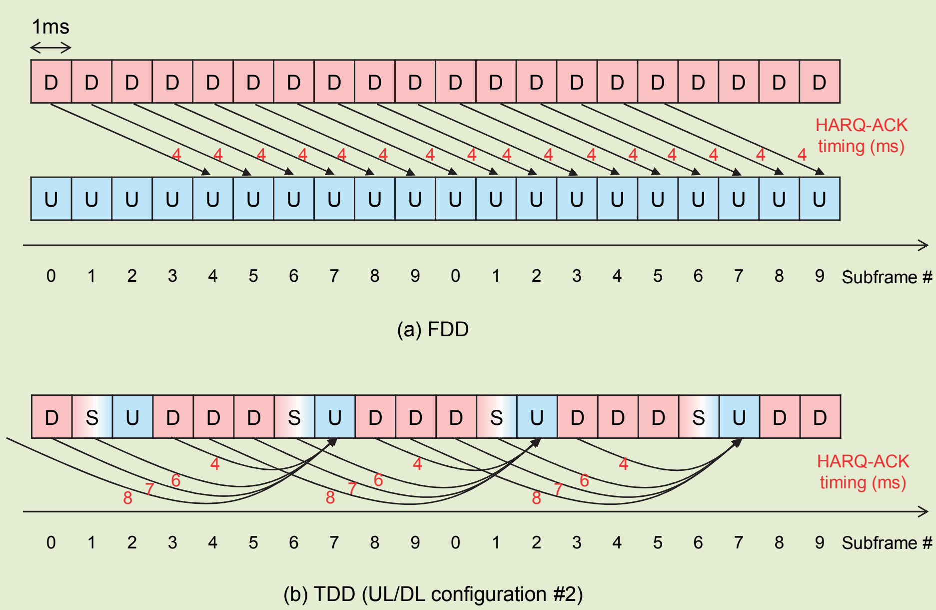

Figure 2 DL HARQ-ACK transmission timing for FDD and TDD

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

*11 **PDSCH:** A shared channel used in DL data transmission in LTE.

*12 **ACK:** An acknowledgement feedback from the receiving node to the transmitting node when a data frame has been received successfully.

*13 **PCell:** A cell that maintains the connection between UE and network in CA.

*14 **SCell:** A cell that provides radio resources in addition to a PCell.

*15 **PUCCH:** Physical channel used for sending and receiving control signals in the UL.

the FDD has the advantage that there is opportunity for UL transmission in every subframe. To take the advantage of the FDD frame structure, HARQ feedback signals for the TDD SCell can be sent utilizing the same timing as for the FDD carrier. Specifically, HARQ feedback signals corresponding to DL received data on a TDD SCell are sent 4 ms after the subframe, as with an FDD PCell (**Figure 3**(a)). Thus, since HARQ response signals are sent with the same timing as for FDD and CA among FDD carriers, HARQ feedback delay for TDD SCells is comparable to that for FDD. In other words, HARQ transmission control can be applied to TDD SCells, as if the SCells were FDD carriers.

(2) PCell is TDD carrier

On the other hand, in the case that PCell is a TDD carrier (TDD PCell), the same constraint as with conventional TDD applies; UL transmission can be performed only in a limited number of PCell UL subframes. Accordingly, there are cases when there is no UL subframe 4 ms after DL data is received on an FDD carrier added as an SCell (FDD SCell). In order to be able to schedule all DL subframes on FDD SCells, a new DL HARQ feedback timing was specified for FDD SCells (Fig. 3(b)). The timing for transmitting HARQ feedback

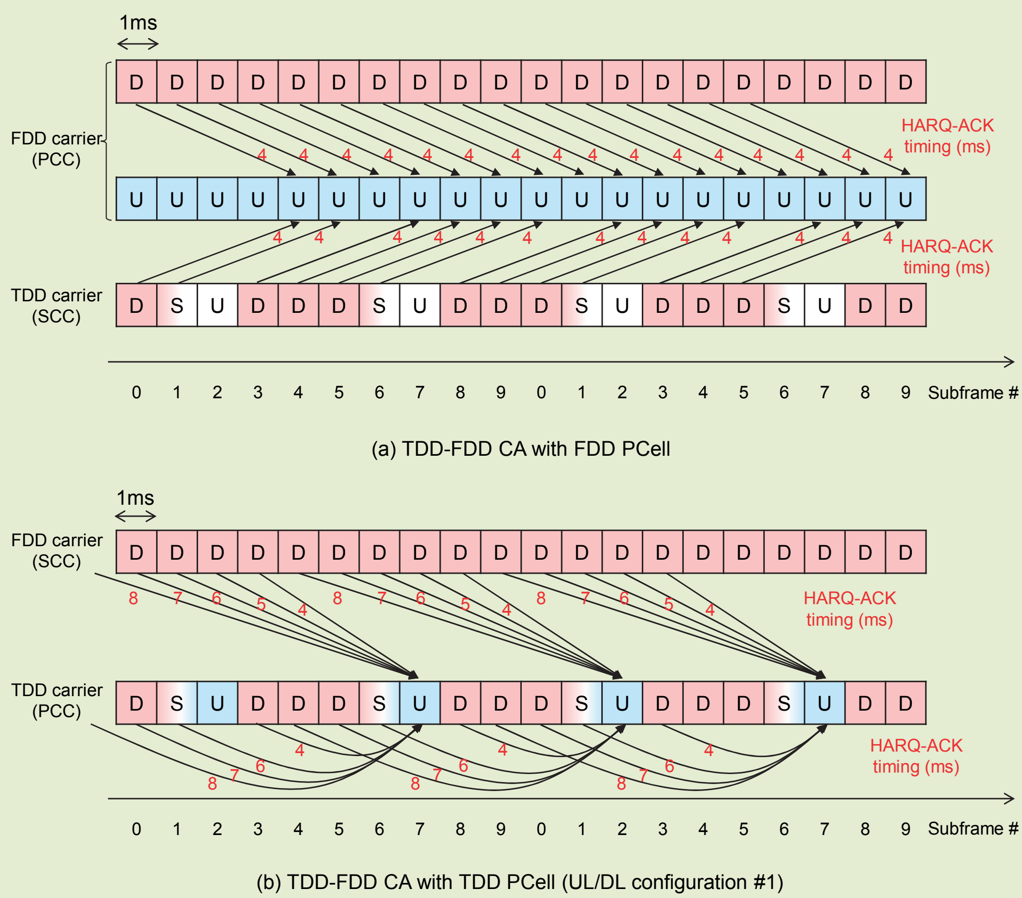

Figure 3　DL HARQ-ACK transmission timing for TDD-FDD CA

signals for FDD SCells is determined based on the UL/DL configuration of the TDD PCell. Thus, with a TDD PCell, HARQ transmission control for the TDD carrier can be applied to FDD SCells, as if the SCells were TDD carriers.

2.2 RF Requirements for CA Supporting More Carriers

As specified in the Release 10, up to five LTE CC can be aggregated in CA to realize 100 MHz bandwidth communication. However, the RF requirements for CA operation (e.g., reference sensitivity requirements, spurious emission requirements*16, etc.) are quite different and diverse depending on frequency band, number of CCs and bandwidth of CCs. For this reason, to develop UE that supports specific CA band combinations, it is first necessary to specify corresponding RF requirements in 3GPP specifications. 3GPP specifies such RF requirements according to demand from operators and in Release 10 and 11, requirements for CA band combinations consisting of two CCs were specified. In Release 12, to achieve even higher throughput using more CCs, new RF requirements for CA band combinations consisting of three CCs on the DL were specified. This will enable development of UE which can serve higher throughput thanks to a total of 60 MHz aggregated bandwidth.

Moreover, 3GPP is working to achieve such higher throughput due to CA in the UL as well. Up to Release 11, the requirements for CA band combinations consisting of only two CCs in the same frequency band had been specified. In Release 12, those for CA band combinations consisting of two different frequency bands are specified.

3. DC

As mentioned in the first article [2] of this special feature, a new technology called DC has been specified. This feature increases user throughput by aggregating multiple CCs from different eNBs connected by a backhaul*17 with non-negligible delay, considering that such backhauls can be provided with relatively lower cost and are used in many countries and regions. Compared with conventional CA, which aggregates CCs from a single eNB, the following issues had to be studied in order to aggregate carriers from different eNBs.

(1) Network architecture for aggregating carriers from different eNBs
- U-plane data routing to the different eNBs
- Termination point of Control Plane (C-plane)*18 and User Plane (U-plane)*19 protocols
- Coordination between Master eNB (MeNB) and Secondary eNB (SeNB)

(2) Physical layer functions for simultaneous connection to different eNBs
- Transmission of control signals
- Transmission power control*20 for simultaneous transmission

(3) Supporting synchronous and asynchronous networks

How each of these issues was resolved to specify DC is described below.

3.1 Network Architecture for Aggregating Carriers from Different eNBs

1) U-plane Data Routing to the Different eNBs

DC in Release 12 utilizes the radio resources*21 from two eNBs, called MeNB and SeNB. To achieve throughput comparable to that with CA, the user data from one bearer*22 needs to be transmitted from two eNBs. There are two architecture options defined in DC. In the first architecture, the MeNB acts as an anchor point for splitting user data, and the DL data delivered via an S1 interface*23 from the Serving Gateway (S-GW)*24 is transmitted on the MeNB carrier or forwarded via X2 interface*25 to the SeNB and then transmitted on the SeNB carrier (**Figure 4**(a)). The second architecture is defined for deployments emphasizing the off-loading effects rather than the throughput enhancement, which is the first architecture's main focus. In this architecture the user data from the bearer is transmitted on only the SeNB carrier (Fig. 4(b)). In this case, the DL data arrives at the SeNB directly from the S-GW without going through the MeNB. Note that for both architec-

*16 **Spurious emission requirement:** Requirement to avoid interference from unnecessary radio emissions.

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

*18 **C-plane:** The protocol used for transmitting control signals for connection establishment and other procedures.

*19 **U-plane:** The protocol used for transmitting user data.

*20 **Toransmission power control:** A technique of controlling transmission power such that the signal-to-noise ratio (SNR) and signal-to-interference and noise ratio (SINR) at the receiver exceed the required values.

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

*22 **Bearer:** A logical user-data packet transmission path established along P-GW, S-GW, eNB, and UE.

*23 **S1 Interface:** An interface connecting an MME or S-GW to eNB.

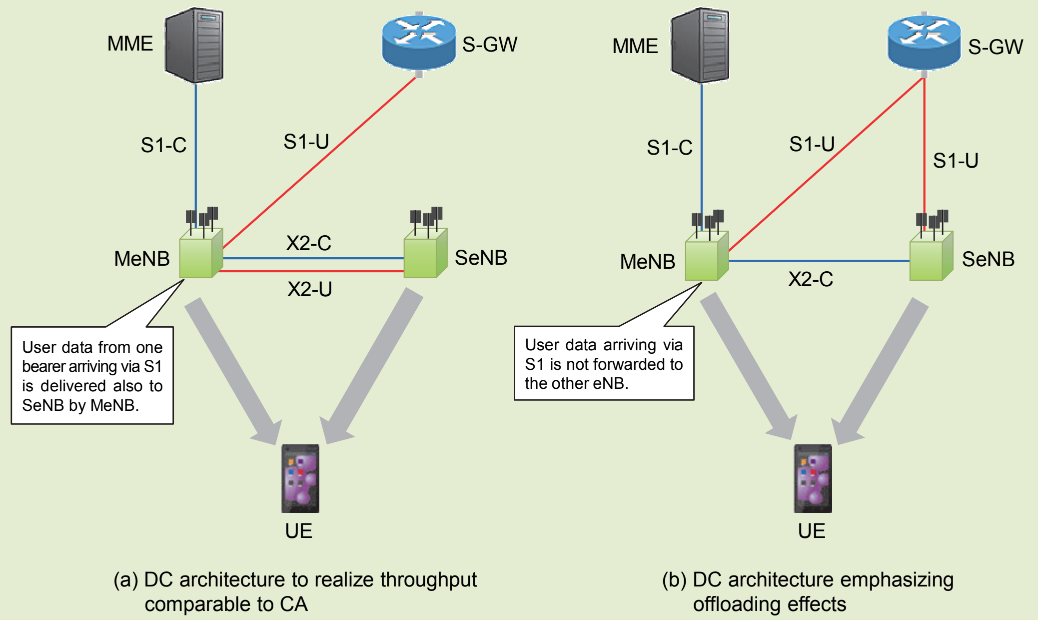

Figure 4 DC architectures

tures, only the MeNB establishes a connection with the Mobility Management Entity (MME).

In this article, we focus on the first architecture, which emphasizes user throughput enhancement. Note that in Release 12, such throughput enhancement by utilizing the radio resources of two eNBs is supported only for the DL, and for the UL, user data transmission is handled by only one of the eNBs.

2) Terminating C-plane Protocols

In LTE networks, a UE first establishes a Radio Resource Control (RRC)*26 connection with an eNB, and then uses this connection to receive radio resource configuration and measurement configuration for handover*27 from the eNB and transmit measurement reports. For DC, this conventional RRC connection concept is utilized, an RRC connection is established with the MeNB only, and the SeNB connection is controlled through the MeNB. Several procedures are specified specifically for DC, such as SeNB Addition, to configure the UE for a carrier provided by a SeNB, and SeNB Release or Change of SeNB, to remove a carrier.

With DC, it is assumed that the macro cell is covered by the MeNB and the small cells are covered by SeNBs. In such a configuration, the add-on cell concept can be applied, even when aggregating multiple CCs from different eNBs that are connected by a backhaul with non-negligible delay. Even if the user moves across multiple SeNBs, the degradation of mobility performance caused by handover can be avoided with RRC control, using SeNB Addition, SeNB Release and Change of SeNB.

3) Terminating U-plane Protocols

Conventional LTE uses a protocol stack on eNB and UE as shown in **Figure 5**, consisting of, from higher to lower, a Packet Data Convergence Protocol (PDCP)*28 layer, a Radio Link Control (RLC)*29 layer, a Medium Access Control (MAC)*30 layer and a physical layer. In contrast, with DC, since multiple eNBs communicate with the UE, the protocol stacks split below the PDCP layer in the MeNB on the network side, such that both MeNB and SeNB have their own protocol stacks that are the same as the conventional stack from the

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*24 **S-GW:** A packet switch that processes user data in an LTE network.

*25 **X2 Interface:** An interface for connecting between eNBs.

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

*27 **Handover:** The technique of switching from one base station to another without interrupting communication when a terminal moves between base stations.

*28 **PDCP:** One of the sublayers in Layer 2 of the radio interface in LTE that provides protocols for ciphering, integrity protection, header compression and the like.

*29 **RLC:** One of the sublayers in Layer 2 of the radio interface in LTE that provides protocols for retransmission control, duplicate detection, reordering and the like.

*30 **MAC:** One of the sublayers of layer 2 of the radio interface in LTE, providing protocols for radio resource allocation, mapping data to TBs, and performing HARQ retransmission control.

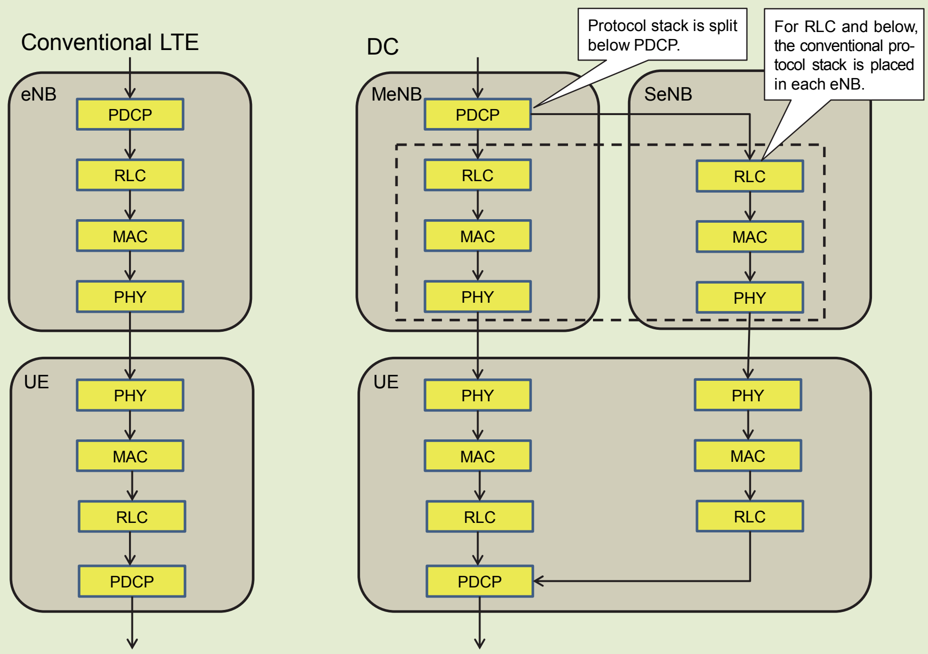

Figure 5 Protocol stacks for conventional LTE and DC

RLC layer down. The UE side has the corresponding protocol layers.

4) Coordination Between MeNB and SeNB

When splitting the data as described in 1), the MeNB needs to split the user data appropriately between its own carrier and the SeNB carrier. A flow control function is defined for this purpose, enabling the SeNB to feedback acknowledgement of data transmitted from the SeNB to the UE and to notify the MeNB of available buffer size in the SeNB.

Also, to enable configuration of radio resources for the UE as mentioned in 2), procedures for sending information on radio resources allocated by the SeNB to the MeNB via the X2 interface are defined. The SeNB Addition procedure for DC is shown in **Figure 6**. The UE first connects to the eNB acting as the MeNB and reports to the MeNB when the quality of the cells under a neighbour eNB is good. If the reported quality satisfies a certain threshold, then the MeNB configures DC with the relevant neighbor eNB (which is refered to SeNB) with the following procedure.

(1) MeNB sends SeNB a request to configure DC (SeNB Addition Request).
(2) SeNB responds to the DC configuration request, sending MeNB a SeNB Addition Request Acknowledgement containing radio parameter information for the SeNB cell.
(3) MeNB receives the response from the SeNB and sends a radio resource configuration signal (RRC connection reconfiguration) to the UE.
(4) The UE sends the MeNB a RRC connection reconfiguration complete message, and starts the random access procedure for the SeNB. Upon the completion of the procedure, the connection with the SeNB is established.
(5) When the MeNB receives the completion message from the UE, it informs SeNB of the completion (SeNB reconfiguration complete), completing the DC configuration procedure. Thereafter, the MeNB starts forwarding DL user data arriving from the S-GW to the SeNB.

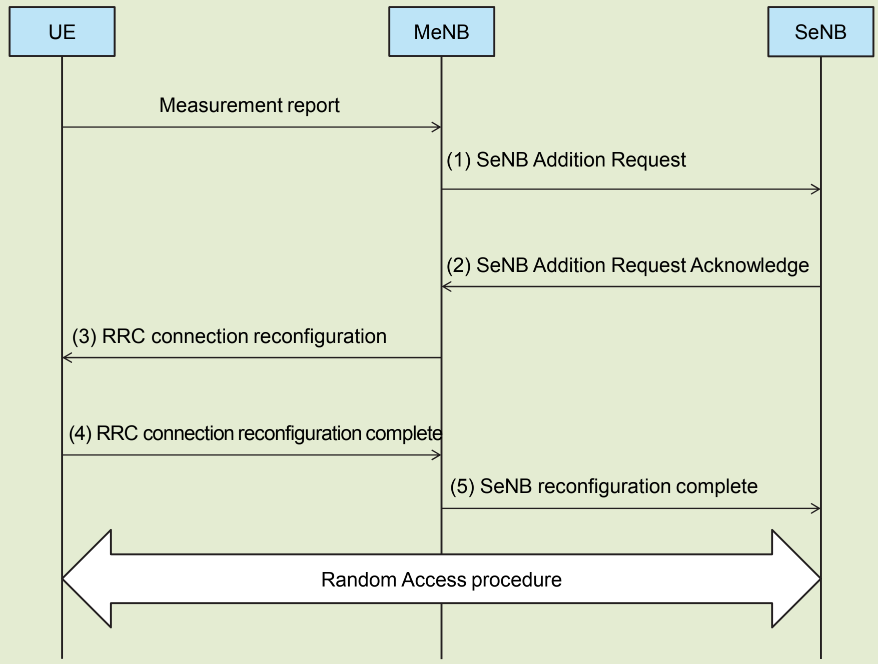

Figure 6 SeNB addition procedure

3.2 Physical Layer Mechanism for Simultaneous Connection to Different eNB

For CA, aggregated carriers are managed and scheduled by a single eNB. For this reason, information regarding each of the carriers is known in real time by that eNB. On the other hand, since carriers aggregated with DC are managed and scheduled by two eNBs that could be connected by a backhaul with non-negligible delay, it is difficult for the eNBs to share information about each carrier in real time. To solve this issue, advanced physical layer mechanisms were introduced.

1) Transmission of Control Signals

The PCell for CA supports all physical channel[*31] functions in Release 8, while SCells only support some of them. For example, PUCCH and Contention Based Random Access (CBRA) are not supported on SCells, and transmission of UL Control Information (UCI), such as HARQ feedback signals, channel quality information feedback, and UL scheduling requests to the eNB, are basically handled by the PCell.

With DC, there can be non-negligible delay between the eNBs of the aggregated carriers, making it difficult for eNBs to share information such as UCI and scheduling requests through the backhaul in real-time, so that scheduling can be carried out taking them into account. Thus, in DC, in addition to the PCell, one carrier under the SeNB is used as the Primary SCell (PSCell) supporting PUCCH transmission and CBRA, and UCI and scheduling requests for carriers under the SeNB are sent directly from the UE to the SeNB (**Figure 7**). This allows communication with multiple eNBs to be implemented without being affected by delay between the eNBs. The PSCell also provides functionality such as Radio Link Monitoring, which was only supported by the PCell earlier.

DC UEs can be configured with CA within MeNB and/or SeNB to increase throughput. In this case, the UE transmits the UCI of the carriers under the MeNB in the PUCCH of the PCell and the UCI of the carriers under an SeNB

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

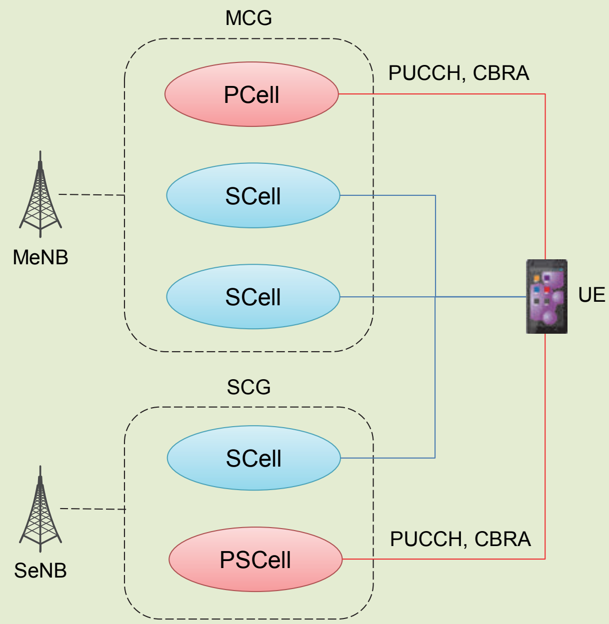

Figure 7 Cell-Groups in DC

in the PUCCH of the PSCell. In this way, each carrier configured for the UE is associated with a PCell or PSCell, forming a Cell-Group (CG). For this reason, the CG under the MeNB is called a Master Cell-Group (MCG) and a CG under an SeNB is called a Secondary Cell-Group (SCG). MAC layer and physical layer control, such as scheduling, is performed per CG.

2) Transmission Power Control for Simultaneous Transmission

Conventionally, when multiple UL carriers are configured for a UE, the eNB manages the transmission power for the UE, allocating resources of each carrier and adjusting transmission power so that the transmit power does not exceed a certain value (called maximum transmit power in this article). The transmit power can be controlled dynamically in Transmission Time Interval (TTI)*32 units. However, with DC, it is difficult for each eNB to know and control the transmission power of each carrier in real time, and it is inevitable that the total UE transmit power, the sum of UL transmit power for all the carriers over the two eNB, will at times exceed the maximum transmit power per UE. If the UE has UL transmission which will result in excessive transmission power, the UE itself reduces (scales) the power of the UL signal to keep the transmit power within the allowable range. However, if scaling of control information and other important UL signals occurs often, user throughput could be degraded. Thus, with DC, power control was introduced that guarantees a minimum transmission power for each CG, to maintain minimum UL coverage with each eNB and prevent important UL signals from being scaled. Specifically, the UE allocates certain transmission power for each CG to guarantee a minimum transmission power, according to the Maximum Guaranteed Power (MGP) configured by the eNB. If the total required transmission power of both CGs exceeds the maximum transmit power per UE, the UE allocates transmit power to the UL signals for each CG at least until the MGP value for the CG.

Since DC supports both synchronous and asynchronous operation as mentioned in section 3.3, two power control modes

*32 **TTI:** The time interval at which signals are transmitted.

were specified. With synchronous DC operation (mode 1), MCG and SCG subframe boundaries coincide closely (**Figure 8**(a)). Therefore, the UE can calculate transmission power allocated for each CG at the same time. Thus, if the maximum transmission power per UE is expected to be exceeded, the UE re-calculates the transmission power for each CG so that the transmission power not guaranteed by MGP is allocated for UL transmission based on channel type. Then, transmission power scaling is applied starting with lower priority channels as for CA. This can avoid scaling of high-priority signals, even if the power allocated is not being guaranteed by MGP.

On the other hand, with asynchronous DC operation (mode 2), MCG and SCG subframe boundaries can differ significantly (Fig. 8(b)). Therefore, the transmission power to be allocated for each CG is determined based on the transmission timing. For this reason, the transmission power not guaranteed by MGP is allocated sequentially, in the order UL transmission is performed. If the maximum transmit power is expected to be exceeded, the transmission power for the UL transmission of the CG having later transmission is restricted, regardless of the channel type. Since it is not necessary to compute the transmit power of the UL transmission between MCG and SCG having large timing difference at the same time, the UE computational complexity can be alleviated.

3.3 Supporting Synchronous and Asynchronous Networks

Since all CCs configured for CA are accommodated in the single eNB and these CCs are synchronized to each other, UE supporting conventional CA are implemented under assumption of synchronization among CCs. However, CCs accommodated in different eNB are not always synchronized even if they are on the same network. For this reason, a UE implemented assuming the CCs are synchronized may not be able to operate DC in an unsynchronized network, which will limit where DC can be deployed. Thus, to implement more flexible DC operation, in addition to DC operation assuming synchronization between eNBs, an asynchronous DC operation, which

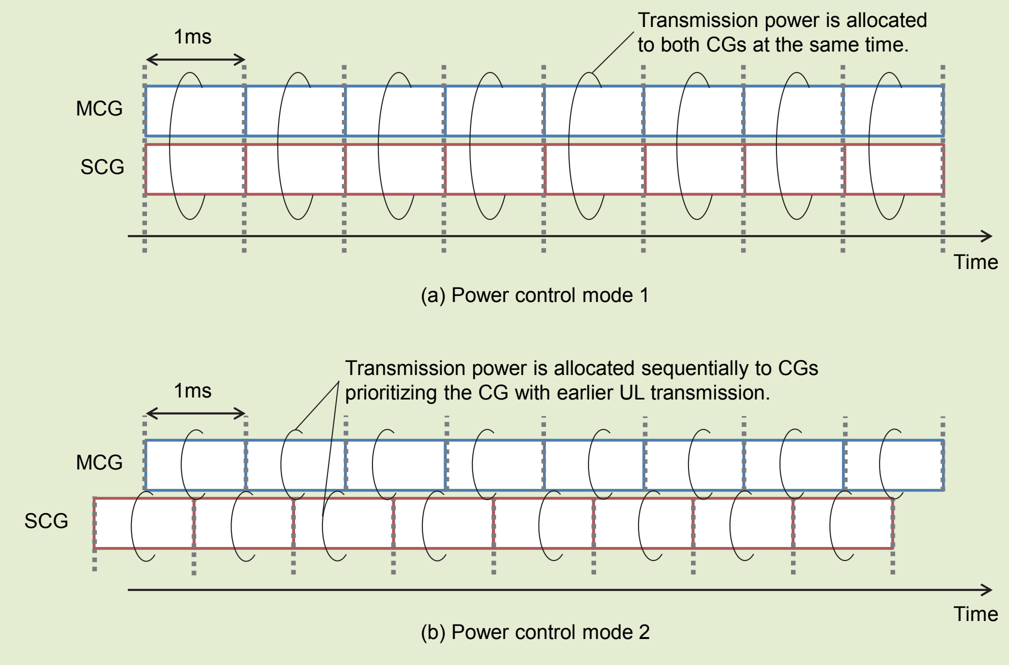

Figure 8 Power control modes for synchronous and asynchronous DC operation

does not assume synchronization between CCs, has been specified. Thus, UE supporting DC is implemented assuming these two types of operations.

For synchronous DC operation, CCs are assumed to be synchronized as those for CA. This means that although it can be operated only on synchronized networks, UE supporting DC can be implemented reusing the CA implementation. On the other hand, for asynchronous DC operation, although UEs need to be able to handle signals of different carriers arriving with a large delay, operators can apply DC without synchronization between eNBs and flexible deployment can be achieved.

4. Conclusion

In this article, we have described the functional characteristics and basic operations of TDD-FDD CA, RF requirements for CA using more CCs, as well as DC as specified in 3GPP Release 12. With these functions, higher throughput can be served in a larger expanded area by more flexible add-on cell deployment.

To further accommodate traffic as it continues to increase, in Release 13 we are studying further enhancement of CA utilizing bandwidths exceeding 100 MHz and enhancement of DC which increases user throughput in the UL as well.

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Further Development of LTE-Advanced—Release12 Standardization Trends—

Higher Order Modulation, Small Cell Discovery and Interference Cancellation Technologies in LTE-Advanced Release 12

In order to handle the rapid traffic increase in recent years, there have been a lot of studies on technologies to increase the network capacity by using small cells with low transmission power. However, when small cells are deployed with high density, interference from the neighboring cells increases dramatically and it becomes difficult to obtain the desired improvement in capacity. In this article, we describe related new technologies introduced in LTE Release 12, including higher order modulation, small cell discovery, and techniques to suppress and cancel interference from the neighboring cells.

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1. Introduction

Recently, with the spread of smartphones and tablets as well as the expansion of high-resolution video services and video telephony, mobile data traffic has been increasing radically. In order to deal with this increase, there has been intensive study of technologies that improve network capacity by increasing cell density, and particularly the number of small cells[*1] with low transmission power. Small cell environments have different characteristics from conventional macro cell[*2] environments: fewer users per cell, extremely good radio quality due to receiving signals directly from nearby base stations (called line-of-sight environments), and ability to accommodate users with low mobility only. As cell density is increased to further boost network capacity, the amount of interference from neighboring cells rises as well. Thus, it has become more difficult to achieve the desired capacity. Another issue is in the spatial domain, where Multiple-Input Multiple-Output (MIMO)[*3] with spatial multiplexing is being used to achieve high-speed transmission. However, this can result in interference between trans-

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

*2 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

mission streams within the cell. Considering the interference situations above, methods to reduce interference between individual small cells, between small cells and macro cells, and also within macro cells are being studied.

In this article, we describe new technologies introduced in the 3GPP LTE Release 12 specifications (hereinafter referred to as "Rel. 12"), including higher order modulation, small cell discovery, and inter-cell interference suppression.

2. SCE Technologies

2.1 SCE Scenarios

LTE Advanced Rel. 12 specifies requirements for small cells [1], and a basic Study Item (SI) regarding Small Cell Enhancements (SCE) was initiated in January 2013, in Radio Access Network (RAN)*4 Working Group 1 (WG1). During the SI phase, discussions were held and consensus was reached among operators regarding hypothetical scenarios for the evaluation of SCE, and as a result a co-signed document was successfully submitted [2]. According to this document, the following four scenarios were agreed upon:

(1) Scenario #1 (same frequency/outdoor environment)
- Small cells are deployed on top of an overlaid macro cell
- Outdoors
- Use the same carrier frequency as the macro cell

(2) Scenario #2a (different frequency/outdoor environment)
- Small cells are deployed on top of an overlaid macro cell
- Outdoors
- Use a different carrier frequency from the macro cell

(3) Scenario #2b (different frequency/indoor environment)
- Small cells are deployed on top of an overlaid macro cell
- Indoors
- Use a different carrier frequency from the macro cell

(4) Scenario #3 (isolated cell environment/indoor environment)
- No overlaid macro cell
- Indoors

Technologies for small cells in the above identified evaluation scenarios were proposed by various operators and vendors. Meanwhile, simulations for evaluation were also conducted on specific techniques such as higher order modulation and suppression of interference between small cells. The results of these evaluations were summarized in a technical report [3], recognizing their effects on increasing peak data rate and capacity in the small cell scenarios. In the Work Item (WI) phase, in which the specifications of LTE Advanced Rel.12 were completed, the aforementioned simulation results led to and helped in specifying the techniques of 256 Quadrature Amplitude Modulation (QAM)*5, small cell on/off control, and small cell discovery.

2.2 Advanced Modulation Schemes

In Rel. 8 to 11 specifications, Quadrature Phase Shift Keying (QPSK)*6, 16QAM, and 64QAM were supported as modulation schemes. Modulation schemes with larger modulation multiplicity*7 (number of bits that can be sent with one symbol*8), can be used under conditions with higher received Signal to Interference and Noise Ratio (SINR)*9. The received SINR is high for indoor environments and outdoor environments with Line-Of-Sight (LOS) conditions, so modulation schemes with high multiplicity are more likely to be usable than in conventional macro cell environments. Thus, a new modulation scheme that is able to send up to 8 bits per symbol, called 256QAM, was introduced in Rel. 12 to increase the downlink peak data rate. Specifically, the base station decides on a Modulation and Coding Scheme (MCS)*10, which is a combination of a modulation scheme and an error correction coding scheme*11, based on the Channel Quality Indicator (CQI)*12 received from the UE, which is related to the value of SINR. In order to avoid increases in the amount of uplink CQI feedback as well as the amount of downlink control information on the MCS due

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

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

*5 **QAM:** A type of digital modulation in which carrier amplitude and phase correspond to a bit array. There are various types, according to the number of patterns defined, such as 16QAM and 64QAM.

*6 **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.

*7 **Modulation multiplicity:** The number of signal phase points in data modulation. For example, four with QPSK, and 16 with 16QAM.

*8 **Symbol:** A unit of data for transmission. In OFDM, it comprises multiple subcarriers.

*9 **Received SINR:** The ratio of desired-signal power to the sum of all other interference-signal power and noise power.

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

to the introduction of 256QAM, some of the existing CQI and MCS values were replaced by new CQI and MCS values for 256QAM, as shown in **Figure 1**. As a result, both the conventional CQI/MCS tables without 256QAM values and the new CQI/MCS tables with 256QAM values are supported in Rel.12. Higher layer signaling is used to switch between the conventional tables and the new tables. For example, if the results of User Equipment (UE) reception quality measurements are better than pre-determined threshold values, the CQI and MCS tables including 256QAM values are used. In indoor and LOS environments with good quality reception, for instance, 256QAM can be used to achieve higher downlink peak throughput [4].

2.3 Small Cell ON/OFF Switching and Discovery Technologies

1) Issues

For SCE in Rel. 12, it is assumed that small cells are deployed in scenarios with much higher density than the Heterogeneous Networks (HetNets)[*13] in Rel. 10 and 11. Correpondingly, technologies to facilitate efficient operation of such high-density small cells were studied. In high-density small cell environments, each cell has a smaller coverage area than in conventional macro cell environments. Therefore, traffic tends to concentrate in only some of the small cells in certain areas at times, as shown in **Figure 2**. Even through some small cells have no traffic, control information such as the Synchronization Signal (SS) and Cell-specific Reference Signal (CRS)[*14] continue to be sent in these conditions, to ensure UEs can discover the cells and perform measurement on the channel quality at any time. In particular, the CRS sent in each subframe can result in significant interference to downlink transmission in neighboring cells. The interference due to CRS transmission will continuously increase with the density of the small cells, and will contradict the original intention of introducing more

Table switched according to upper-layer signaling

Existing CQI table

CQI index	Modulation format	Coding rate (×1024)	Frequency utilization (bps/Hz)
0	Out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

CQI table specified in Rel. 12

CQI index	Modulation format	Coding rate (×1024)	Frequency utilization (bps/Hz)
0	Out of range		
1	QPSK	78	0.1523
2	QPSK	193	0.3770
3	QPSK	449	0.8770
4	16QAM	378	1.4766
5	16QAM	490	1.9141
6	16QAM	616	2.4063
7	64QAM	466	2.7305
8	64QAM	567	3.3223
9	64QAM	666	3.9023
10	64QAM	772	4.5234
11	64QAM	873	5.1152
12	256QAM	711	5.5547
13	256QAM	797	6.2266
14	256QAM	885	6.9141
15	256QAM	948	7.4063

Figure 1 Change of CQI tables when introducing 256QAM

*11 **Coding scheme:** 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.

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

*13 **HetNet:** A network deployment that overlays nodes of different power. It typically mixes-in, links and integrates base stations of lower transmission power than conventional base stations.

*14 **CRS:** A reference signal specific to each cell for measuring received quality in the downlink.

small cells, i.e. to increase the system capacity.

2) Small Cell ON/OFF Switching and Discovery Technologies

In order to solve this issue, Rel. 12 SCE specifies a small-cell ON/OFF switching technology [5]. As shown in **Figure 3**, a small cell stops transmitting reference signals when it has no traffic (OFF state) to decrease interference to neighboring cells that are transmitting data to UEs, thereby improving the throughput. However, if the transmission of SS and CRS stops completely when a small cell is in the OFF state, UEs will not be able to detect the OFF state cell and make measurements on the channel quality by using the legacy cell detection procedure. Therefore, the cell cannot quickly return to the ON state and establish communication with an active UE when UE approaches the OFF state cell and cannot detect and measure the cell. Consequently, a long transition time before communication can start will be required. In order to enable ON/OFF small cells to be detected efficiently, a small cell discovery technology that uses a new cell discovery signal was also specified. An overview of small cell ON/OFF switching using the discovery signal is shown in **Figure 4**.

Small cells with ON/OFF switching transmit a discovery signal periodically at intervals of 40 ms or greater. The discovery signal is sent even if a cell is OFF, to ensure that a UE approaching the cell in the OFF state can detect the cell and report it to the network. After receiv-

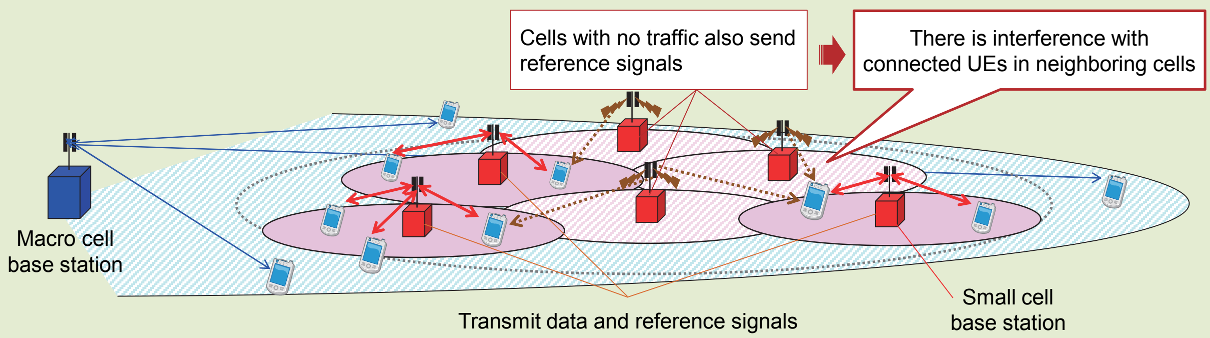

Figure 2 Traffic tendencies in dense small-cell environments

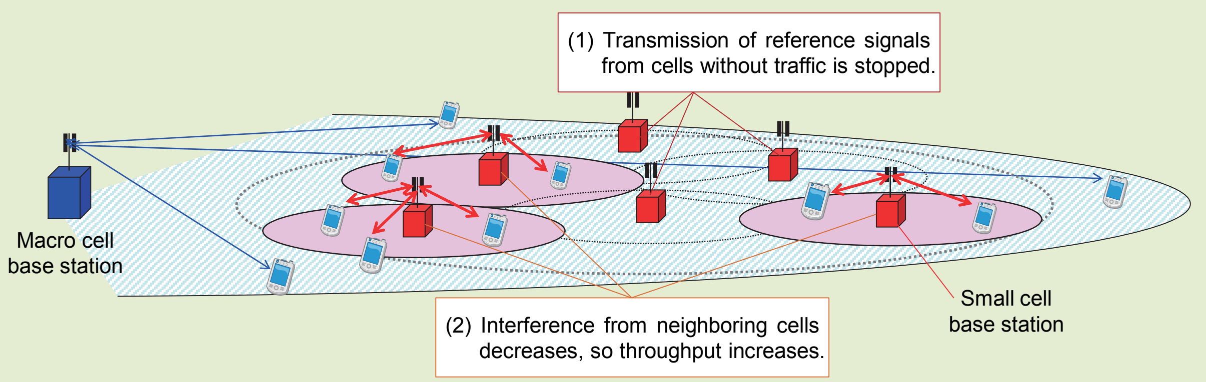

Figure 3 Small cell ON/OFF

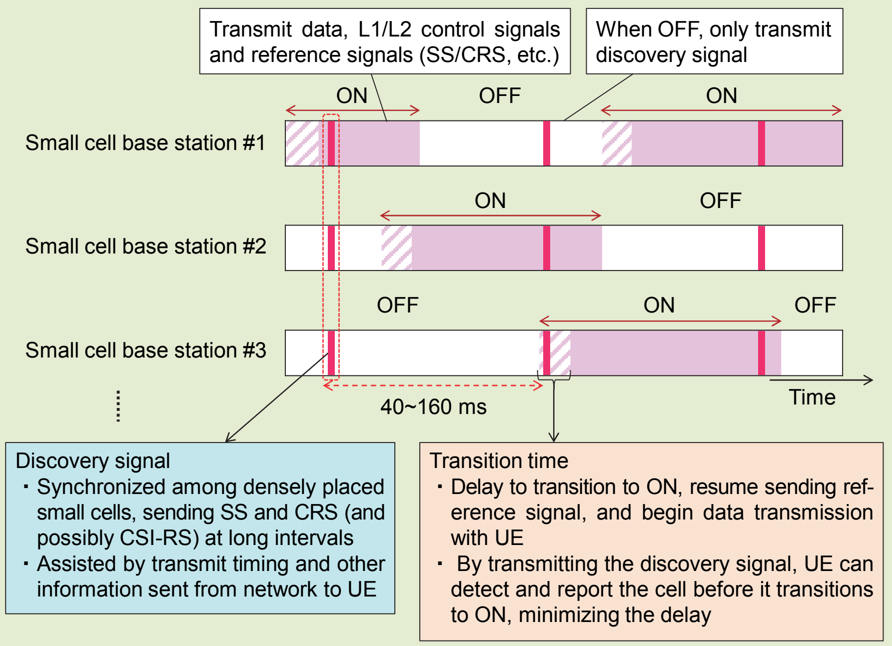

Figure 4 Small cell ON/OFF using a discovery signal

ing the report, the cell can transit to the ON state at an appropriate time, to minimize the transition time before starting communication with the UE. Compared to small cells without ON/OFF switching and discovery signals (i.e., using legacy CRS in every subframe), cells sending discovery signals at long intervals in the OFF state cause much less interference to neighboring cells.

The discovery signal is composed of SS and CRS which are synchronized with neighboring small cells and sent at long intervals. The UEs are notified by their connected cells (e.g., the macro cell) with assistance information consisting of transmission interval and starting time of the discovery signal. This information helps UEs to receive discovery signals from multiple surrounding small cells simultaneously without significant power consumption or loading. The Channel State Information-Reference Signal (CSI-RS)*15 can also be included in the discovery signal with long-interval transmission in addition to the SS and CRS to support efficient shared-cell-ID operation (i.e., the same cell ID*16 for multiple small cells). With this design of discovery signal, the same SS and CRS are used among small cells with the same cell ID, which is correlated to the transmission resources of the CRS. Therefore, there is no resource collision between the CRS of specific small cells and the data signals in neighboring cells, so CRS interference can be avoided. Meanwhile, UEs do not need to detect and measure each small cell based on the SS and CRS, since they can identify individual small cells and make corresponding measurements based on the CSI-RS in the discovery signal [6].

3. Interference Cancellation Technologies for Mobile Terminals

As shown in **Figure 5**, the interference between macro cells has increased due to denser deployment. Moreover, in SCE scenario #1 as explained in Section

*15 **CSI-RS:** A reference signal transmitted from each antenna to measure the state of the radio channel.

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

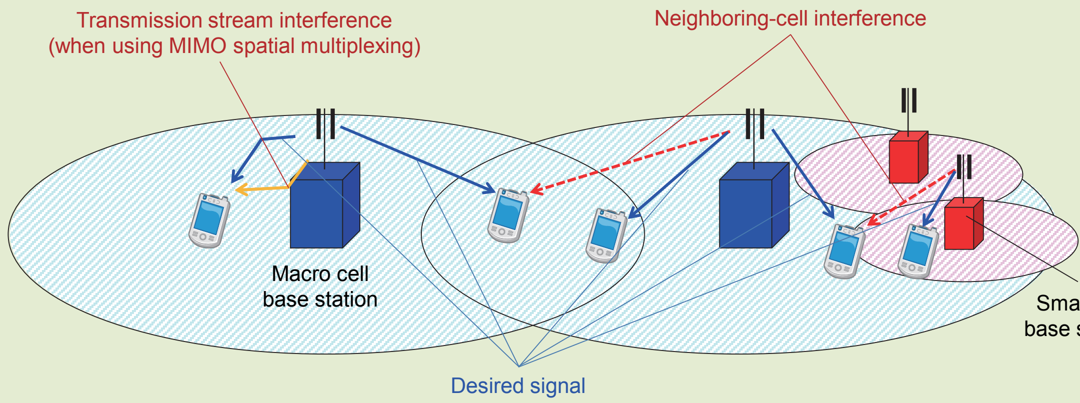

Figure 5　Interference from neighboring cells and transmission streams

2.1, interference between macro cells and small cells is also expected to become more serious. Although interference from neighboring cells is smaller for UEs near the connected base station, as also shown in Fig. 5, interference between transmission streams will still be an issue, assuming MIMO spatial multiplexing is applied to improve throughput.

In Rel. 12, both Network Assisted Interference Cancellation and Suppression (NAICS) and Single User-MIMO (SU-MIMO) receivers were studied to reduce the interference from neighboring cells and between transmission streams in the receiver as described above.

3.1 NAICS Receiver Reducing Neighboring-cell Interference

1) Conventional MMSE/MMSE-IRC Receivers

In the Rel. 8 specifications, UE performance requirements were specified assuming a Minimum Mean Squared Error (MMSE)*17 receiver. But the standard MMSE receiver cannot suppress interference signals from neighboring cells because they are generally assumed to be equivalent to white Gaussian noise in the reception process of the MMSE receiver. Consequently, the UE throughput could be limited due to inter-cell interference, especially in areas with high interference, such as at cell edges. In order to reduce this interference, the MMSE Interference Rejection Combining (IRC)*18 receiver was studied [7], and UE performance requirements based on this MMSE-IRC receiver were specified [8] in the Rel. 11 specifications. The MMSE-IRC receiver uses multiple receiving antennas to suppress interference signals by creating antenna gain*19 and null*20 points in their arrival direction. By using this receiver, UE throughput could be improved especially near cell edges [9]. Another benefit is that the MMSE-IRC receiver can be used on Rel. 8 LTE based systems, so the interference suppression capability can be obtained on Rel. 8 LTE networks that have already begun commercial services.

2) NAICS Receiver Features

In the Rel.12 specification, more advanced interference cancellation technologies were studied for NAICS receivers, to further improve cell edge UE throughput. Specifically, application of Successive Interference Cancellation (SIC)*21 [10] and Maximum Likelihood Detection (MLD)*22 [11] were investigated, which are reception technologies that generally promise much better interference cancelling effect than MMSE-IRC receivers. However, in order to apply these reception technologies, the interference signal must be demodulated to the transmission symbol level on the UE side. For example, SIC is able to

*17 **MMSE:** A method for demodulating a signal that minimizes mean square error.

*18 **IRC:** A method for rejecting an interference signal by creating an antenna-gain drop point with respect to the arrival direction of that signal.

*19 **Antenna gain:** The power emitted by an antenna relative to an ideal antenna.

*20 **Null:** A direction in the beam pattern for which the antenna gain is very small.

*21 **SIC:** A MIMO signal separation method in which multiple signals combined in a received signal are successively detected and cancelled out of the signal one at a time. It usually yields better performance than Zero Forcing (ZF) or Minimum Mean Square Error (MMSE).

*22 **MLD:** A method for separating MIMO multiplexed signals by comparing all sequences of received signals with those that could possibly be received and finding the combination nearest the received pattern.

cancel the interference signal effectively by subtracting a replica of the interference, which is generated from the received signal by demodulating the interference in symbol level and using an estimated channel matrix*23. However, base stations under Rel. 8 to 11 specifications do not provide signaling*24 containing control information from neighboring cells, which is needed to demodulate the interference signals. Therefore, it is difficult to perform the interference subtraction process as described above. Accordingly, the NAICS technology supports a new function which provides signaling from the connected base station to the UE with control information for neighboring cells, so they can demodulate the interfering signals to the transmit symbol level*25 [12]. In order to reduce signaling overhead, only some of the control information from neighboring cells needs to be sent (physical cell ID, CRS data, etc.), and any other remaining information is blindly estimated by the UE itself. Thus, the control information obtained through both signaling and blind estimation can be used to when applying SIC or MLD to the interference signal. As a result, interference signals from neighboring cells can be greatly reduced.

3) Throughput Improvement due to NAICS Receiver

Results of throughput improvement by using the NAICS technique are shown in **Figure 6**. Here, we simulated a case with a macro cell and two neighboring cells with sufficiently large Interference-to-Noise power Ratio (INR). For the desired signal, MIMO transmission diversity*26 was applied assuming the UE near the cell edge and the MCS scheme was QPSK (coding ratio of 1/3). MIMO spatial multiplexing and 64QAM was assumed for the interference signal. The results showed that, compared to the existing MMSE-IRC receiver, the NAICS receiver can achieve approximately 1.0 dB improvement in the reception SINR required to achieve 70% of the maximum throughput (approx. 10% on the throughput characteristic).

3.2 SU-MIMO Receiver Reducing Interference Between Transmission Streams

1) Features of Conventional MMSE/SU-MIMO Receiver

In the Rel. 8 specifications, UE performance requirements for MIMO spatial multiplexing were specified assuming the MMSE receiver. As mentioned in section 3.1, the MMSE receiver is unable to suppress interference from neighboring cells. However, when MIMO spatial multiplexing is applied, the MMSE receiver is able to suppress interference between transmission streams by using multiple receiver antennas.

For the SU-MIMO receiver in the Rel. 12 specification, advanced reception processing to further reduce the aforementioned interference between transmission streams was studied, to yield improvements in throughput for the UEs near the base station. Specifically, UE performance requirements were specified, assuming that the inter-stream interference when assuming MIMO spatial multiplexing would be cancelled using MLD [8]. It is noted that, similar to the MMSE-IRC receiver, if the network is based on Rel. 8, the SU-MIMO receiver can be used without any particular configuration on base stations. Moreover, different from the NAICS receiver, the SU-MIMO receiver does not require any new signaling to be specified, so the interference cancellation capability can be obtained on Rel. 8 LTE based networks.

2) Throughput Improvements due to SU-MIMO Receivers

Throughput improvements due to the SU-MIMO receiver are shown in **Figure 7**. Here, MIMO spatial multiplexing was applied assuming the UE was near the connected base station, and 16QAM (coding rate 1/2) was assumed for the MCS scheme for the desired signal. All interference from neighboring cells was also assumed to be equivalent to white Gaussian noise in this evaluation. It is shown that, the SU-MIMO receiver can improve SINR by approximately 1.7 dB (approximately a 30% improvement in throughput characteristic) compared to the existing MMSE

*23 **Channel matrix:** A matrix composed of the changes in amplitude and phase on the channels between each transmit and receive antenna pair.

*24 **Signaling:** The sharing of information necessary for communication between base station and mobile terminals before such communication can begin (e.g. frequency band, coding and modulation formats, etc.).

*25 **Transmit symbol level:** A digitally modulated signal (symbol). Here, this refers to decoding a received signal to a digitally modulated signal.

*26 **Transmission diversity:** Technology which utilizes the differences in channel fluctuation between transmission antenna channels to obtain diversity gain.

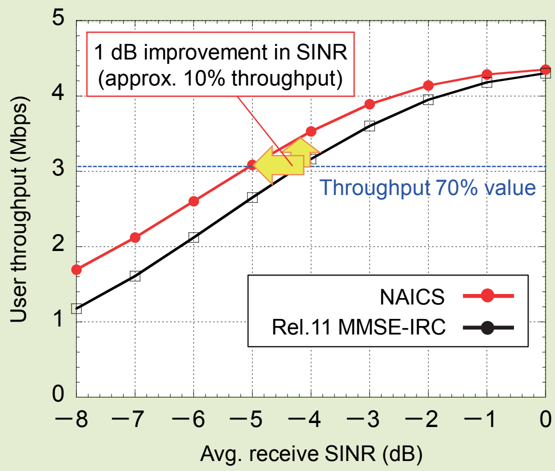

Figure 6 Throughput improvement using a NAICS receiver

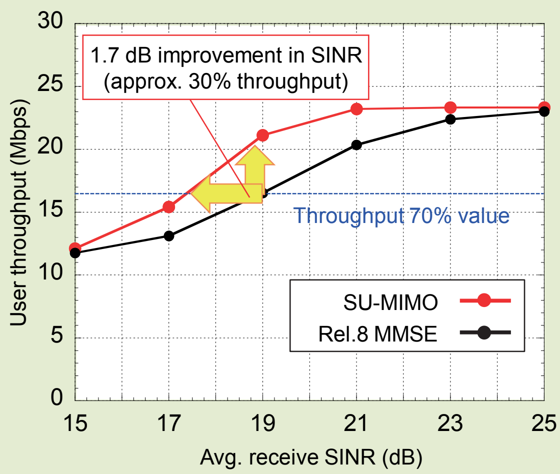

Figure 7 Throughput improvement using a SU-MIMO receiver

receiver.

4. Conclusion

In this article, we have described technologies introduced in the LTE-Advanced Rel. 12 specification to increase user throughput*27 and network capacity, including higher order modulation, small cell detection, and suppression of interference between cells. In order to handle future increases in mobile traffic, we will continue standardizing radio interface technologies to increase user throughput and system capacity.

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*27 **User throughput:** The amount of data that one user can transmit without error per unit time.

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D2D | Direct Communication | Device Discovery

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

D2D Communications in LTE-Advanced Release 12

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Public safety radio systems are communications methods used during emergencies. Currently, LTE-based public safety radio systems are being considered to reduce network deployment and operational costs, and to convert these radio systems to support broadband. For this reason, Direct communication functions that bypass eNB were introduced in 3GPP Release 12 LTE for public safety radio systems so that communications can be provided even if an eNB is down due to a situation such as a large-scale disaster. Also, Device discovery functions that enable commercial D2D for functions such as distributing information to terminals in proximity were also introduced. This article describes the D2D Direct communication and Device discovery functions in Release 12 LTE.

1. Introduction

Public safety radio systems are communication methods used in emergency situations. Currently, LTE-based public safety radio systems are being considered to reduce network deployment and operational costs, and to provide broadband communications with these systems. Public safety radio systems should ideally be able to provide communications when an eNodeB (eNB)*1 isn't operational due to a situation such as a large-scale disaster, or in areas outside of eNB coverage such as mountainous regions. Therefore, since the United States government and other administrations have demanded that "Device to Device (D2D)" direct communications be supported in LTE, the 3rd Generation Partnership Project (3GPP) has designed specifications for D2D communications functions that bypass core networks*2 [1]-[3]. Also, because commercial D2D usage is also under consideration to provide "Device to Device Proximity Services (ProSe)" to terminals in proximity, specifications were designed for technologies for Device discovery between terminals in proximity. Thus, as shown in **Figure 1**, D2D communications in LTE consist of two functions: Direct communication and Device discovery.

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

*2 **Core network:** A network consisting of switching equipment and subscriber information management equipment etc. A mobile terminal communicates with the core network via a radio access network.

D2D communications in LTE are assumed to include two scenarios, the first being autonomous D2D communications outside eNB coverage areas, and the second being D2D communications with eNB assistance in eNB coverage areas. In the latter scenario, eNB assistance enables more efficient communications [4]. However, even if eNB assistance is available, in D2D communications data is transmitted and received directly between terminals without going through the core network. Furthermore, for effective frequency use and to minimize additional implementation required for existing terminals, D2D communications in LTE will use a subset of uplink radio resources*3. Therefore, co-existing while protecting the uplink is one of the major challenges for D2D communications in LTE with frequency sharing between D2D and the cellular uplink.

This article describes the functions introduced in 3GPP LTE Release 12 for D2D communications that bypass the core network.

2. Background of D2D Communications

2.1 Public Safety LTE

Currently, there are various communication methods for public safety communication systems in use around the world, such as Project25 (e.g. North America, Australia) and TETRA (e.g. Europe). Many countries have systems deployed independently by their organizations (e.g. fire and police services), which means there are challenges for network deployment, reducing network operating costs and improving interoperability between government agencies and their emergency services. Thus, many countries (e.g. The U.S., U.K. and Korea) are considering switching existing public safety network to LTE since it offers the following advantages:

- Lower network and terminal costs with the LTE economy of scale
- Lower costs through sharing of commercial LTE network facilities
- Interoperability ensured by standardized specifications
- Broadband communications

In 2012, in response to the September 11 terrorist attacks, the United States made a decision to build a nation-wide LTE-based public safety network (FirstNet) to enable communications between responders and first responders during emergencies such as terror incidents or natural disasters, and then in 2013 the US Department of Commerce presented use cases and requirements etc. to 3GPP [5] [6]. These requirements include support for Direct communications outside network coverage areas, group call and Push To Talk (PTT)*4, which are being

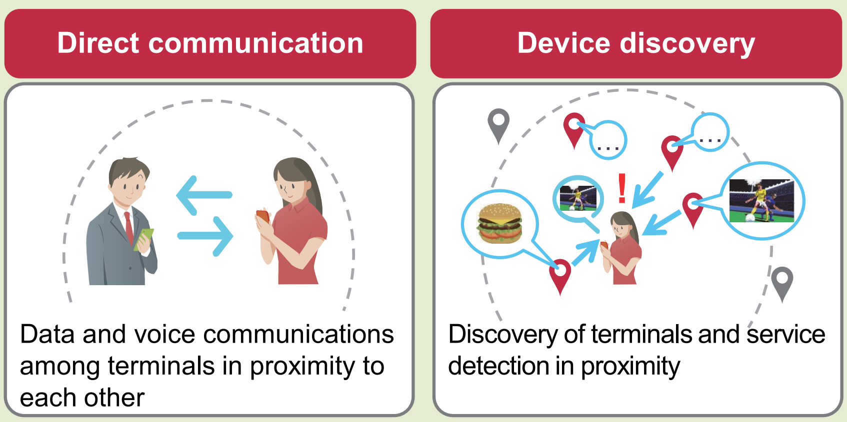

Figure 1 Direct communication and Device discovery

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

*4 **PTT:** A half-duplex voice communications method in which only one party can transmit at one time. A communications method that enables group communications and that is generally used with transceivers.

standardized by 3GPP. As described above, it is expected that in many cases D2D communications, especially Direct communication will be used in addition to cellular communications in public safety LTE systems.

Frequency spectra for the public safety LTE systems are being discussed by the International Telecommunication Union-Radiocommunication sector (ITU-R) *5 as broadband public safety and Public Protection and Disaster Relief (PPDR). The 700 MHz frequency band with Frequency Division Duplex (FDD)*6 is planned for use in both the U.S. and Korea.

2.2 Commercial D2D

D2D communications for commercial purposes that have been attracting attention in recent years include various Device discovery and communications functions such as the Bluetooth® Low Energy*7 (BLE)-enabled iBeacon®*8 and Wi-Fi Aware™*9—functions that support beacon (ID data transmitted over the air) transmission for discovering devices in the vicinity. Generally, this type of Device discovery entails user ID and the ID associated with user interest information embedded in the beacon to enable various services. For example, this technology could be applied to the sharing economy*10 gaining attention in recent years to achieve services to share and exchange services, products or monetary funds based on the location of the user or their interests. These systems could also enable services such as local advertising distribution to terminals in the area, local guidance for tourists and remote pet monitoring.

These LTE-based Direct Discovery services can provide stable communications in a wide range of communications areas as well as telecommunication carrier-grade security (e.g. countermeasures for spoofing attacks).

3. Network Architecture

3.1 Overview

Figure 2 shows an example of LTE D2D architecture [7]. A terminal in the coverage area (User Equipment (UE)) interacts with ProSe Function [8], which is a logical function in Evolved Packet Core (EPC)*11 for D2D. ProSe Function authenticates the terminal using Home

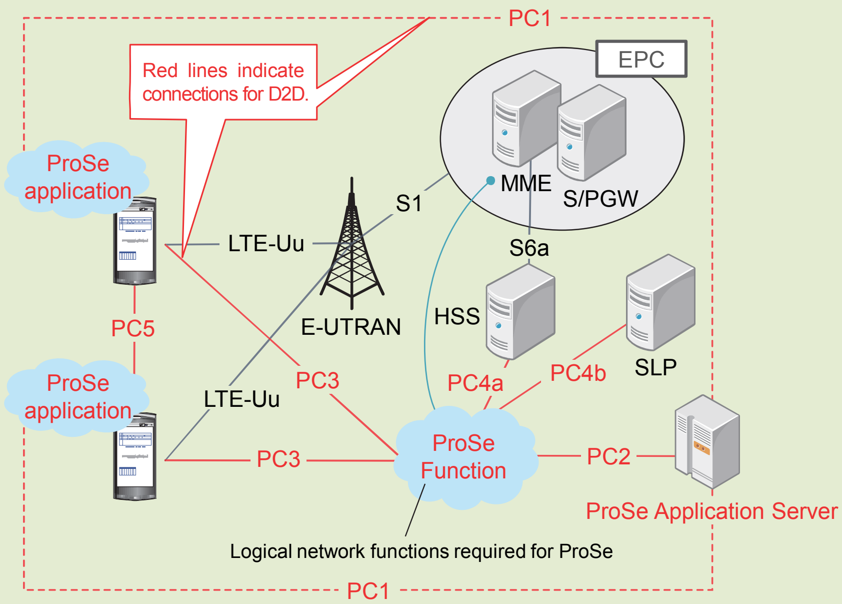

Figure 2 LTE D2D Architecture

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*5 **ITU-R:** A department of ITU, an organization that specializes in the field of telecommunications. It manages and coordinates international matters related to radio communication, such as radio regulations and spectrum use in various countries.

*6 **FDD:** A method for implementing simultaneous transmission and reception with radio communications etc, in which transmission and reception are done using different frequencies.

*7 **BLE:** An extension function of Bluetooth®, and a standard defined for low powered devices as part of the Bluetooth 4.0 standard. Bluetooth is a short-range wireless communication specification for radio connection of mobile terminals, and is a registered trademark of Bluetooth SIB Inc. in the United States.

*8 **iBeacon®:** A short-range BLE wireless communication technology developed by Apple. The transmitter (the beacon terminal) broadcasts a unique ID, and the beacon ID is utilized for short data distribution and positioning by estimating distance between terminals based on signal strength. A registered trademark of Apple. Inc.

*9 **Wi-Fi Aware™:** A standard for detecting terminals in the vicinity using Wi-Fi. The Wi-Fi Alliance industry association set down this specification and published a draft specification in March 2015.

Subscriber Server (HSS)*12, while SLP (Secure User Plane Location (SUPL) Location Platform)*13 is used to distribute suitable communications settings according to the terminal location.

The ProSe Function enables configurations necessary for communications outside coverage areas. Settings for communications outside coverage areas are associated with the region, which prohibits transmission (and reception) in areas where regulation does not permit it. Also, by managing security keys with the network, high levels of security required for services such as group calling can be ensured [9]. Apart from this configuration via the network, there are also methods to pre-configure settings in terminals or Subscriber Identity Module (SIM)*14 cards.

In coverage areas, in addition to the configurations transferred from the ProSe Function, D2D radio parameters are indicated from eNB. Furthermore, EPC ProSe user IDs and ProSe Function IDs are stored in the ProSe Application Server which also associates the user ID in the application layer with the EPC ProSe user ID [10].

Terminals are enabled for Direct communication and Device discovery after setting these out-of-coverage parameters or configuration from eNB in coverage areas. However, Device discovery outside coverage areas is not supported in Release 12 although discussions of it are ongoing for Release 13.

3.2 Network Processing Example for Device Discovery

As shown in **Figure 3**, when the sending user registers the user ID or interest information (ProSe Application ID) and metadata such as telephone numbers and URLs in ProSe Function (fig. 3 A (1)), a 184 bit ID (ProSe Application Code) embedded in the actual transmitted beacon (called the LTE Discovery Message) is assigned (fig. 3 A (2)). Then, a reception filter for interest information registered at the receiver side (fig. 3 B (1)) is assigned (fig. 3 B (2)). The ProSe Application Code assigned to the sending user is notified to the other terminal (fig. 3 A (3), B (3)), and the results of matching to the reception filter of the receiving user's ProSe Application Code is reported to ProSe Function (fig. 3 B (4)), which enables the metadata registered by the sending terminal to be acquired via the ProSe Function (fig. 3 B (5)). Additionally, ProSe Application Code assigns namespace (an area availa-

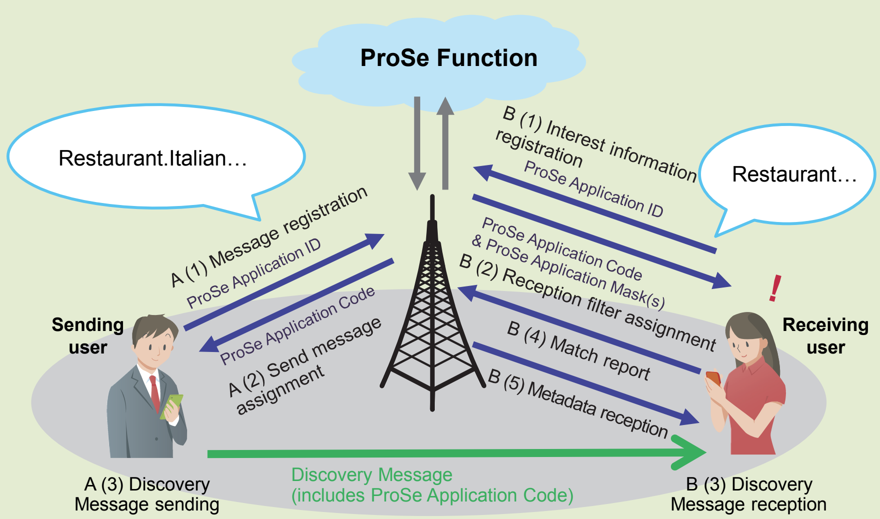

Figure 3 Network role in Device Discovery

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*10 **Sharing economy:** An economy created by sharing or exchanging goods and services or by money lending. In a narrow sense, the sharing economy usually entails individuals offering their unused products or assets, or their services to others.

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

*12 **HSS:** A subscriber information database in a 3GPP mobile communication network that manages authentication information and network visiting information.

*13 **SLP:** A location information server in SUPL, which is a method of measuring location that entails sending and receiving location information between terminals and a server.

*14 **SIM:** An IC card which stores mobile phone subscriber information.

ble for a bit string) to each operator (a Public Land Mobile Network (PLMN)*15), which prevents ID conflicts on shared networks or with inter-operator Device discovery.

3.3 EPC Level Discovery

Apart from Device discovery that directly sends radio signals from UE, there are also provisions for EPC Level Discovery that notifies terminals about other terminals detected in the vicinity based on user interest information and UE location information registered by terminals in ProSe Function. A practical example of this function would be setting up and initiating Wi-Fi Direct*16 communication with EPC assistance.

4. Layers 1 and 2 Basic Structures

The following describes basic structure of the physical layer (layer 1*17) and the Media Access Control (MAC) layer (layer 2*18). As described in Chapter 1, a subset of the uplink radio resources of cellular communications are used for D2D communications, while physical channels*19 are structured as shown in **Figure 4**. The following describes the various signals, channels and their uses.

4.1 Synchronization and Radio Parameter Settings

1) Synchronization Method

(1) In eNB coverage areas

In eNB coverage areas, D2D transmission and reception are performed in synchronization with Primary/Secondary Synchronization Signal (PSS/SSS)*20, which is the synchronization signal*21 transmitted by eNB. Apart from some exceptions, D2D transmission timing is PSS/SSS reception timing, and Timing Advance (TA) used with transmission on cellular uplink is not applied.

(2) Outside eNB coverage areas

Primary/Secondary Sidelink Synchronization Signals (PSSS/SSSS)*22 transmitted by UE inside and outside coverage areas are prescribed as signals for synchronization between D2D terminals outside eNB coverage areas. Similar to PSS/SSS, PSSS/SSSS uses Zadoff-Chu sequences*23 and M sequences*24 respectively which are sent at 40 ms intervals using the center of the system bandwidth. As shown in **Figure 5**, when UE in a coverage area sends PSSS/SSSS based on the eNB sync timing, UE outside the coverage area can also perform Direct communication with eNB sync timing. In Direct communication, D2D frame number, system bandwidth, and Time Division Duplex (TDD)*25 UL/DL subframe*26 configuration etc. are transferred through Physical Sidelink Broadcast Control CHannel (PSBCH)*27 as well as PSSS/SSSS.

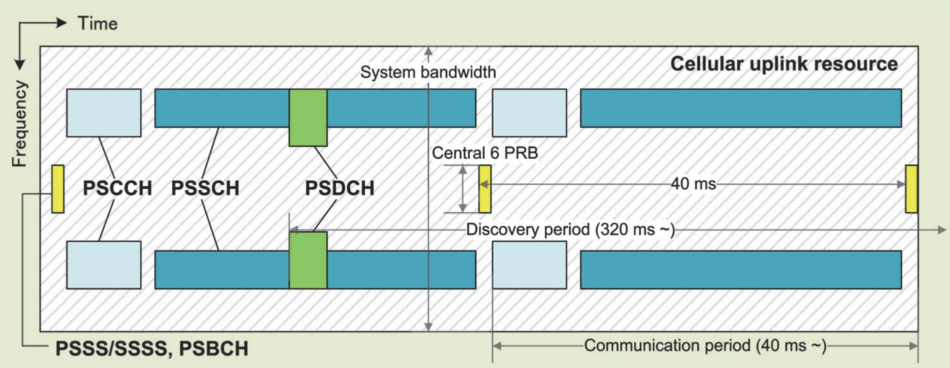

Figure 4 D2D channel structure example

*15 **PLMN:** Operators are identified in various countries by country codes or IDs assigned to them.

*16 **Wi-Fi Direct:** Specifications for D2D communications using Wi-Fi. The Wi-Fi Alliance industry association defines these specifications and certifies compatible equipment.

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

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

*19 **Physical channel:** Channels separated by physical resources such as frequency and time in radio interfaces.

*20 **PSS/SSS:** A synchronization signal sent by a base station in LTE.

*21 **Synchronization signal:** A physical signal that enables detection of the synchronization source identifier (cell ID etc.), and frequency and reception timing required by the mobile terminal to start communications.

*22 **PSSS/SSSS:** A synchronization signal sent by a terminal in LTE. This is a new specification for D2D communications in Release 12.

*23 **Zadoff-Chu sequence:** A type of orthogonal spreading sequence (number sequence) that uses cyclic shifting and that has superior autocorrelation and cross-correlation characteristics as well as constant amplitude and low PAPR in the areas of time and frequency.

Even with Device discovery only supported in coverage areas, PSSS/SSSS can be used for synchronization between UE in different cells.

In addition to relays*28 of the above synchronization timing, there are also plans to study network coverage extension to transfer UE data outside coverage areas enabled by UE relaying in layer 3*29 in coverage areas in Release 13.

2) Radio Parameters

D2D radio parameters are notified in broadcast information*30 from eNB in coverage areas. For example, these notices include PSSS/SSSS configurations, candidate time and frequency resources (a resource pool) used for sending and receiving Physical Sidelink Control CHannel (PSCCH), Physical Sidelink Shared CHannel (PSSCH) and Physical Sidelink Discovery CHannel (PSDCH)*31 and so forth. As described in Chapter 3, UE outside coverage areas uses pre-configured parameters for D2D.

4.2 Direct Communication

PSCCH and PSSCH defined with the ProSe Communication cycle (e.g. 40 ms cycle) are used in Direct communication. Similar to uplinks, to achieve low Peak to Average Power Ratio (PAPR)*32 in both channels, a signal structure based on Physical Uplink Shared CHannel (PUSCH)*33 is used. PSCCH is a control channel that notifies scheduling for data sent with PSSCH and part of the layer 2 destination IDs. PSSCH is a shared data channel for Direct communication. By sending multiple Media Access Control Protocol Data Units (MAC PDU)*34 in series in the ProSe Communication cycle, sending single control data in PSCCH enables multiple MAC PDU transmissions, which reduces the overhead due to control signaling especially with voice communications.

The address IDs attached to the layer 2 header are defined for Unicast/Groupcast/Broadcast respectively. Differing from conventional cellular communications, this achieves reception filtering in layer 2. Also, Direct communication does not support a feedback channel defined in the physical layer while many functions such as ACKnowledgement (ACK)/ Negative ACK (NACK) *35 transmission are kept in the upper layers.

4.3 Device Discovery

Device discovery uses PSDCH defined with the ProSe discovery cycle (e.g. 320 ms cycle), while UE sends Discov-

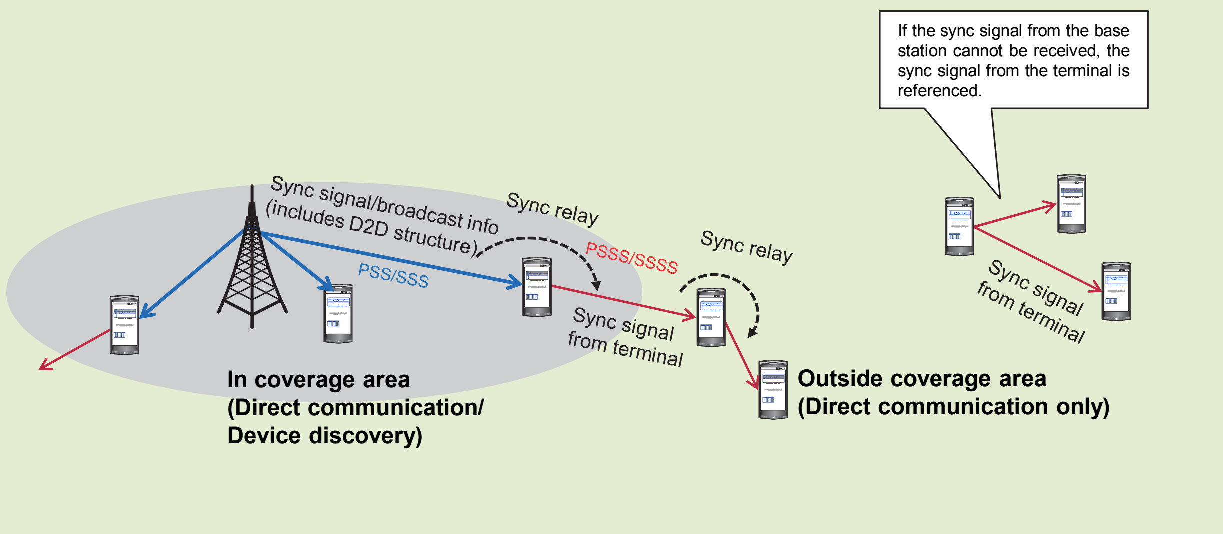

Figure 5 Sync timing relay with communications between terminals in and out of coverage areas

*24 **M sequence:** The maximum length shift register sequence. A type of pseudo-random number with sharp autocorrelation properties that consists of only two values, 0 (-1) and 1.

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

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

*27 **PSBCH:** A broadcast channel transmitted by terminals in LTE D2D communications. This is a new specification for D2D communications in Release 12.

*28 **Relay:** Technology for repeating communications to transfer them.

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

*30 **Broadcast information:** Information simultaneously broadcast to each cell that includes a location registration area number which is required to determine whether location registration is needed for a mobile terminal, surrounding cell data, info on radio wave quality of service etc. in those cells, and call restriction information.

ery Messages periodically. The signal structure is based on PUSCH in the same way as PSCCH/PSSCH. Differing from Direct communication, control information like PSCCH is not sent with Device discovery, but the receiving UE directly detects the Discovery Message in the PSDCH resource pool and performs reception filtering in the application layer based on the user interest information it contains. In general, since the content of Discovery Messages are not changed frequently, the ProSe discovery cycle is set comparatively long, ranging from 320 ms to 10.24 s. Discovery Message transmission and reception is performed for all UE in sync within the cell for PSS/SSS sent by eNB in the coverage area, which enables a low duty ratio (Discovery Message transmission time ratio) that achieves effects such as overhead and terminal power consumption reduction.

5. Issues and Solutions with D2D

The major issues in the physical layer with D2D are caused by radio resources sharing with the cellular uplink as discussed earlier. The most serious issue is to reduce interference impact on cellular communications (mainly uplink interference). There is a risk of unexpected interference because eNB cannot directly control D2D communication outside coverage areas, and even with UE in coverage areas and orthogonal multiplexing of radio resources for cellular communications and D2D communications, there is a danger of high-level interference in adjacent frequency resources due to in-band emissions*36, as shown in **Figure 6** (a).

As well as that, since D2D transmission and receiving use half duplex*37 with shared bands, there is the additional limitation that UE cannot transmit and receive D2D messages simultaneously as shown in fig. 6 (b). Also, if D2D communications use multiple carrier frequencies, carrier frequency switching is required which complicates terminal control. Release 12 offers the following solutions to these issues.

1) Resource Assignment

There are two resource assignment methods used with D2D—either eNB assigns transmission resources or the UE autonomously selects transmission resources. With the former, orthogonal resources can be assigned to terminals in coverage areas, and efficient resource sharing between cellular and D2D is

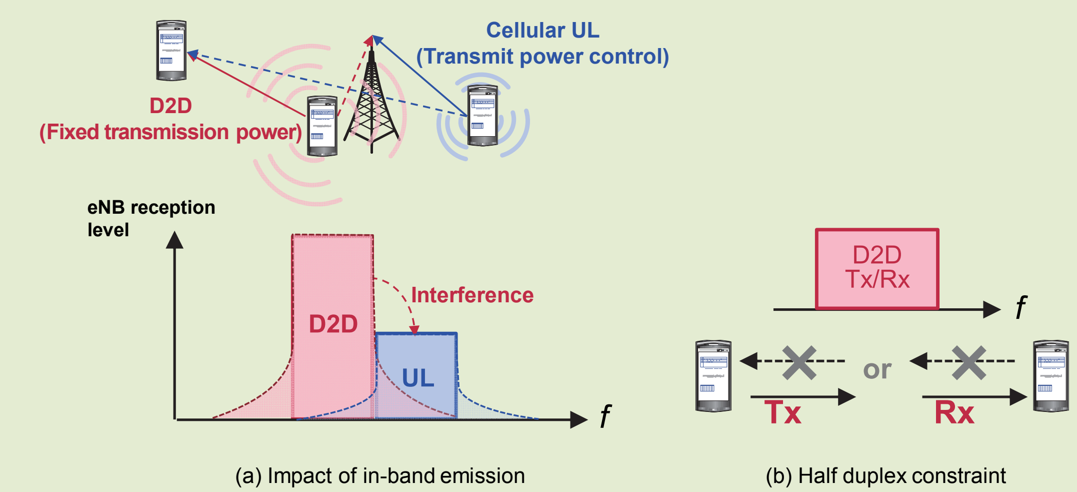

Figure 6 Physical layer issues in D2D

*31 **PSDCH:** A physical channel for sending Discovery Messages in LTE D2D communications so that terminals can discover other terminals in the vicinity. This is a new specification for D2D communications in Release 12.

*32 **PAPR:** The ratio of the maximum power to the average power. If this value is large, the amplifier power back-off has to be large to avoid signal distortion, which is particularly problematic for mobile terminals.

*33 **PUSCH:** A physical shard channel for transmitting uplink data in LTE. Low-PAPR Single Carrier-Frequency Division Multiple Access (SC-FDMA) is used as the radio access method.

*34 **MAC PDU:** A protocol data unit on the MAC layer. PDU expresses protocol data including the header and payload.

*35 **ACK/NACK:** Request signals for retransmission.

*36 **In-band emissions:** Unwanted radiation in a band that can interfere with resources on adjacent frequencies.

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

possible. In Direct communication, eNB resource assignment is signaled dynamically using downlink L1/L2 control signals (Physical Downlink Control CHannel (PDCCH)*38/EPDCCH), while eNB resource assignment in Device discovery is done by Radio Resource Control (RRC)*39 signaling*40.

UE autonomous selection of transmission resources is available both inside and outside of coverage areas, while the transmitting UE can send using any resources available in the resource pool discussed above. For this reason, transmission resource conflicts can occur in D2D.

2) Repetition Transmission and Time and Frequency Hopping

PSCCH, PSSCH and PSDCH transmission support repetition transmission of the same signal and time/frequency hopping with transmission. Having each piece of UE using a different time hopping pattern*41 with repetition transmission reduces the impacts of conflicts and half-duplex constraint. Also, because it is possible to obtain combining gain or time and frequency diversity gain*42 with repetition transmission and time/frequency hopping, these systems can provide sufficient coverage for public safety usage.

3) Transmission Power Control

The aim of the transmission power control in D2D is to balance between the interference level on the cellular uplink and D2D coverage without controlling transmission power depending on D2D link quality. For this reason, as shown in **Figure 7**, D2D transmission power is decided based on propagation loss from eNB using open loop transmit power control*43 similar to uplinks in both Direct communication and Device discovery in D2D. Because this type of power control is not feasible outside coverage areas, the fixed-level pre-configured transmission power in UE is used.

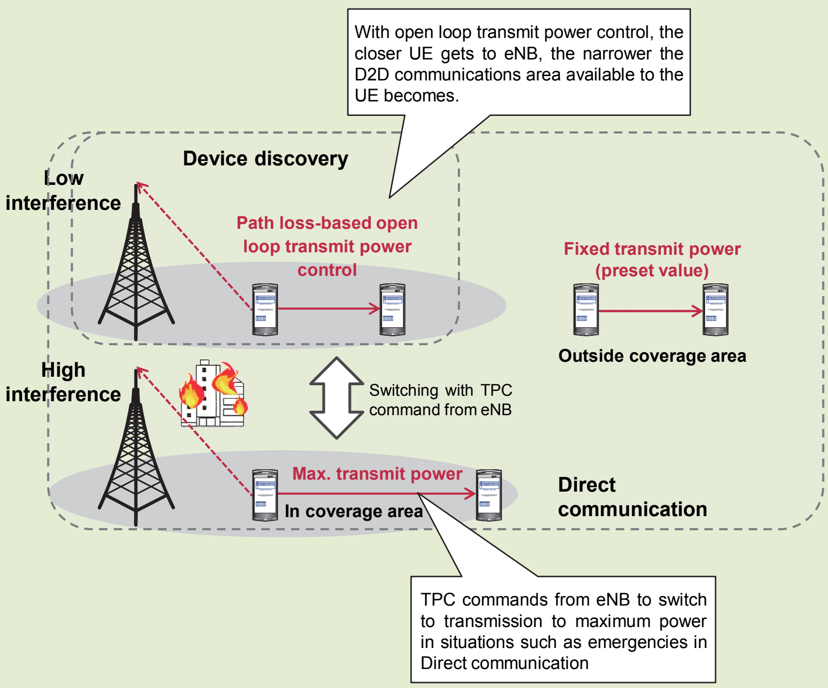

Figure 7 Transmit power control in D2D

*38 **PDCCH:** A physical channel for transmitting downlink control information in LTE, using a maximum of three symbols at the front of each subframe.

*39 **RRC:** A Layer 3 protocol for controlling radio resources.

*40 **Signaling:** Control signals necessary for a terminal to communicate with radio control and exchange equipment.

*41 **Hopping pattern:** A pattern of determining time and frequency resources for sending signals using discontinuous radio resources.

*42 **Time/frequency diversity gain:** Communications quality improvement attained by using radio quality variation with time and frequency.

*43 **Open loop transmit power control:** Transmit power control that does not involve feedback.

With open loop transmit power control, the closer UE gets to eNB, the narrower the area in which D2D communications from the UE are possible becomes, thus, a Transmit Power Control (TPC) command is sent from eNB to switch to transmission with maximum power to provide maximum coverage for Direct communication during emergency incidents. Moreover, with the 700 MHz band planned for use with American public safety LTE, UE capable of transmitting at a max. 31 dBm*44 has been prescribed which will increase the communications range compared to conventional UE (max. 23 dBm). In addition, for Device discovery, since optimum communications range relies on services and areas, the maximum transmit power can be adjusted to three levels to meet the UE request.

4) Device Discovery Between Operators

With Device discovery for commercial purposes, mutual discovery of UE from different operators is preferable. For this reason, UE should be able to receive Discovery Messages transmitted on frequencies of other operators. Release 12 anticipates UE switches reception frequency, and (1) acquires D2D radio resources structure from information broadcast by other operators, and (2) receives Discovery Messages on other operators' frequencies. So that UE's own cellular communications are not hindered, a delay to detecting UE of other operators is predicted due to the limited opportunities for this reception frequency switching. For these reasons, improvements to Device discovery between operators and carrier frequencies are to be considered for Release 13.

6. Conclusion

This article has described an overview of D2D communication introduced with LTE Release 12 and scenarios for its application. Various countries plan to deploy LTE-based public safety radio systems with D2D Direct communications, while LTE-based D2D also supports Device discovery which will enable services to distribute information to terminals in proximity.

There are discussions about expanding the public safety functions of D2D in Release 13, and it is anticipated that D2D communications will play a key role in responding to demands for service diversification, and will also form part of the 5G radio interface.

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

ACB SSAC SCM

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

Access Class Control Technology in LTE/LTE-Advanced Systems

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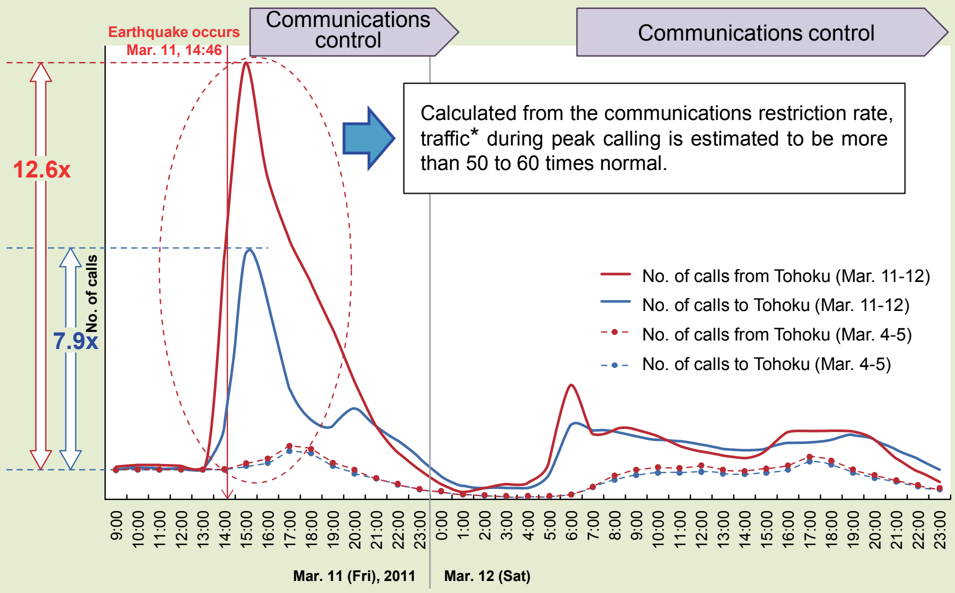
Fast market penetration of smartphones has caused not only rapid growth of mobile data traffic, but also changes to communications types (e.g., human to human, human to server/machine and machine to machine). These have brought demands for access control technologies to ensure robust and reliable communications in situations where networks are highly congested such as disasters. The importance of access controls to secure communications during disasters has increased, especially since the Great East Japan Earthquake. Thus, mechanisms to control mobile data traffic for different scenarios and needs have been specified and standardized in 3GPP in recent years. This article describes and explains the motivation for developing and the behaviors of these standardized access control mechanisms.

1. Introduction

The advances of the smartphone and its rapid market penetration in recent years have brought about massive amounts of mobile data traffic on mobile communications networks as well as dramatic changes to the types of communications traffic, ranging from traditional peer to peer communications to communications in which applications autonomously exchange signals with servers. In high-speed, high capacity mobile communications systems, traffic congestion controls are crucial for maintaining service stability in different situations. Furthermore, during major disasters such as the Great East Japan Earthquake, mobile data traffic can increase to unanticipated levels and cause the network to malfunction, which is a major cause for concern (**Figure 1**). Therefore, mobile communications systems need mechanisms to prevent such unanticipated high traffic before it occurs. Moreover, to ensure successful communications for emergency calls (e.g. emergency numbers 110, 118, 119 in Japan) and/or disaster message boards, traffic congestion control mechanisms must reduce non-critical/non-high priority calls to make sure that network resources for critical/high-priority and emergency calls are available

† Currently Network Department



* Because 80% of communications were restricted between 15:00 and 16:00, the traffic increase can be estimated to be approx. 60x (12.6 ÷ (1 - 0.8) = 60).

Figure 1 Example of mobile phone congestion and communication restrictions in the Tohoku region

to as many users as possible. In addition, under the law in Japan, mobile terminals must be equipped with access control functions (Telecommunications Business Law, Terminal Equipment Regulations, Article 28 stipulates that, in order to secure critical communications, in case of receiving call restriction request signal transmitted from a mobile communications facility, a mobile telephone terminals must be equipped with functions to refrain from sending a call).

3GPP has been standardizing a series of traffic congestion mechanisms to control mobile communication access to the network. One access control mechanism standardized as part of 3G (UMTS) specification and widely used in LTE is called "Access Class (AC)" control, which is a control technology that uses priority identifier data stored in terminals. Responding to the development of terminals and communications services of recent years and the dramatic changes to the types of traffic, these controls offer more detailed traffic control. This article describes an overview of the trends and mechanisms of access class control in LTE/LTE-Advanced systems.

2. Overview of Access Class Control in Traffic Congestion Control

2.1 Radio Access Barring Control

Radio access barring control refers to a traffic congestion control technology whose main purpose is to secure and ensure the success of critical communications such as emergency calls, by restricting connection request (RRC CONNECTION REQUEST) from mobile terminals to base stations. Radio access barring control can be categorized as the following two methods:

- Access Class control method (control in mobile terminals)

  Before a mobile terminal sends the connection request to the base station, the mobile terminal identifies the type of call and determines whether a connection request for the call should be barred.

- RRC CONNECTION REJECT method (control in the base station)

  The base station identifies the type of signals that triggers the connection request sent from mobile terminals, and decides whether this request should be rejected (by sending RRC CONNECTION REJECT) or accepted.

Mobile network operators may use one or both of the above two radio access barring controls depending on network congestion and traffic conditions. This article focuses on the former method, i.e., the Access Class control. Access Class control enables controlling traffic from all terminals simultaneously in a given area by setting barring information for each AC in the system broadcast information *1 sent continuously by base stations. Also, this method does not cause network processing load because connection request are restricted/barred, i.e., are not being sent to the base station, by each terminal. Therefore, this control is suitable for application in overload scenarios such as spikes in signal processing that occur in base stations, since this control can be implemented quickly over a wide area.

Also, compared to the RRC CONNECTION REJECT method performed by base stations, since Access Class control is performed by identifying the types of calls or services to be restricted in the mobile terminals, the control of radio access restriction for different type of call (e.g. voice, applications) can be done much more precisely and with better flexibility. Thus, in 3GPP standards, Access Class controls have been gradually enhanced in different 3GPP Releases to meet the needs of network operators and the market. These enhancements are described in **Figure 2** and explained as follows.

(1) Access Class Barring (ACB)

Firstly, because all services in LTE/LTE-Advanced network architecture including voice utilize the Packet Switch (PS) domain*2, ACB was defined in 3GPP Release 8 as a basic access class control mechanism for all packet transmissions (see Chapter 3).

(2) Service Specific Access Control (SSAC) and ACB for Circuit Switch FallBack (CSFB)

SSAC was standardized to handle communications during large scale disasters, because people tend to use voice services to confirm the safety of family and friends since voice services are known to have higher reliability than other packet services. This tendency results in sudden increases in voice traffic. Thus, to satisfy the above service requirements, voice services in these circumstances need to be restricted. For this purpose, SSAC access class control for Voice over LTE (VoLTE) services and ACB for CSFB access class control for CSFB voice services were defined in Releases 9 and 10 respectively (see Section 4.1).

(3) Smart Congestion Mitigation (SCM)

In addition to the data communications done intentionally by users,

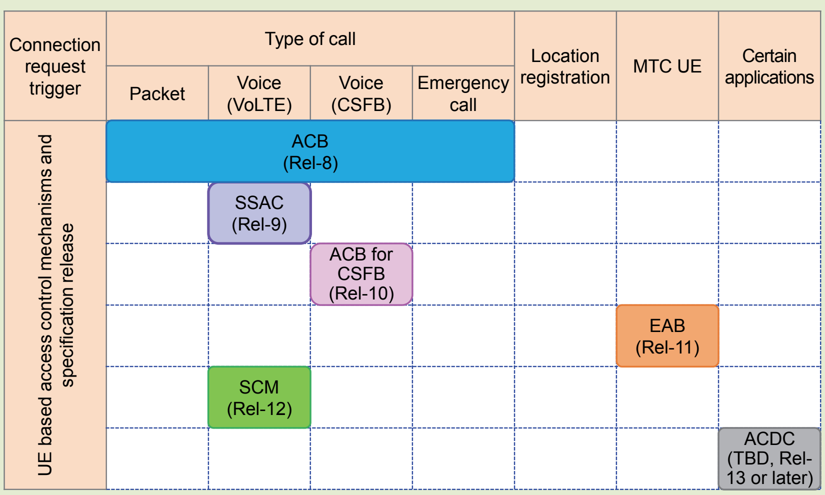


Figure 2 Access class control in LTE/LTE-Advanced systems

*1 **Broadcast information:** Information necessary for a mobile terminal to connect to a cell, which includes call restriction and barring information. This information is unique to each cell.

*2 **PS domain:** A network domain that provides services based on packet switching.

most smartphones run background applications that regularly send connection request to the network for exchanging data with application servers. For these reasons, in public festivity scenarios such as fireworks displays or concerts where many users come together in the same place, smartphone data communications can trigger network congestion*3. The ACB controls mentioned above prevent network congestion caused by smartphones by restricting all packet data transmissions including voice calls, which lowers the success rate of voice services. Therefore, there have been demands to enable prioritizing voice data above packet data (non-voice data). To satisfy these demands, SCM, an access control for prioritizing voice services (VoLTE) while restricting other packet data services, was defined in Release 12 (see Section 4.2). Combinations of SCM and other access class controls such as ACB and SSAC enable independent control of packet and voice data.

(4) Extended Access Barring (EAB)

There has also been ongoing study and implementation of Machine-to-Machine (M2M) communications technologies and services in recent years. There are a range of businesses that could utilize M2M terminals such as automatic vending machines and smart meters, hence a huge number of access from these terminals is foreseen. To accommodate both M2M terminals and typical smartphone terminals on the same network, the network needs to ensure that access from M2M terminals does not impede access from typical smartphone terminals. To achieve this, EAB access control that enables differentiation between the two types of terminal was defined in Release 11 (see Section 5.3).

(5) Access Control for general Data Connectivity (ACDC)

There are also discussions about requirements for emergency situations such as natural disasters, where packet data for “disaster message boards” (message board services where people can post whether they are safe so that relatives and friends can confirm that information via the Internet) should be given priority compared to other smartphone applications. To satisfy these requirements, new access class controls are being considered for Release 13 called “Access Control for general Data Connectivity (ACDC)” (see Section 5.1).

2.2 Access Class Control Features

AC is an identifier assigned by operator to each user to indicate its access priority and is stored in the Subscriber Identity Module (SIM)*4. As standardized in 3GPP, AC 0 to 9 is assigned to general users, AC 10 is assigned for emergency calls (e.g., emergency numbers 110, 118, 119 in Japan), while AC 11 to 15 are assigned for special or high priority users such as the users in public institutions or authorities such as police, fire departments and users/terminals belonging to network operators for maintenance purposes [1].

In access class control, the base station sends broadcast information containing control data (e.g. barring rate) set for each AC so that all terminals in its coverage area can receive the information simultaneously and promptly perform the access control (**Figure 3**). Thus, this mechanism is effective in reducing the amount of traffic accessing the network shortly after the broadcast (**Figure 4**). Appropriate adjustment of these control data settings enables optimized access restriction for different levels of network congestion. For example, when the network congestion level is high, the broadcast information can be updated to increase the barring rate (meaning reduce the successful call establishment rate). When a terminal attempts to perform a connection request, it reads the control data set in the broadcast information. Then, if the terminal’s AC is subject to barring, based on the set parameter in the control data, the terminal will refrain from sending the connection request for a certain period of time.

In general, the purpose of applying access class control to AC 0 to 9 is to protect network equipment and to optimize communications traffic, while applying access class control to AC 10 and 11 to 15 such that no barring is applied, is to achieve secure communication for

*3 **Congestion:** A state in which the load (e.g., processing capabilities, resources, etc.) on a network entity exceeds a certain threshold per unit time due to traffic burst. This state can degrade services provided by the mobile network operator.

*4 **SIM:** An IC card which stores mobile phone subscriber information.

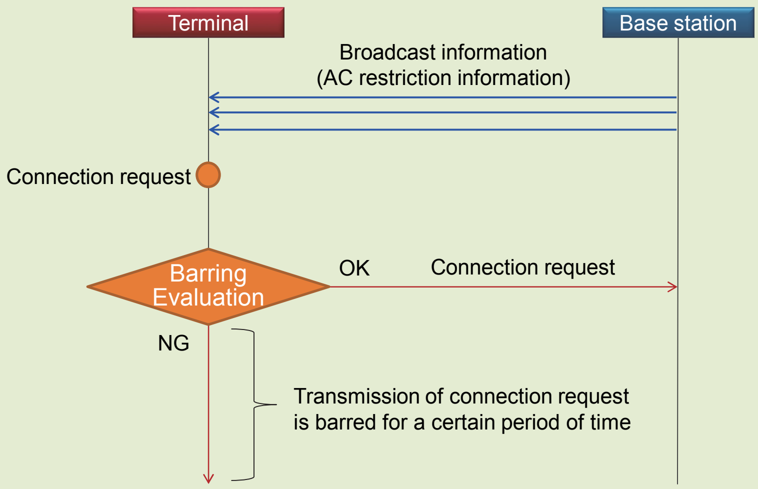


Figure 3 Access class control flow

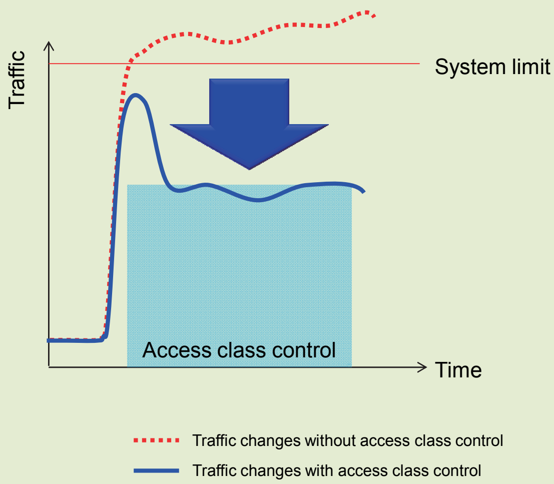


Figure 4 Traffic changes with and without access class control

emergency and high priority communications.

3. Access Class Control (ACB)

3.1 Packet Data Barring

As discussed above, ACB is applied to all packet data traffic originating in the LTE terminal traffic including VoLTE, because in LTE/LTE-Advanced network architecture, all packet data communications including voice services (VoLTE) are enabled by the PS domain.

In 3G, because 3G network architecture consists of two domains - the Circuit Switching (CS) domain that processes voice service and the PS domain that provides packet data service - Domain Specific Access Control (DSAC) was defined [1] to enable separate evaluation of access class control to each domain to enable independent and separate traffic control for voice/packet services. **Figure 5** describes how ACB is achieved for the different LTE and 3G architectures.

ACB is performed in the terminal RRC layer [2]. Based on the barring rate information broadcasted by the network, the terminal determines whether the connection request is allowed to be transmitted based on its AC. Furthermore, there are two types of packet data transmissions controllable with ACB - transmission of the connection request for general packet calls and emergency calls. For emergency calls, AC 10 is used.

3.2 Mobile Terminating Access Permission

When access control in 3G was first studied, connection requests for both “mobile-originating calls” from terminals and “mobile-terminating calls” as responses to paging sent from the network to terminals, were seen by the network as the same type of signal and thus handled in the same way, which meant that barring controls were applied to those signals in the same way.

During disasters, there are cases such that public authorities (police or fire department) call back victims who have already called an authority in an emergen-

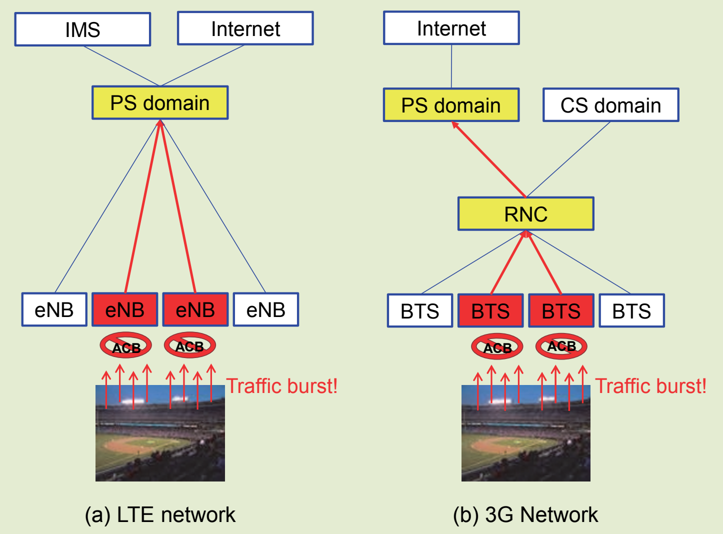


Figure 5 Different ACB mechanism for LTE and 3G architectures

cy to confirm their safety. In this case, the mobile-terminating call as a response to paging should not be barred. If the network decides to minimize the mobile-terminating call, the network will refrain from sending paging messages to UE. This mechanism was considered for LTE, and mobile-terminating access permission was standardized as part of the ACB functions. This is because paging response for voice services are also considered to be part of critical communications [3].

In 3G, this mechanism realized by defining a function called Paging Permission Access Control (PPAC), which was standardized in 3GPP Release 8 [1].

3.3 Access Control for Location Registration (Mobile Originating Signal)

Tracking Area Update (TAU)*5 (location registration in a service area) is required by terminals to receive incoming calls (paging) as described in Section 3.2. However, because it was not possible to separately set barring information for location registration signaling separate from packet data and voice data in 3G, connection requests for location registration were also barred in terminals. Therefore, if terminals move into new location registration areas, location registration cannot be performed because connection request to perform location registration is barred. In this case, the network cannot send paging to such a terminal because the network does not recognize where the terminal is camping and incoming calls cannot be received. To solve this issue, an AC to allow location registration was required. Barring of location registration signals is required for scenarios in which many terminals could send location registration signals simultaneously when crossing the border of a location registration area, which can lead to network congestion. For this reason, a barring parameter of location registration signaling (ac-Barring For MO-Signaling) separate from the barring parameter for ordinary data signaling (ac-Barring For MO-Data) is defined for ACB in LTE [1] [3]. Barring control for location registration signaling is performed in the same way as for barring evaluation performed by packet data connection establishment signaling described in Section 3.1 above. This function enables control of location registration traffic in different kinds of operational scenarios. For example, restricting packet data but allowing location registration means terminals can receive incoming calls during a disaster. The function can also prevent network congestion due to mobile terminals sending simultaneous location registration signals when buses or trains pass through location registration border areas during situations such as rush hour.

As mentioned, separate restriction functions for location registration have been standardized in 3G since Release 8 [1] as a part of PPAC.

4. Enhancements of Access Class Controls for Voice Services

4.1 Voice Service Restriction Controls

In large-scale disasters, traffic bursts

*5 **TAU:** A procedure for updating location registration in LTE.

occur due to signaling generated by people trying to contact friends and family to check their safety. When a traffic burst causes congestion on a network, simultaneously providing access for all types of communications and for all traffic is problematic. Generally in such cases, network resources for critical communications are secured by restricting traffic such as voice and video that use large amounts of resources while giving priority to services such as email and disaster message boards so that services are available to the largest number of users possible. The needs for these kinds of controls have become even more pronounced with the increase in communications with the various applications such as social networking accompanying the recent popularization of smartphones. For this reason, mechanisms to restrict voice services are specified in 3GPP, and described below. Emergency calls can be set so such that they are not subject to barring with any of these controls.

1) VoLTE Access Barring Controls (SSAC, SSAC in Connected)

(1) SSAC

In LTE, real time voice and video call services are provided in the PS domain as VoLTE using the IP Multimedia Subsystem (IMS)*6. In 3G, independent access restrictions known as DSAC are available for each CS domain that provides voice service and PS domain that provides packet data services. Unlike 3G, access restrictions only for voice services were not possible in LTE. Therefore, SSAC was defined to enable access restriction for IMS-based voice and video [1]. SSAC has also been designed to enable independent restriction of Video over LTE (ViLTE). NTT DOCOMO considers this functionality critical to ensure successful critical/emergency communications during disasters, and has provided it since the VoLTE service rollout in June 2014.

(2) SSAC in connected

Typically, smartphones applications have settings to regularly synchronize with servers. This results into frequent connection to the network and increasingly more time spent in the RRC connected state (the state in which a terminal is connected to the network, not in the IDLE state). Since the main purpose of access class control is to restrict the transmission of connection requests to the network, restrictions do not apply to terminals in the RRC connected state, because they are already connected. Due to concerns that traffic burst (generated by both background synchronization traffic or the foreground actual traffic) during disasters may impact the core network*7 equipment such as IMS nodes as well as base stations, SSAC should ideally be similarly applicable to terminals in the RRC connected state. For this reason, an access control function for IMS-based voice and video calls applicable to terminals in the RRC connected state called "SSAC in connected" was defined in 3GPP Release 12 [1]. Basically, SSAC is similar in functionality to ACB, but in SSAC, the barring control/evaluation is performed in the IMS layer instead of the RCC layer as it is in ACB. Here, AC barring information for SSAC broadcast by the network is used by the terminal to determine whether a VoLTE call is allowed or barred.

2) Access Control for CSFB Call (ACB for CSFB)

For LTE terminals that do not support the aforementioned VoLTE functions, voice services are provided with a mechanism called CSFB. CSFB is a mechanism that allows the network to transition an LTE terminal firstly connecting to an LTE network to a 3G CS domain to provide voice services on the 3G network. With CSFB, regardless of whether access class control is applied in LTE, terminals that have successfully transitioned to 3G from LTE apply access class controls broadcast by the 3G network. This means after successful CSFB transition, terminals making connection requests to the CS domain apply the 3G access class controls such as DSAC and PPAC, as described in Chapter 3. On the other hand, ACB for CSFB was defined to restrict connection request for CSFB calls when the terminal is still camping on the LTE network [1]. ACB for CSFB access class control works in similar man-

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

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

ner as the ACB restriction control. In this case, whether CSFB call is barred is determined by the ACB for CSFB access class control information broadcast by the network.

4.2 VoLTE Prioritization Mechanism

As explained in previous chapters, background data from applications in smartphones result in frequent attempts to connect to the network. In addition to that, there may be situations in which many users occupy the same coverage area (such as public events) or are simultaneously moving from one coverage area to another (such as on trains or buses). In these situations, since traffic burst due burst to smartphone application background and foreground date and also due to location registration can be expected, services such as VoLTE calls that are deliberately generated by the user should be prioritized over other traffic. Therefore, a mechanism that enables prioritization of voice services was defined and standardized in 3GPP. The following describes this priority control mechanism for voice services (**Figure 6**).

1) VoLTE Priority Control (SCM)

SCM is a mechanism newly defined in 3GPP Release 12 for UE to prioritize voice service so that even when ACB has been invoked by the network, ACB is not applied to VoLTE calls [1]. In other words, ACB evaluation is skipped for VoLTE calls. Service types to which ACB need not be applied are included in broadcast information. In addition to VoLTE, ViLTE and SMS are also defined as services that can be prioritized with SCM. The terminal decides which services to prioritize based on the broadcast information from the network indicating the service types for which ACB is to be skipped. In previous releases, prioritization by allowing access (not applying barring mechanisms) to a particular service was not possible, because the modem part of terminal where access control evaluation is performed cannot distinguish different kind of service types - i.e. whether it is a VoLTE call or some other packet data call. However, as part of SCM standardization, a function to notify the type of service of a packet (whether the packet is VoLTE, ViLTE or SMS) from the terminal IMS layer to the modem has been defined. This enables the modem to identify the type of service of a packet, and enables the terminal to skip ACB and allow the transmission of connection requests for VoLTE calls even when ACB is applied, thus enabling priority handling (Fig. 6 (a) bottom). Furthermore, SCM is designed so that it can be combined with SSAC described in Section 4.1. Hence, the combination of SSAC, ACB and SCM

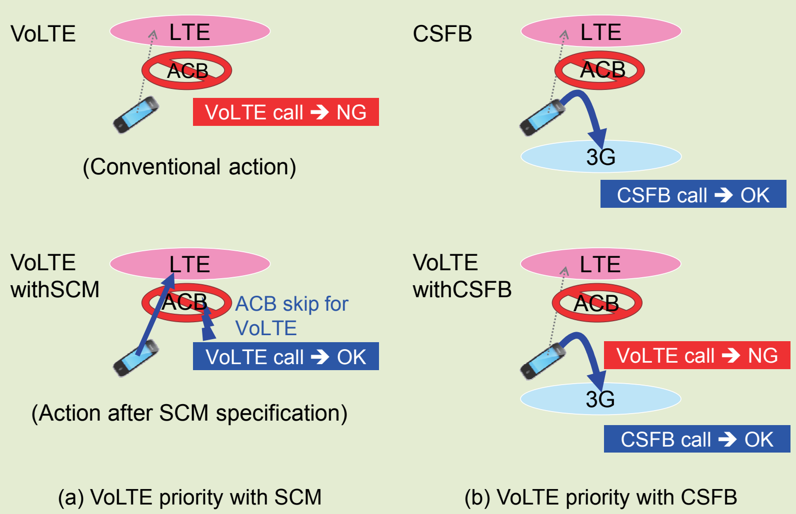


Figure 6 VoLTE priority control using SCM and CSFB

enables separate and independent access class controls for voice data and packet data. In other words, barring evaluation for voice calls will be governed only by SSAC, while in previous releases voice calls are always barred again by ACB after SSAC barring evaluation. These mechanisms enable LTE access barring capabilities comparable with 3G, since separate restriction controls for CS and PS domains are also available in 3G.

2) CSFB Priority Control (CSFB behavior when ACB is applied)

When ACB is applied in LTE, all mobile-originating calls are subject to ACB including CSFB calls. However, the standard specifies that if a CSFB call is barred as a result of ACB barring evaluation, the connection request for CSFB call not be transmitted in LTE, the terminal autonomously switch to the 3G network (by means of cell selection), and the CS connection request be sent in 3G [3] (Fig. 6 (b) top). In other words, in practice this action enables priority control of voice services by enabling CS calls in 3G even when CSFB calls are barred by ACB. The reasons for this specification are as follows: (1) a connection request for a CSFB call does not necessarily have to be sent to the LTE network because the main purpose of CSFB is to enable connection to the 3G CS domain, and (2) based on the concept of access class control, ideally a radio access network (in this case LTE) should not control the access barring of another system (in this case 3G). This is because after moving from LTE to 3G, access controls such as DSAC can be applied to handle 3G network congestions, as described in Section 4.1.

In contrast, bearing in mind that all packet data is subject to access control by ACB, voice calls from terminals that support VoLTE cannot be prioritized if the terminal or network does not support SCM described in Section 4.2 (Fig. 6 (a) top). Thus, from the user experience perspective, non-VoLTE CSFB terminals could access voice services more easily than VoLTE terminals if the LTE network is more congested than the 3G network, which is an issue in terms of the fairness of radio access barring controls. To prevent this situation, when VoLTE call is subject to ACB restrictions, standard specifications allow those terminals to switch to CSFB call autonomously to make a call request on the relevant voice service [4]. Hence, with this mechanism, voice services using VoLTE can be provided with behavior and performance comparable to CSFB when ACB is invoked. NTT DOCOMO has enabled this function since the VoLTE service rollout in June 2014.

5. Further Enhancement of Radio Access Barring Control and Future Developments

5.1 Access Class Control for Individual Applications (ACDC)

As a future access class control development, discussion on Access Control for general Data Connectivity (ACDC) is ongoing as part of 3GPP Release 13. The purpose of ACDC is to allow priority handling for individual applications [1]. In ACDC, data for categorizing applications is stored in terminals, and the network broadcasts barring information for the application categories subject to access control. Then, when a call from a certain application is generated, the terminal determines whether to allow the connection request for the call by referencing the barring information for the relevant application category in the broadcast. If ACDC standardization is completed and implemented in terminals and networks, application-based access control (i.e., allowing or barring connection requests for certain applications) will be possible. As a result, more precise access class control tailored to particular services will also be possible (**Figure 7**).

5.2 Network Sharing Support for Access Class Controls

Network sharing is technology that allows two or more telecommunication carriers to share the same network equipment. Different mobile network operators have different policies about the Quality of Experience (QoE) of the services they provide and set different values for their ACB restriction rates for the level of congestion on shared network equipment based on their own policies. Also, when networks are shared, access class controls by a telecommuni-

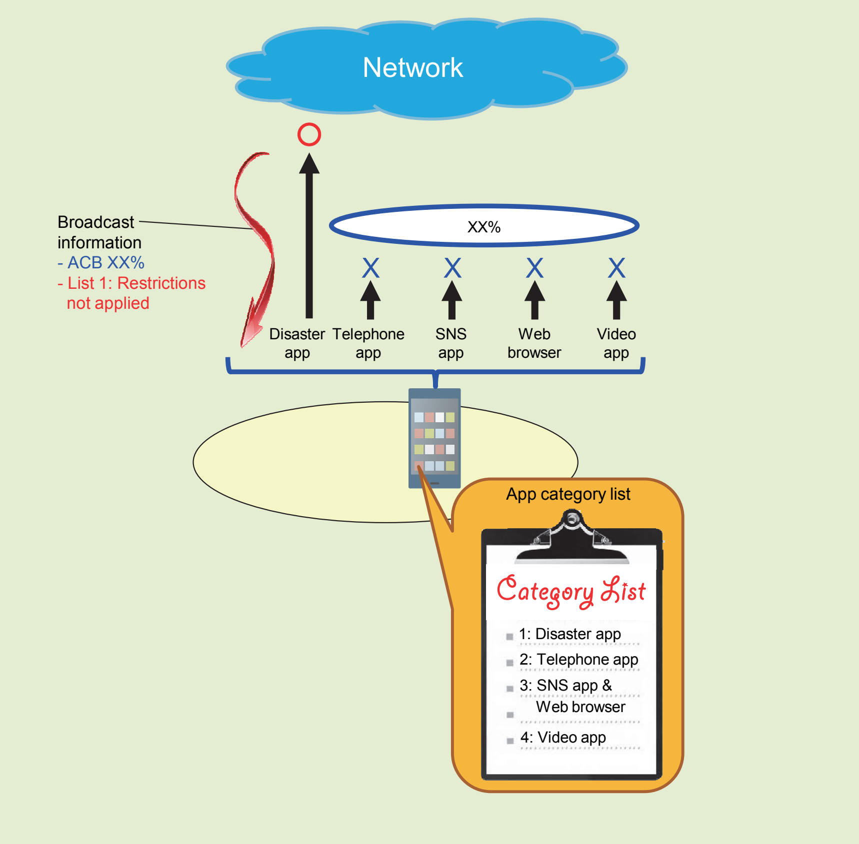


Figure 7 Access controls with ACDC

cation carrier due to their traffic must be prevented if it can dramatically affect the quality of another telecommunication carrier's services. For this reason, suitable methods for each mobile network operator to apply access class controls must be implemented in shared network environments.

Support of access control functionality for network sharing is defined for LTE in 3GPP Release 12 [1], and is achieved by allowing separate access control parameters to be set for each Public Land Mobile Network (PLMN)*8 ID that identifies the mobile network operator sharing the network equipment. When the network broadcasts access control parameters for a specific PLMN, the terminals that are registered to that PLMN apply and evaluate restrictions using the relevant parameters in the broadcast. If a broadcast does not contain any PLMN access restriction parameters, but contains common access restriction parameters, those common restriction parameters are applied.

5.3 Radio Access Barring Controls for M2M and MTC

In recent years, there have been extensive and popular studies on the so-called Internet of Things (IoT), a form of Internet communications between devices such as automatic vending machines, home appliances and smart meters. These communications could be used to address different kinds of business needs and purposes, such as IoT module-equipped vending machine, stock control, electricity usage management with smart meters, management of public transport with IoT terminal-equipped buses displaying the exact time buses will arrive at bus stops, etc.

To realize these systems using mobile communications networks, studies of M2M communications and Machine Type Communications (MTC) between devices and servers are ongoing [5]. However, as these businesses expand and applications of these technologies become more common and varied, the number of MTC (IoT) modules and communications traffic will increase dramatically, which could seriously affect the mobile communications networks.

In particular, there are concerns about traffic bursts triggered by MTC terminals sending connection requests all at once because they become disconnected from the network in the case of a server failure. Thus, Releases 10 and 11 included studies of access controls specifically for MTC terminals (**Figure 8**). Similar to normal traffic (non-MTC) control methods described in Chapter 2.1, access barring control for MTC terminals can be performed using (1) terminal-based access control mechanisms (EAB) that operate with the same concepts as the Ac-

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

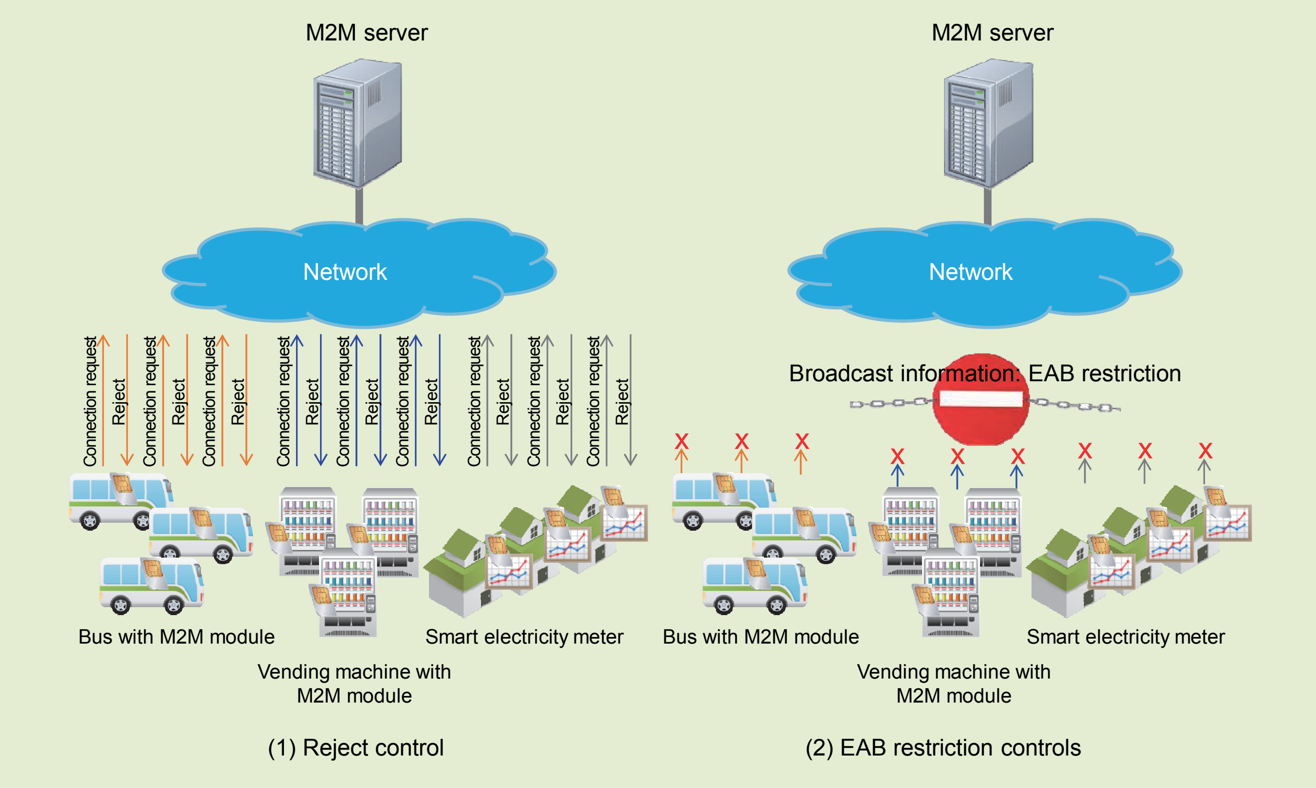


Figure 8 Radio access restriction controls for MTC

cess Class control mechanisms and (2) network-based controls, i.e., the RRC CONNECTION REJECT control mechanism. The network-based reject mechanism is performed using Delay Tolerant Access identification received in the connection request. This section describes both mechanisms to provide a clear overview of access restriction controls for MTC.

1) Reject Controls for Connection Requests Performed by Base Stations Using Delay Tolerant Access Identification

In the mechanism defined in Release 8, depending on the network congestion level, network equipment can reject connection requests from different call types (e.g., mobile originating calls (mo-Data), mobile terminating calls (mt-Access), and mobile originating signaling (mo-signaling) such as connection requests for location registration, and emergency calls) included in the RRC CONNECTION REQUEST message. However, it is not possible to distinguish MTC terminals using the above data identifiers.

For this reason, "Delay Tolerant Access" was defined in Release 10 to identify MTC terminals in the RRC CONNECTION REQUEST message. Network equipment identifies MTC terminals using Delay Tolerant Access, and performs controls such as rejecting access from MTC terminals in response to network congestion. Since most MTC communications are expected to be generated autonomously from ubiquitous devices, the requirements for connection latency and data speeds are not as demanding as conventional packet data services typically used by people such as Internet browsing or online gaming. Therefore, the above reject mechanisms can be used to delay MTC connection requests and spread out an MTC access burst over time [5].

2) EAB

On a network where MTC modules are used in different kinds of businesses, traffic bursts due to many MTC terminals simultaneously sending connection requests can occur. Simultaneous connection requests from MTC terminals could happen during server outages or the simultaneous movement of large numbers of MTC-equipped mobile terminals from one coverage area to another. In such scenarios, access controls to stop terminals sending connection requests (such as ACB) are effective at reducing traffic congestion. For this reason, EAB access control that uses barring parameters for MTC terminals sent in broadcast information was defined in Release 11 [1]. One of the differences between EAB and ACB is how the terminal is differentiated/identified. In EAB, in addition to AC explained in Chapter 2, EAB categories are used to distinguish terminals and determine whether to bar access. EAB categories can also identify whether MTC terminals are roaming and whether terminals are registered to a mobile operator sharing the relevant network. Network can indicate whether EAB is supported during the Attach*9 procedure for instance, so that networks can set whether terminals are subject to EAB based on terminal capabilities and subscription data, etc.

6. Conclusion

This article has described an overview of access class control mechanisms defined for LTE/LTE-Advanced systems.

Progressing from LTE to LTE-Advanced and onwards to 5G, mobile communication systems will provide higher capacity and higher data speeds. At the same time, the need for dynamic, flexible and precise traffic congestion controls that can be applied in a wide variety of traffic situations will increase. R&D for real-time communications traffic congestion control during disasters or sudden events is regarded as a challenging aspect of raising reliability for the mobile communications networks of the future. Traffic congestion control mechanisms described in this article and their future enhancements play a critical role in maintaining the reliability of mobile communications networks. Into the future, NTT DOCOMO will continue to research, develop and enhance these technologies.

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

Skin Acetone | Biochip | Health Management

Technology Reports

Wearable Skin Acetone Analyzer and its Applications in Health Management

NTT DOCOMO is progressing toward realizing the "biochip mobile phone"– a device that will enable advanced health management and diagnosis by biochemical analysis of biological samples that are simple to collect. Among the health management issues worthy of attention, obesity is one issue that is known to cause a wide range of diseases, and hence there are demands for technologies that can measure fat burning automatically, and thus relieve users from the need to perform any operations. To meet these demands, we developed an easy-to-wear skin acetone analyzer to enable "visualization" of fat burning in daily life. To prevent and rectify obesity, this analyzer makes it possible to provide health advice tailored to the individual based on the individual's pattern of fat burning throughout the day.

Research Laboratories

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1. Introduction

In the burgeoning cost of national healthcare, the medical expenses of the late elderly have become particularly high. In 2012, the late elderly medical expenditures*1 were 39.2 trillion yen and are projected to reach 52.3 trillion by 2025 [1] [2]. Thus, urgent measures are needed to bring down these costs. To bring down these costs, it is crucial that the period that people can live independently and healthily without being bed-ridden or requiring nursing care, i.e. healthy life-span, should be extended as long as possible. The keys to achieve this are improving lifestyle habits and preventive care*2 to prevent diseases before they take hold and retard the advance of existing ailments.

For preventive care to succeed, ideally, analyzers that are easy to use and that can be used every day to examine and confirm the state of the user's health in detail so that suitable advice can be provided to the user are important. Here, because smartphones and mobile phones are now in wide use by 94.5% of the population [2], powerful healthcare tools can be enabled by including these analyzers in smartphones or wearable devices that can connect to smartphones and deploying preventive care services linked to these technologies.

NTT DOCOMO is leading the world with its ongoing R&D of its world first concept of a "biochip mobile phone" that will enable advanced preventive care and diagnostic services tailored to individuals by biochemical analysis of biological samples*3 such as the breath or skin gases*4 that are easy to collect and analyze on biochips*5 connected to smartphones [3]-[5].

One of these technologies enables

*1 **Late elderly medical expenditure:** The cost of healthcare for those over 75 or those over 65 with certain disabilities.

*2 **Preventive care:** Medical actions and services that serve to prevent illnesses before they happen.

measurement of the acetone[*6] emitted from the skin (skin acetone), which is a chemical marker of body fat burning. We have developed the world's first compact and lightweight wearable skin acetone analyzer, which we exhibited at CEATEC JAPAN[*7] 2014 [6]. This article provides an overview of the analyzer and introduces examples of its practical applications in healthcare (**Figure 1**).

Figure 1 CEATEC JAPAN 2014 reference exhibit

2. Significance and Challenges of Skin Acetone Measurement

Skin gas contains a range of constituents that relate to the state of the body (**Table 1**) [7]-[9]. Skin acetone is a metabolite emitted from the surface of the skin produced in the blood during exercise or hunger when body fat is broken down. For this reason, it is a useful indicator of the dynamic state of fat metabolism. Because obesity is said to cause a range of diseases and thus raises the risk of contracting a lifestyle-related illness, measuring the amount of acetone emitted from the skin to monitor the state of fat burning can play a pivotal role in daily health management. Acetone is constantly and unnoticeably emitted from the skin. Thus, measuring it with an easy-to-wear device such as a watch or innerwear-type device would make preventive care services more easily available to users. Conventionally, large analyzers (gas chromatography apparatus) were normally used to measure skin acetone emissions because the amount of acetone emitted from the skin is extremely low (normally between 10-200 pg/cm^2・min[*8]). This meant that wearable, compact and lightweight skin acetone analyzers were not commercialized.

Table 1 Examples of skin gas constituents and their body condition markers

Skin gas constituent	Body condition
Acetone	Fat burning
Ethanol	Alcohol intoxication
Acetaldehyde	Hangover
Methane	Changes in intestinal environment, constipation
Nonenal	Progress of aging
Formaldehyde	Onset/progress of cancer

NTT DOCOMO planned a new gas analysis device to concentrate and measure skin acetone (**Figure 2**) [10], and developed the world's first analyzer small and light enough to wear.

3. Overview of Device Development

For this development, a compact, high-sensitivity, low-cost, long-life and maintenance-free semiconductor-based gas sensor[*9] is preferable as the gas sensor to be implemented in the wearable device. However, measuring the low skin acetone emission is difficult even with

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*3 **Biological sample:** A sample derived from a living organism for analytical purposes.

*4 **Skin gas:** A gas emitted from the surface of the skin.

*5 **Biochip:** A chip which has a built-in mechanism to detect or analyze biological samples.

*6 **Acetone:** A highly volatile organic compound - chemical formula C_3H_6O.

*7 **CEATEC JAPAN:** The largest international imaging, information and communications technology exhibition in Asia.

*8 **pg/cm^2・min:** The amount of acetone emitted from 1 cm^2 of skin per minute. 1 pg is 1 trillionth of 1 g.

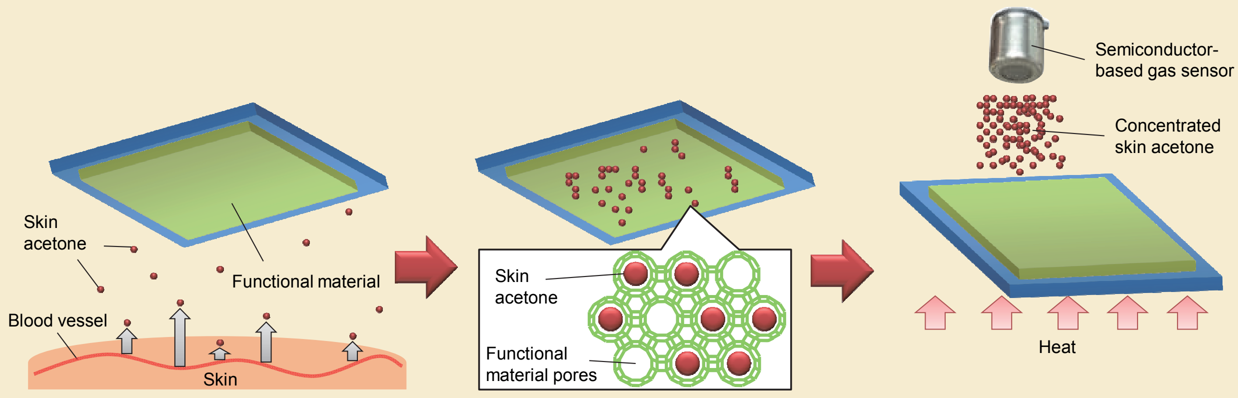

Figure 2 Concentration measurement mechanism

the world's most sensitive semiconductor-based gas sensors [5], which means, for example, a method to concentrate the skin acetone so that it can be measured is required [10]. Thus, the device in this development consists of a semiconductor-based gas sensor and a functional material*10 with pores slightly larger than the molecular size of acetone. The acetone molecules naturally emitted from the skin surface are collected for a certain amount of time by using the functional material to adsorb the skin acetone. Then, by flash heating the functional material, the adsorbed acetone is released from the functional material all at once, which temporarily concentrates it so that it can be measured by the semiconductor-based gas sensor (fig. 2). For the semiconductor-based gas sensor, we selected a tungsten oxide sensor for its particularly high sensitivity to acetone.

The device weighs 54 g, is 40 × 78 mm in size - smaller around than a credit card - and at 13 mm thick can easily fit into a breast pocket. We have successfully prototyped a compact and lightweight device roughly 1/120 of the weight of the conventional apparatus and 1/380 of its volume. The results of skin acetone measurement can be sent by radio to a paired smartphone or tablet by Bluetooth®*11. To respond to the skin acetone measurements, we also developed an application to visualize and display the user's current state of fat burning and healthy diet advice on the Graphical User Interface (GUI)*12 of the paired smartphone or tablet that receives the data from the device (**Figure 3**).

4. Performance Testing

To verify the principle of this developmental skin gas measurement mechanism, we tested the performance of the device. Because skin acetone is a constituent of biological gas that originates in the blood and can therefore be measured from various parts of the body as well as the arms, we measured skin acetone from the palms of multiple subjects and compared measurements taken with the device with measurements taken using conventional large-sized measuring equipment (gas chromatography apparatus). This test showed that the measurements taken by the device we developed had a strong positive correlation with those of the large-size apparatus (correlation coefficient*13 $R = 0.96$) (**Figure 4**). This level of accuracy means that this device could make it easy users to know their fat burning trends and targets. The performance of this prototype remains close to conventional large size apparatus, but we have succeeded in drastically reducing size and weight.

5. Service Examples

1) Dietary Support

This system could be used to offer services to users who are concerned about

*9 **Semiconductor-based gas sensor:** Using metallic oxide semiconductors as sensor elements, these sensors enable gas concentrations to be measured from the changes in electrical resistance in the sensor element that occur due to oxidation-reduction reactions with gas constituents in gaseous mixtures.

*10 **Functional material:** A material whose functions can be controlled externally. In this case, these materials selectively adsorb molecules which are then released by external stimulus such as heat.

*11 **Bluetooth®:** A standardized short-range wireless communication (IEEE 802.15.1) that operates in the 2.4 GHz band, and does not require registration or licensing for use. Bluetooth and the Bluetooth logo are registered trademarks of Bluetooth SIG, Inc. in the United States.

Figure 3　Examples of results displayed from measurement by the skin acetone analyzer

their diet or users who are troubled by metabolic syndromes, and could be used at work and at home on a daily basis. Specifically, this opens the potential to provide dietary support programs that include appropriate timing for meals and exercise, recommendations for menus and the size of meals, and exercise amount and load tailored to the characteristics of the user's metabolism (**Figure 5**). **Figure 6** shows the results of measurement taken by the device being worn for one day. In fig. 6, it's clear that the amount of emitted acetone from the skin changes throughout the day. For example, when the amount of emitted skin acetone is low before lunch, body fat is not being burnt much, which suggests that there is a high amount of sugar remaining in the body. In this case, because eating can lead to weight gain at this time, the user is advised to eat only a light snack and avoid large amounts of carbohydrates. In contrast, when the amount of emitted skin acetone is markedly high, the user is advised to beware of potentially excessive dieting with unreasonable dietary restriction. In a different usage scenario, the user can compare the amount of emitted skin acetone before and after exercise to determine whether the exercise burnt fat effectively. Fig. 6 shows a successful exercise session, however, if there is not a marked change in the amount of emitted skin acetone before and after exercising, either the load was too low or the session was too short. Thus, advice can be given to adjust the amount of time and load for exercise in stages.

2) Monitoring Support for the Elderly

This system could be used for care

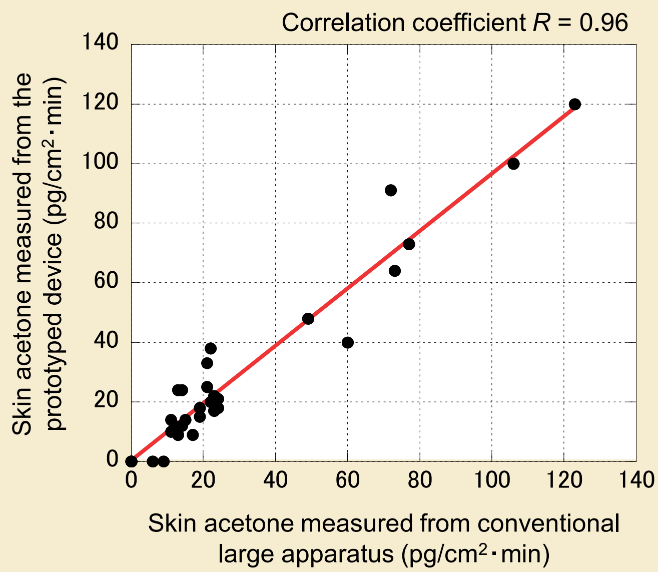

Figure 4　Comparison of skin acetone measurements

*12 **GUI:** A superior type of interface that offers visibility and intuitive operability by expressing operations and objects visually on a screen.

*13 **Correlation coefficient:** An index used in statistics to indicate the degree of similarity between two variables. The closer to 1 this value is, the more similar the variables, while the closer to 0, the more dissimilar.

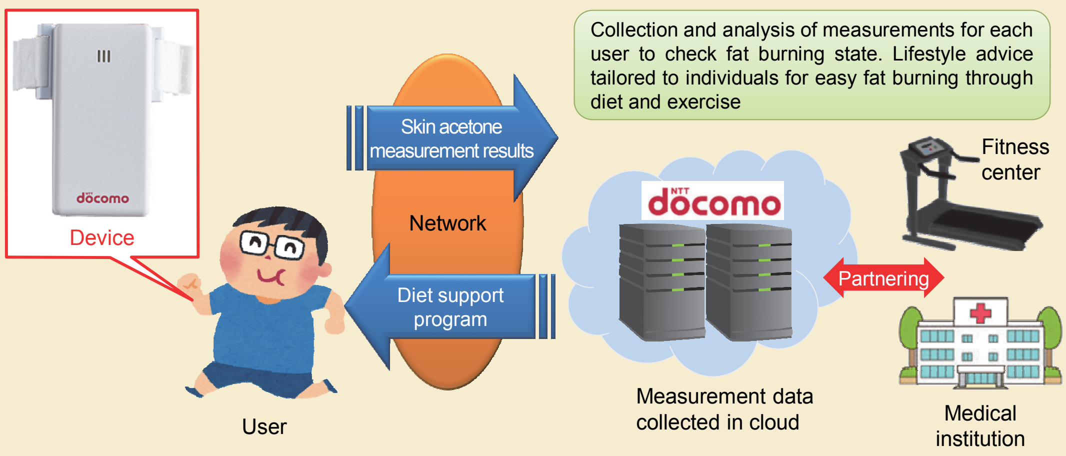

Figure 5 Service example with the wearable skin acetone analyzer

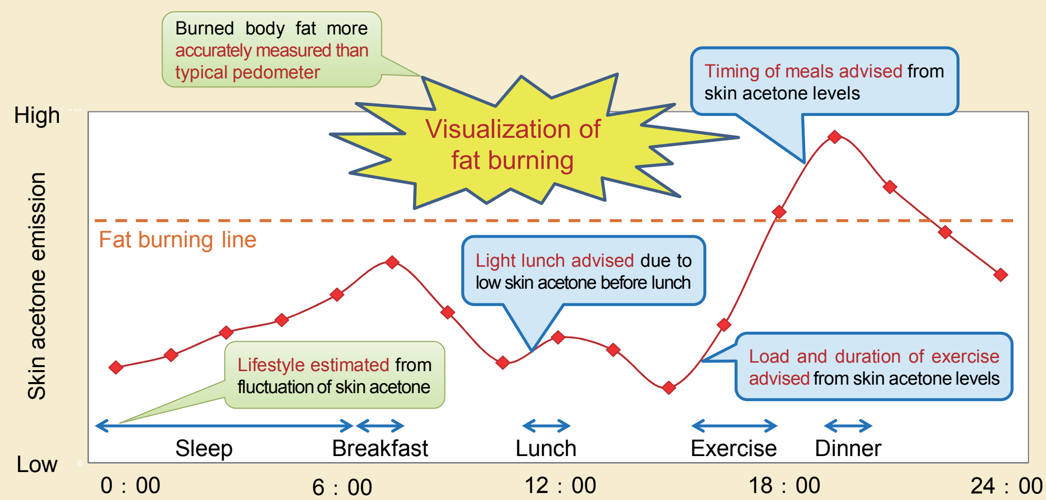

Figure 6 Measuring skin acetone emissions and advising improvement to lifestyle

and dietary management for the elderly. When an elderly person dramatically reduces the amount of food they consume or forgets to eat they can unwittingly fall into a state of malnutrition. In such a case, the skin acetone levels will be very high. Thus, whether the elderly person is eating properly can be determined objectively by measuring the skin acetone level regularly and sharing the data with families and carers to contribute to maintaining the safety and security of the elderly.

3) Support for Diabetics and Potential Diabetics

Users who suffer from diabetes and potential diabetics could also use this system. The first attempt to treat diabetes often involves dietary changes. However, if symptoms do not improve, treatments include oral medication or insulin injections. In any case, if treatments are not effectively controlling symptoms, the emitted skin acetone tends to rise and could therefore be used as an indicator in diabetes diagnosis and follow-up. In particular, this system could be used to take measurements in situations that have conventionally been problematic such as in the homes of outpatients or at the bedside of hospital inpatients.

6. Conclusion

As an example of development towards the realization of the "biochip mobile phone," this article has introduced an easy-to-wear skin acetone analyzer that enables visualization of body fat burning patterns. As a world first, this device features an independent concentration measurement mechanism with performance close to that of a conventional large-size device but much more compact and lightweight. Able to be worn like a watch or innerwear, or be incorporated into a range of other wearable devices, this device could be used to provide customized dietary support programs that are easy to follow.

We will continue our research and development into the "biochip mobile phone" and aim to develop analyzers that can comprehensively measure other gas constituents as well as acetone. These developments will contribute to the creation of new value in the healthcare and medical fields by enabling preventive care services and thus help deal with the social issue of increasing cost of national health services.

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Green Base Station | Electric Power Interchange | Power Production Forecast

Collaboration Projects

Green Base Station Power Control Technologies for Reducing Costs and Disaster Risks

NTT DOCOMO continues to develop green base stations that are environmentally friendly and resilient to disasters to improve the availability of base stations during disasters and reduce base station costs. Therefore, in view of the coming liberalization of the retail electricity market planned for 2016, we devised technologies for predictive and linked control between multiple base stations that have achieved significant efficiencies in green base station power usage, battery cost reductions and that have secured backup time. This research was conducted jointly with the Computer Aided Electromagnetics Laboratory (Professor Shinji Wakao), Graduate School of Advanced Science and Engineering, Waseda University.

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1. Introduction

Energy issues are in focus around the world. In Japan, vulnerabilities in energy supplies were exposed due to large-scale power outages caused by the Great East Japan Earthquake, with approximately 4.66 million households supplied by Tohoku Electric Power Co., Inc. and 4.05 million households supplied by Tokyo Electric Power Company, Incorporated suffering blackouts [1]. When the earthquake occurred, NTT DOCOMO also suffered communications disruptions due to battery depletion in its base stations, which emphasized the importance of securing energy supplies during disasters.

In addition, visible preparations are underway for the 2016 liberalization of the retail electricity market and utilities are beginning to offer a wide range of electricity fee plans designed for a variety of consumer lifestyle patterns. Also, as users find out that their use of expensive daytime electricity is high thanks to the recent installations of smart meters*1, they are more than ever searching for ways to reduce their electricity fees by changing to more optimized fee plans.

Thus, in addition to these changes to the social situation surrounding energy, the managerial issues of energy and environment in terms of reducing costs and carbon dioxide emissions became even more serious when electricity consumption by the NTT DOCOMO Group reached 2.9 billion kWh in FY 2013.

For these reasons, NTT DOCOMO is continuing research into disaster resilient and environmentally friendly renewable energy systems for its radio base stations. This approach involves green base stations equipped with large capacity lithium-ion batteries (hereinafter referred to as “batteries”) and photovoltaic panels (hereinafter referred to as “PV”), that

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

are able to operate using only batteries or only PV depending on the situation. **Figure 1** shows the configuration of equipment in such a green base station.

In a green base station, surplus electricity generated by PV during the day or cheap nighttime off-peak electricity is stored in batteries, which can then be discharged to reduce the high costs of daytime commercial power and hence make the use of energy more effective [2] [3]. **Figure 2** describes an example of control using PV and nighttime off-peak electricity and the relationship with the State Of Charge (SOC) of batteries.

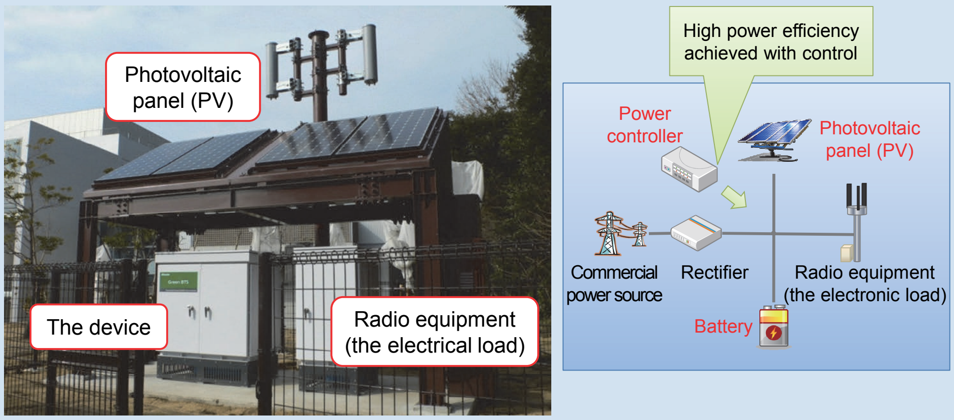

Figure 1 Green base station equipment configuration

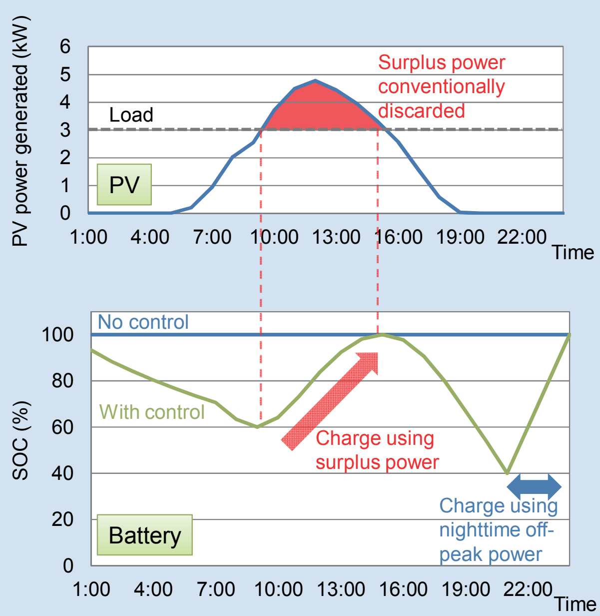

Figure 2 Example of control with PV and nighttime off-peak power, and SOC

To confirm the effectiveness and reliability of green base stations, ten test stations have been set up in the field in the Kanto Koshinetu region, and based on the performance of these test stations, commercial green base station deployment has begun with 11 stations already set up around Japan.

There are two main issues with implementing this type of green base station. The first issue is base station costs. Converting an existing base station to a green base station entails additional initial costs of installing batteries to provide backup power for six or more hours during the heavy traffic that directly follows a disaster, PV to generate sufficient electricity, and efficient power controllers. Therefore, in green base stations, power control must be even more efficient and outrank that of existing base stations in terms of running cost savings.

The second issue is base station disaster resilience. As discussed, the combination of PV and batteries in green base stations raises effectiveness in terms of environmental considerations as well as costs by enabling reduction of daytime use of commercial power by using surplus PV power that was previously discarded and nighttime off-peak power to charge batteries. However, because discharge reduces the backup time available for disasters, battery capacity and discharge must be calculated to keep discharge to a required minimum.

Accordingly, further improvements must be made to both cost reduction and disaster resilience for the ongoing deployment of green base stations. This article describes the power control technologies we have used to solve the above two issues.

This research was conducted jointly with the Computer Aided Electromagnetics Laboratory (Professor Shinji Wakao), Graduate School of Advanced Science and Engineering, Waseda University. As discussed later, our objective in this research was to establish predictive control technologies to estimate the amount of sunlight, because predictive control technologies have been shown to be effective for solving the issues discussed in this article [4]. In this research, we used Japan Meteorological Agency Grid Point Value (GPV) data*2 and Just-In-Time (JIT) modeling*3 for sunlight amount estimation.

2. Calculation for Optimizing Power Control

2.1 Multi-objective Optimization

To optimize power control, it's necessary to simultaneously solve both of the aforementioned issues of cost and disaster resilience as these two issues are in a tradeoff relationship. In this research, we studied solving these issues by multi-objective optimization calculations.

Generally in most cases, optimization implies optimizing for one objective. However, in reality, many of the varied issues in society entail simultaneous consideration of multiple evaluation criteria. As a method of handling these kinds of issues, multi-objective optimization involves calculating multiple solutions called a "Pareto optimality" which enables selection of controls to suit objectives.

As an example with a green base station, **Figure 3** shows a Pareto optimality using the two evaluation functions of battery capacity and electricity cost. As shown in fig. 3, increasing battery capacity reduces the cost of electricity, a running cost, but increases initial installation costs. In contrast, lowering battery capacity increases electricity costs but lowers installation costs. Hence, there is more than one solution (Pareto optimal solution) to this Pareto optimality – solutions for electricity cost reduction or battery cost reduction. Thus, the optimality enables selection of a solution to suit the situation. The following describes specific calculation criteria.

2.2 Evaluation Functions and Design Variables

To solve the two issues, we set the two evaluation functions of "electricity costs" and "disaster resilience index." Electricity costs are the product of the electricity unit price times the amount of power purchased, while the disaster resilience index was obtained by indexing battery operational capability during a power outage. Because it's necessary to consider green base station battery capacity and radio equipment power consumption when making an evaluation, we made our evaluations using a value

*2 **Japan Meteorological Agency GPV data:** Grid point value data for meteorological numerical simulation provided by the Japan Meteorological Agency.

*3 **JIT modeling:** A type of black box modeling for selecting neighborhood data in a database.

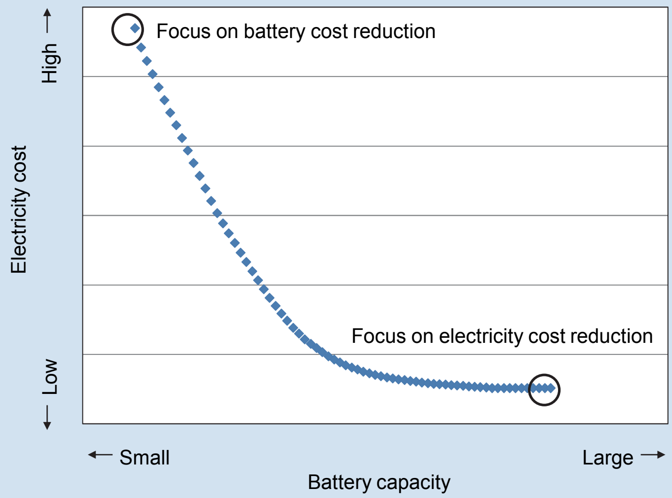

Figure 3 Example of a Pareto optimality

obtained by dividing the depth of discharge*4 with the maximum backup time. In both evaluation functions, the lower the value, the better the control. Also, to calculate the optimum power control techniques for both electricity costs and disaster resilience index, we set design variables*5 for changing the amount of battery charge/discharge and the amount of power for sending to other base stations. Specifically, these are an adjustment coefficient for estimating power generation and an SOC threshold value for power transfer between base stations. These variables are described in detail later.

2.3 Other Prerequisites

The following describes the prerequisites necessary for these calculations. Firstly, we set the range of charge/discharge such that at least six hours of backup power will always be available so that the period of high traffic directly after a disaster will be covered. Also, for green base station equipment requirements, we used the actual data for PV power generation of the three field test stations already set up, and based those requirements on the three test station equipment specifications. **Table 1** describes equipment requirements for each station. We based electricity costs on the unit prices of the low voltage power supplied by the utilities serving the locations of the three stations.

3. Wide Area Linked Control Using Prediction

3.1 Predictive Control

1) Overview

When using optimization calculations to actual power control, it's necessary to estimate power generation using technology to predict the amount of sunlight because the irregularity of PV power generation must be taken into account. Also, studies of discharge control have confirmed the effectiveness of Prior Discharge Equivalent to Surplus PV power (PDESP) as a simple control method for discharging the same amount from a battery right before generating surplus power [5]. However, even though PDESP is an effective solution for both issues of cost reduction and disaster resilience, there can be estimation errors because only the estimated amount of generation is used for control. For this reason, we studied optimization calculations to minimize the effects of errors using simulated estimated values to take prediction errors into account.

2) Handling Prediction Errors

If the amount surplus power is overestimated, backup time for disasters would

*4 **Depth of discharge:** An index indicating what percentage of a full charge has been discharged.

*5 **Design variables:** Variable parameters used for optimizing evaluation functions.

Table 1 Specifications for the three field test base stations

	Ibaraki station	Nagano station	Niigata station
Load	1.2 kW	2.3 kW	1.0 kW
Battery capacity	40 kWh	27 kWh	9.3 kWh
PV capacity	2.0 kW	3.0 kW	4.5 kW

be reduced because of a low SOC due to discharge greater than the actual available charge capacity. In contrast, if power generation is underestimated, surplus power exceeding spare battery capacity will be generated, which would lead to avoidable extra costs due to surplus power being discarded. For these reasons, we devised ways to compensate for these potential overestimations and underestimations.

To handle overestimations, we implemented a setting for an estimate adjustment coefficient in the design variables. Specifically, this entails applying a reduction rate to the estimated amount of power generation to prevent batteries from falling into a low SOC. This method enables significant improvements to the disaster resilience index while having almost no adverse effect on cost reduction.

To handle underestimation, we implemented settings for standard SOC values. Here, we set an upper charge limit (an SOC standard value) to prevent full charging from commercial power sources, which enables batteries to absorb the difference from underestimated power generation, which thus minimizes the surplus power that ends up being discarded.

3.2 Cooperative Control

Historically, NTT DOCOMO has controlled power individually in its base stations, but has studied cooperative controls to transfer power between base stations to further raise power control efficiency. Cooperative control entails moving power from base stations with surplus PV power generation to those lacking PV power generation due to weather conditions, and holds promise of reducing battery costs, improving battery lifespan and improving backup time because it enables reductions in installed battery capacity and the frequency of battery charging. In this development, we performed optimization calculations for power transfer control that take into account power sales and wheeling of electric power*6.

Considering that the liberalization of the retail electricity market is a precondition for wheeling of electric power, we set requirements so that more power than reverse power flow*7 is purchased, because excess supply to demand is not possible. Also, with buying and selling power, due to the falling sales price of power in recent years, we assumed the selling and purchase price to be equal to clarify the effectiveness of linked control. We calculated the total unit price using the prices of the utilities servicing each base station location.

We also performed calculations using two patterns for cooperative control—from the perspective of a single base station, and from the wide area perspective. The single base station perspective is a method that involves PDESP for a single base station irrespective of the power generation conditions of other base stations, which entails only transferring surplus power that cannot be absorbed due to estimation errors. On the other hand, the wide area perspective involves power control that takes into account the power generation state of other base stations. To achieve this wide area control, we added SOC threshold levels to the design variables for optimization calculations. To date, in the single base station perspective, the single base station should give priority to fully charging itself, but by setting a threshold for SOC, once a base station has charged up to its SOC threshold, power can then be prioritized for transfer to base stations that have low PV power generation or backup time. This prevents a base station from overcharging and being unable to accept power from other base stations, or overdischarging because it has used up its surplus power.

4. Power Control Calculation Results

Figure 4 shows the results of optimization calculations. The axes show the evaluation functions. The vertical axis

*6 **Wheeling of electric power:** Supplying generated power to other locations via utility power transmission and distribution networks.

*7 **Reverse power flow:** Flowing generated electric power through a commercial power distribution network.

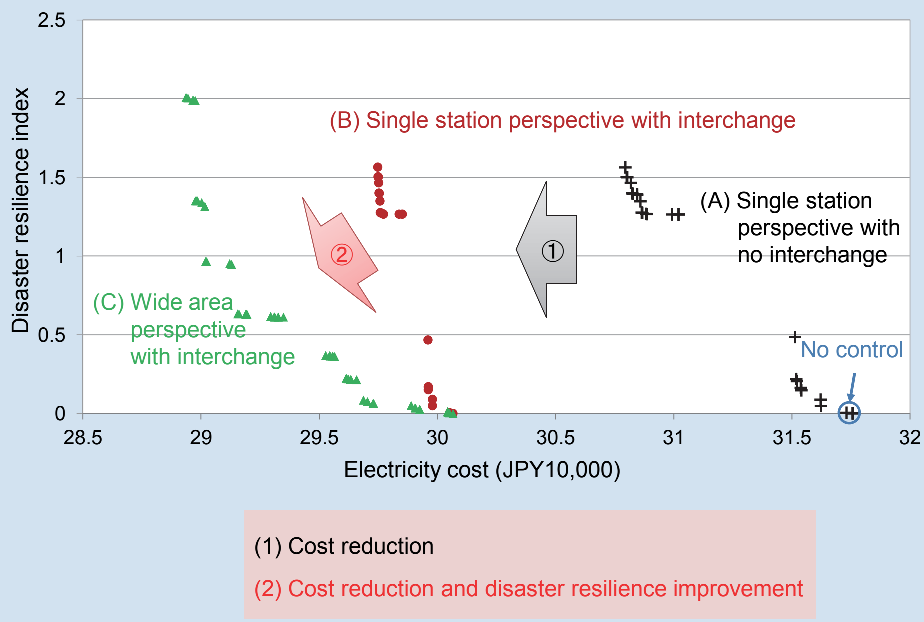

Figure 4　Results of optimization calculations

is the disaster resilience index, while the horizontal axis is the electricity price. This graph shows results calculated for a total of eight months for the three base stations described in Table 1. We performed optimization calculations for the three types of control methods. The first involves power control for a single base station (no power interchange) (fig. 4 (A)). The 0 disaster resilience index for (A) indicates that there was no charging or discharging, and hence no control. The second involves the single base station perspective control with power interchange (fig. 4 (B)), while the third involves wide area perspective control with power interchange (fig. 4 (C)).

Firstly, from the result at (A), it can be seen that electricity cost reduction was achieved with predictive control. Furthermore, in (B) and (C), it can be seen that power interchange enabled lower electricity costs (fig. 4 (1)), while wide area perspective control with power interchange improved both the disaster resilience index and power cost reductions (fig. 4 (2)).　These results indicate that linked controls with the wide-area perspective can further reduce costs and improve disaster resilience compared to conventional controls.

Figure 5 describes the no control case compared to the three types of control in terms of the electricity price, the suppressed output amount, and the self-support rate for a disaster resilience index of around 1.5 at which these three types of control (fig. 4 (A, B, C)) have significant effects. The suppressed output amount refers to the amount of surplus power that could not be utilized, while the self-supplied rate refers to the percentage of power consumed covered by the power generated. This combined optimized usage of backup and surplus power is the result of properly distributing power for charging and discharging to and from base stations with low battery capacity and base stations with comparatively high battery capacity respectively. In other words, these results shows that implementing power transfer in operations with the wide area perspective means surplus power that could not be

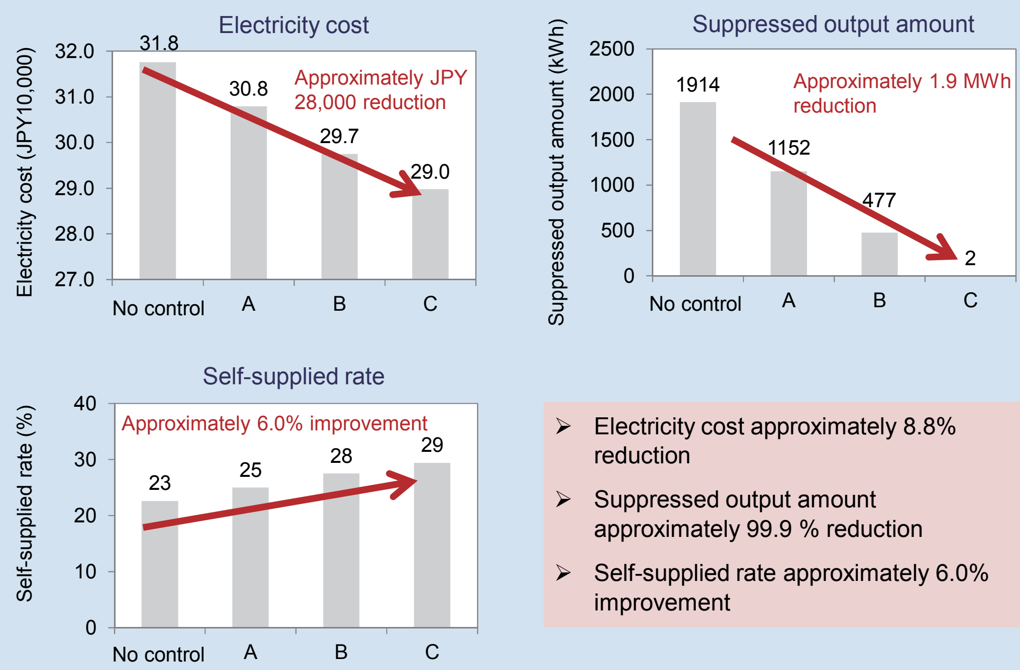

Figure 5　Comparison of results from the three base stations over eight months (with disaster resilience index around 1.5)

completely used by a single base station can be used by other base stations. Compared with no control over eight month at the three stations, wide area linked control enabled an 8.8% electricity cost reduction, a 99.9% reduction in the output suppression rate and a 6.0% percent improvement on the self-supplied rate. Lowering the overall depth of charge with the right controls also promises reduction in frequency of battery replacement and hence costs by slowing down battery deterioration. These systems can also reduce the amount of commercial power consumed which also reduces environmental load.

5. Conclusion

This article has described combined cost reduction and disaster resilience improvements for green base stations enabled by power control through multi-objective optimization calculations. Implementing this control technology promises to not only reduce power costs and raise self-supplied rates, but can also significantly improve the efficiency of battery usage. Going forward, we will continue to research and develop control methods that can respond to the diversification of electricity pricing plans. These control technologies must also be adapted for the small-scale base stations that will be indispensable to the mobile communications systems of the future, as they have the potential to greatly reduce battery capacity requirements compared to those of conventional systems. Thus, into the future, we plan to continue R&D for the implementation of these technologies into a range of different types of base station.

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