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What We Can Do

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The R&D Center is the hub of research and development at NTT DOCOMO. As key part of the R&D Center, the R&D General Affairs Department plays a variety of roles other than research and development. One of those roles is distributing information about research and development achievements and new services of NTT DOCOMO to a multitude of people via our "WHARF" exhibition hall. Welcoming anyone and everyone to come in and take a look, WHARF provides a space where visitors "can actually feel our future vision for the mobile communications originated in NTT DOCOMO's research and development." Since WHARF was established, 120,000 people have "felt" that vision for themselves.

Our other vital roles include cooperating with local communities, ensuring safety and security of the R&D Center, and providing an employee-friendly workplace. Some of our efforts concerning recent hot topics are described below.

The R&D Center has two employee cafeterias. When employees take a healthy meal provided twice a month there, part of the sales proceeds from the meal is automatically given as a gift to provide one meal for school children in developing countries. This activity enables our employees to make social contributions—by simply eating a healthy meal—while their health awareness is improved. So I believe we should continue it indefinitely.

Moreover, to promote self-reliance and social participation of people with disabilities in the Yokosuka area, we provide a place for selling bread, cookies, and other foods that those people made by themselves (six times a year). Although the shop is open for about two hours (including setting up), the disabled participants do their upmost from the moment they set up the stall to when they total up their sales. This activity has continued for more than ten years and has become established as popular event at the R&D Center.

A section of the R&D Center has been registered as a location for shooting TV dramas, movies, and commercials, and several scenes of TV dramas shot at that location have already been shown on TV. A number of businesses in the area are also providing filming locations to reinvigorate the Yokosuka Research Park (YRP).

Every year, around the time schools start their summer holiday, we hold an "Employee's Family Tour" of the R&D Center. As an annual event, year on year, the tour is attended by a great many families of our employees—who otherwise wouldn't get the chance to see where their parents or spouses work. The planning and operation of the tour is mainly undertaken by the employees working at the R&D Center, who dedicate themselves to devising an event that can be enjoyed by adults and children alike through activities such as laboratory tours, various events, "experience corners" for children, and a welcoming by our mascot "DOCOMODAKE" in life size. During the tour, employees' children visited workplaces, exchanged name cards with their parents' bosses, took photos with DOCOMODAKE, and so on while being escorted by mothers and fathers in a fun-packed day.

Some recent topics are described as follows. As part of celebrations for the 150th anniversary of the foundation of the Yokosuka Ironworks (shipyard), Yokosuka City invited representatives of Miss International 2015 (from 75 countries and local regions) to Yokosuka. At that time, the representatives dropped by the R&D Center and experienced some of NTT DOCOMO's latest technologies, including 5G (fifth-generation mobile networks) and services such as handwriting translation (called Tegaki Honyaku™*1). Although we were worried that the technologies presented might be difficult to understand and not so interesting to the representatives, this tour made good impressions on them (manifested in comments like "very impressive") and generated many questions. Moreover, thanks to the representatives of many nations sending messages during the tour (by SNS, etc.), we could appeal to the whole world through NTT DOCOMO's spirit of innovation. I think this event was also precious experiences for the employees who attended.

Introduced in the book entitled "The Cleaning Angels of the Bullet Trains," cleaning staff for bullet trains are referred to as "cleaning angels," and their work, which involves thankless tasks that are indispensable but go unnoticed, is referred to as "the seven minute miracle." In the book, the cleaning staff make statements like "My worksite has lot more to do than what I was told to do," "Things should get even better," and "I ought to be able to do more varied things" [1].

Similarly, although the work of the R&D General Affairs Department is often mundane and goes unnoticed, we can still acquire knowledge and generate ideas and, more than ever, change our work to "Jobs that can only be done ourselves." While holding on to that idea, I think we must continue supporting our colleagues working at the R&D Center while cherishing our relationships with our customers, local communities, and employees.

Reference

[1] I. Endou: "How Were the Cleaning Angels of the Bullet Train (the World's Strongest Workplace Power) Born?," Asa Publishing Company Limited, Oct. 2012 (in Japanese).

*1 **Tegaki Honyaku™:** A trademark of NTT DOCOMO.

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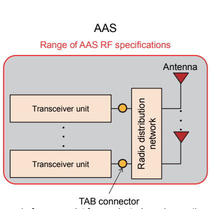

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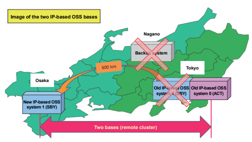

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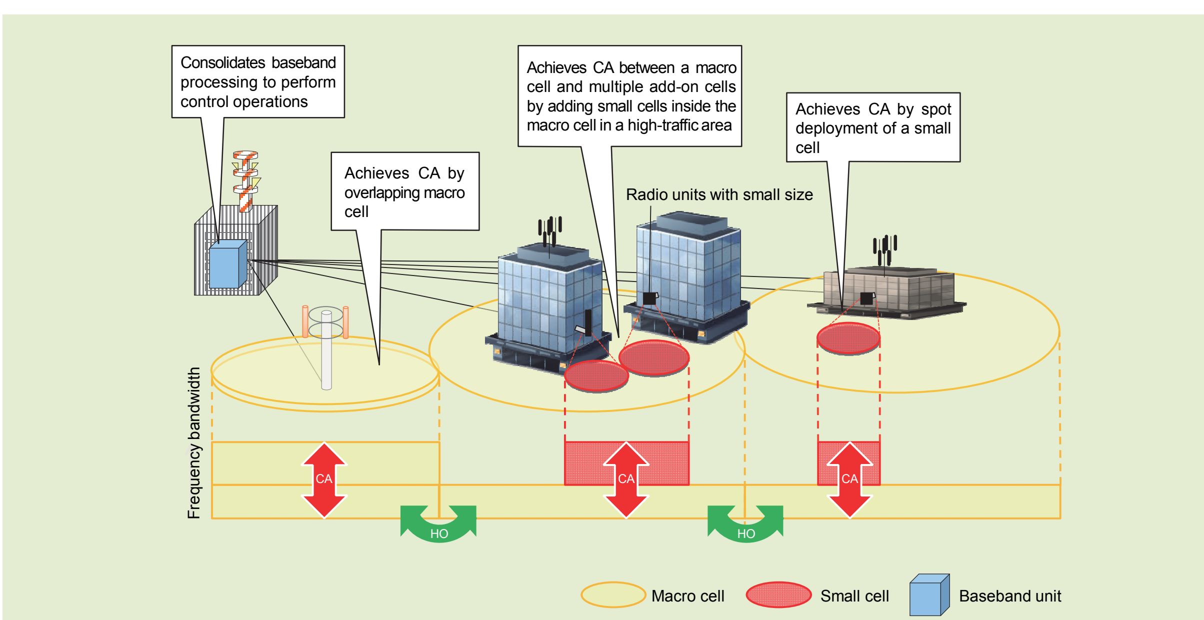

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Technology Reports

Special Articles on Introducing the 3.5-GHz Band

NTT DOCOMO's Efforts Concerning Technical Developments for Introducing TD-LTE in 3.5-GHz Frequency Band

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Hiromasa Umeda
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In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. This article describes international trends concerning the 3.5-GHz frequency band and efforts concerning NTT DOCOMO's technical developments to satisfy the technical requirements specified for domestic use.

1. Introduction

On December 19th, 2014, the Ministry of Internal Affairs and Communications (MIC) approved "Establishment Plan of Specified Base Stations*1 for Introduction of Fourth-generation Mobile Communication Systems*2," and NTT DOCOMO was assigned 3.48 to 3.52 GHz in the 3.5-GHz frequency band [1]. In June 2016, NTT DOCOMO launched a service, called "PREMIUM 4G," utilizing this frequency band.

As for efforts concerning technical developments accomplished by NTT DOCOMO to utilize the 3.5-GHz frequency band up until now, this article explains our contributions to international standardization of frequencies by the International Telecommunication Union (ITU) and our contributions to formulation of LTE-Advanced*3-related specifications stipulated by the 3rd Generation Partnership Project (3GPP).

2. International Standardization of 3.5-GHz Frequency Band

1) Identification of 3.5-GHz Band by ITU

As mobile traffic continues to grow explosively, securing new frequencies

*1 **Specified base station:** A base station that uses a specified frequency stipulated by the Radio Law. A carrier, whose plan for establishing the station is accredited by the MIC, can apply for a license to exclusively use the specified frequency.

for mobile phones is becoming a serious problem. Moreover, if mobile-phone frequencies could be utilized in many countries around the world, benefits of lowering costs of equipment and implementing international roaming would be gained. At the World Radiocommunication Conference (WRC)*4 of the ITU, efforts are being continued to commonalize (i.e., identify) mobile-phone frequencies used in each country as much as possible under the name "International Mobile Telecommunication (IMT)."

As for utilization of the 3.5-GHz frequency band for mobile phones, this band was mentioned as a domestic candidate for frequency reallocation to satisfy medium-to-long-term frequency demand of mobile communication systems in "Restructuring Policy for Frequencies" publically announced by the MIC in October 2003. Through standardization activities of the ITU after that announcement, the 3.4 to 3.6 GHz frequency band was identified for IMT in 90 or so countries (including Japan) at the WRC held in 2007 (WRC-07). Moreover, at the WRC held in 2015 (WRC-15), although some countries planning to utilize (or were already using) this band for satellite-communications systems were in opposition, the number of countries in which this frequency band is identified for IMT was further increased; consequently, this frequency band was accepted as one of the additional mobile-phone frequency bands for universal common usage.

2) Contributions of NTT DOCOMO

To assist the above standardization activities by the MIC, NTT DOCOMO has been actively contributing to these activities at the ITU [2] [3]. In particular, as required for arguments at the WRC, as a member of the Japanese delegations, we took the initiative in regard to technical studies on future demand for mobile-phone frequencies and on frequency sharing between satellite-communications systems and IMT systems. Furthermore, in regard to standardization activities concerning the band plan*5 for the 3.5-GHz frequency band, which was developed at the 3GPP in accordance with the outcome at WRC-07, NTT DOCOMO actively participated in discussions and contributed to formulation of those standards until 2009 [4].

Since the 3.4 to 3.6 GHz frequency band was accepted for mobile-phone usage in many countries in the world, it is expected that utilization of that band for mobile phones will start in various countries (**Table 1**).

3. Technological Developments for Meeting Technical Requirements Concerning 3.5-GHz Band

To get our establishment plans for specified base stations approved by the MIC, a number of requirements concerning utilization of the 3.5-GHz band had to be satisfied [5]. Among those

Table 1 International trends concerning utilization of the 3.5-GHz band

Item		Contents
ITU		・The 3,400-3,600-MHz band is identified for IMT in all countries in Region 1 (122 countries in regions of Europe, Russia, the Middle East, and Africa). ・The 3,400-3,600-MHz band is identified for IMT in all countries in Region 2 (35 countries in the North and South Americas). ・Among the countries in Region 3 (36 countries in the Asia-Pacific region), the 3,400-3,500-MHz band is identified for IMT in 11 countries and the 3,500-3,600-MHz band is identified for IMT in 10 countries.
Trends in major countries	Europe	・Regarding the frequency band covering 3,400 to 3,800 MHz, utilization for mobile-broadband communication is assumed, and in some countries, frequencies have been allocated to operators.
	USA	・Regarding the frequency band covering 3,550 to 3,650 MHz, coexistence with existing systems is being considered, and opening up frequencies for usage by mobile-broadband services is being studied.
	China	・Regarding the frequency band covering 3,400 to 3,600 MHz, under the aim of introduction of mobile-phone systems, coexistence conditions are being studied.

*2 **Fourth-generation Mobile Communication Systems:** Systems beyond the third-generation mobile communication system (IMT-2000), which are referred to as IMT-Advanced in ITU-R. The target data rates are 100 Mbps for high-mobility environments and 1 Gbps for static or low-mobility environments.

*3 **LTE-Advanced:** An enhanced radio-interface technology of LTE; its first version has been standardized as 3GPP Release 10.

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

*5 **Band plan:** A plan for using a particular frequency band. It defines parameters such as frequency range and bandwidth of uplink and downlink transmissions.

requirements, the main ones related to technical matters are listed in **Table 2**.

1) Application of CA with FDD and TDD

As for the radio access technology, it is necessary to employ Time-Division Duplexing (TDD)*6 in LTE-Advanced (TD-LTE*7). Up until now, NTT DOCOMO has introduced LTE-Advanced for our PREMIUM 4G service by Carrier Aggregation (CA)*8 using the frequency bands with Frequency-Division Duplexing (FDD)*9. When TDD is introduced in LTE-Advanced for the 3.5 GHz band, application of CA is effective as well. In particular, if existing macro-cell*10 base stations using existing FDD bands and small-cell*11 base stations using the 3.5 GHz band were linked by means of CA through the advanced C-RAN*12 architecture proposed by NTT DOCOMO, in areas in which communication traffic is dense (such as around train stations and large-scale commercial facilities), it would be possible to provide stable communication at even higher data rates (**Figure 1**) [6]. To enable CA between FDD and TDD in LTE-Advanced, NTT DOCOMO actively participated in discussions at 3GPP and successfully incorporated the relevant CA functionalities into the 3GPP Release 12 specifications [7].

2) Other Technical Developments

As for deployment of base stations to utilize the 3.5 GHz band, it is essential to utilize macro-cell base stations, which can effectively satisfy requirements regarding population coverage. Furthermore, it is necessary to deploy base stations that can handle transmission by eight antennas (i.e., so-called "advanced specified base stations") in heavy traffic demand areas. Details of development of base-station equipment and related equipment as well as development of user terminals are explained in references [8] to [11] in this special article.

4. Conclusion

This article overviewed international trends concerning the 3.5 GHz band, which is now available in Japan for mobile-phone frequencies, and NTT DOCOMO's efforts up until now concerning technical developments for meeting the technical requirements concerning domestic utilization of this frequency band.

From now onwards, it will also be necessary to develop technologies for upgrading NTT DOCOMO's mobile-phone networks in terms of further increasing data rate and expanding network capacity. NTT DOCOMO will continue making great efforts concerning standardization and equipment development so that we can continue providing users with a comfortable environment for mobile communications.

References

[1] Ministry of Internal Affairs and Communications (MIC): "Approval of Establishment Plan of Specified Base Stations for Introduction of 4G Mobile Communication Systems," MIC Press Release, Dec. 2014.
http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/

Table 2 Main technical requirements concerning utilization of the 3.5-GHz band

Item	Contents
Radio access technology	・LTE-Advanced (TDD)
Placement of specified base stations and opening time	・By the end of fourth year from the approval of the establishment plan, specified base stations should be deployed to cover more than 50% of the population within the jurisdiction of regional bureaus of telecommunications. ・By the end of second year from the approval of the establishment plan, operation of advanced specified base stations should be started in specified high traffic demand areas (such as downtown areas and transport terminals in which communications are particularly concentrated). ・In all administrative divisions of Japan, operation of specified base stations should be started.
Introduction of technology for assuring efficient utilization of frequencies	・Application of carrier-aggregation technology, adaptive modulation and coding, and other technologies for assuring efficient utilization of frequencies

*6 **TDD:** A bidirectional transmit/receive mode, which achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions that use the same frequency.

*7 **TD-LTE:** A radio access technology specified in the 3GPP standard for LTE using the TDD mode (see *6).

*8 **CA:** A technology for increasing bandwidth and data rate while maintaining backward compatibility with LTE by simultaneously transmitting and receiving multiple LTE carriers.

*9 **FDD:** A bidirectional transmit/receive mode, which achieves bidirectional communication by using different frequencies for uplink and downlink transmissions.

*10 **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.

*11 **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.

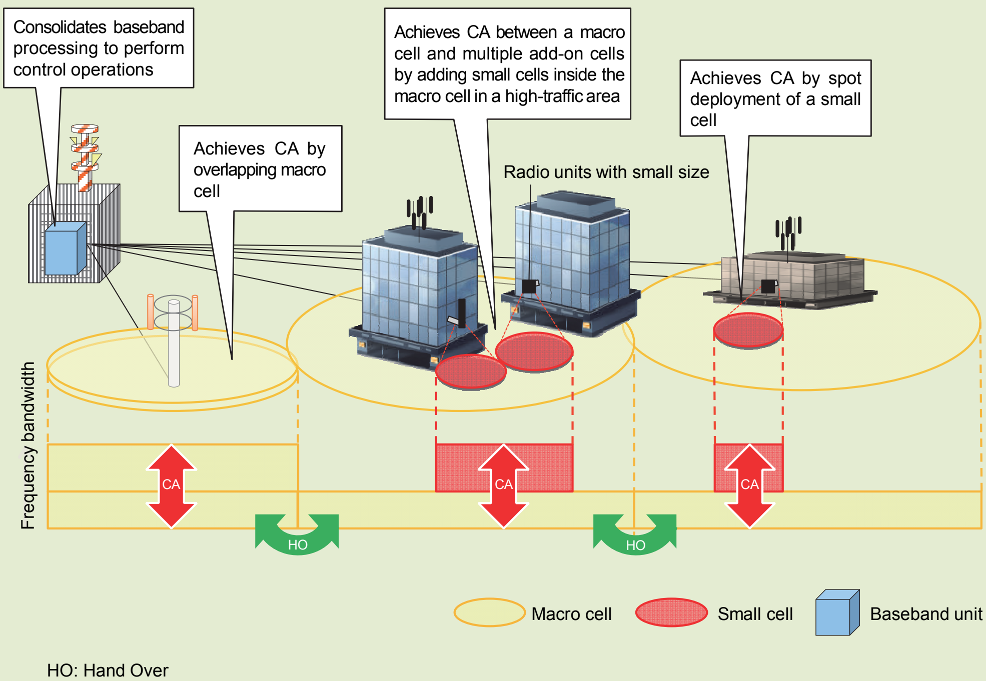

Figure 1　CA by advanced C-RAN architecture

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[3] H. Atarashi et al.: "2015 ITU World Radiocommunication Conference (WRC-15) Report - Standardization of Mobile Phone Spectrum -," NTT DOCOMO Technical Journal, Vol.18, No.1, pp.66-74, Jul. 2016.

[4] 3GPP TR 37.801 V10.0.0: "UMTS-LTE 3500 MHz Work Item Technical Report," Oct. 2011.

[5] MIC: "Results of Appeal for Opinions on Assignment of Frequencies for Introduction of Fourth-generation Mobile Communication Systems and Report from the Radio Regulatory Council," MIC Press Release, Sep. 2014. http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/140910_04.html

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

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[10] T. Yoshihara et al.: "Base-station Antennas for 3.5-GHz band," NTT DOCOMO Technical Journal, Vol.18, No.2, pp.14-17, Oct. 2016.

[11] R. Osawa et al.: "Router-type Mobile Terminal for TD-LTE in 3.5-GHz band," NTT DOCOMO Technical Journal, Vol.18, No.2, pp.27-31, Oct. 2016.

*12 **Advanced C-RAN:** A new centralized radio-access network (C-RAN) architecture proposed by NTT DOCOMO. Being controlled by the same base station, a radio access network makes a linkage between a macro cell (which covers a wide area) and a small cell (which covers a local area) by applying CA.

3.5-GHz Band TD-LTE | High-density BDE | Optical Remote Radio Equipment

Technology Reports

Special Articles on Introducing the 3.5-GHz Band

Base-station Equipment with the Aim of Introducing 3.5-GHz band TD-LTE

In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. In this article, upgrade of high-density BDE for TD-LTE (targeting introduction of 3.5-GHz band), newly developed SRE/RRE for 3.5-GHz band and FHM are overviewed.

Radio Access Network Development Department

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1. Introduction

As a more-evolved version of PREMIUM 4G, a communication service with a receiving rate up to 370 Mbps—achieved by combing newly introduced TD-LTE*1 using the 3.5-GHz band and the existing Frequency Division Duplex (FDD)*2 band by Carrier Aggregation (CA)*3—was launched in June 2016. The NetWork (NW) architecture for introducing TD-LTE using the 3.5-GHz band is shown in **Figure 1**.

PREMIUM 4G has been deployed with newly developed high-density Base-station Digital processing Equipment (BDE)*4 supporting LTE-Advanced for FDD [1] by adopting Advanced Centralized Radio Access Network (C-RAN)*5. TD-LTE is newly supported by high-density BDE with software update.

Moreover, to handle the new frequency band (3.5 GHz), two types of new radio equipment, namely, low-power Small optical remote Radio Equipment (SRE)*6 and Remote Radio Equipment (RRE)*7, were developed. As for covering areas at which required wireless network capacity is low, to accommodate an even-greater amount of radio

*1 **TD-LTE:** A data-transmission scheme, specified in the LTE standard, which uses a single frequency alternating between uplink and downlink transmissions.

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

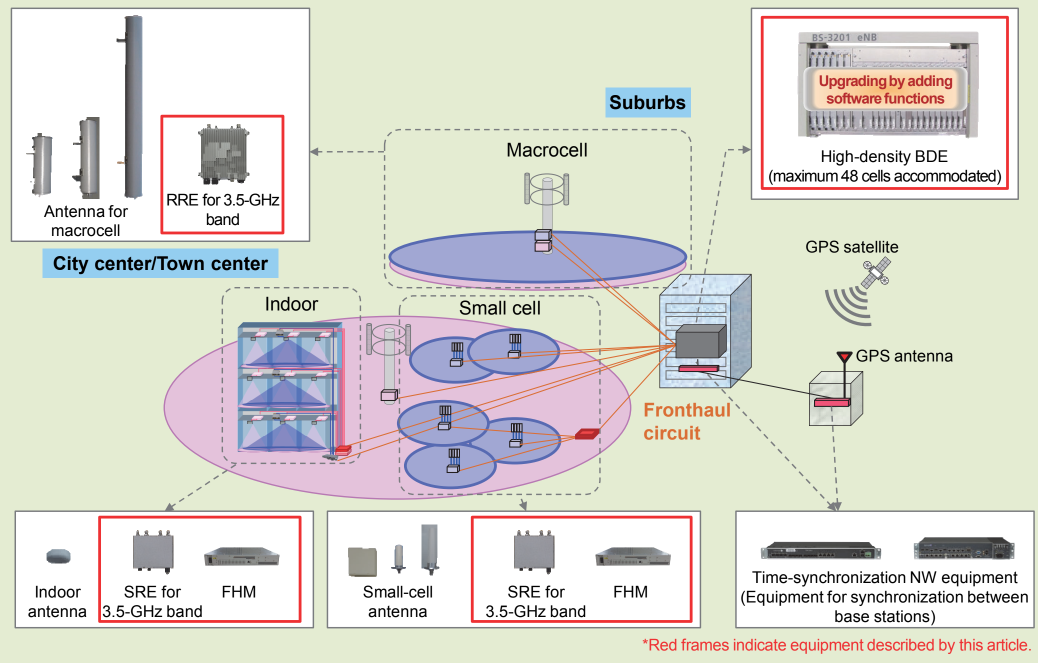

Figure 1 NW architecture for introducing 3.5-GHz band TD-LTE

equipment by one high-density BDE unit, a FrontHaul Multiplexer (FHM)*8, for distributing fronthaul circuits*9 between BDE and radio equipment, was developed. In this article, upgrade of high-density BDE for TD-LTE (targeting introduction of 3.5-GHz band) development of SRE/RRE for handling the 3.5-GHz band and the one of FHM are overviewed.

2. Upgrade of High-density BDE for TD-LTE

Upgrade for TD-LTE (enabled by software update) consists of TD-LTE support of BaseBand (BB)*10 signal-processing units, higher data rate support for the fronthaul, and adding synchronization function among base stations. Each of them is explained in detail in the following sections.

2.1 BBs with TD-LTE Support

For transmitted signals, BB functional unit performs error-correction coding, radio framing, data modulation, frequency-time transformations, Multiple Input Multiple Output (MIMO)*11 transmission, and for received signals, it performs time-frequency transformations, data demodulation, signal separation, error-correction coding, and so on [2]. Except for the signal processing of this functional unit, the ones of other function units are for higher-layer protocols (e.g. call processing) which are common for both FDD and Time Division Duplex (TDD) [3].

To support TDD, this functional unit was updated by software. By making it possible for each cell to switch either FDD or TDD, mixed operation of FDD cell(s) and TDD cell(s) on a single high-density BDE unit becomes possible. In this way, CA combining the FDD band and the TDD band is enabled.

2.2 Supporting High-speed Data Rate of the Fronthaul

As for the fronthaul for 3.5-GHz band, since it has wider bandwidth than conventional ones and we also upgrade MIMO for higher order (described later), data rate of the fronthaul was extended

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

*4 **BDE:** In compliance with LTE, BDE has functions for baseband processing and maintenance and monitoring.

*5 **Advanced C-RAN:** A network architecture—put forward by NTT DOCOMO—for harmonizing macrocells and small cells.

*6 **SRE:** radio equipment (using optical fibers, etc.) for small cells in places remotely located from BDE.

*7 **RRE:** Radio equipment in places remotely located from BDE.

*8 **FHM:** Equipment for distributing multiple fronthaul lines between BDE and radio equipment.

*9 **Fronthaul circuits:** Lines, using optical fibers, etc., between BDE and radio equipment. The interfaces between this equipment comply with the Common Public Radio Interface (CPRI) standard.

to up to 9.8 Gbps from 2.4 Gbps (conventional). In this way, Radio Frequency (RF) signal up to four branches for 3.5-GHz band can be transmitted/received with a single fronthaul line.

2.3 Adding Synchronization Function between Base Stations

In the case of TDD, as shown in **Figure 2**, synchronization between base stations is necessary to avoid interference between uplinks and downlinks. Moreover, as there is no guard band*12 between the bands allocated to operators, synchronization between base stations deployed by different operators is also necessary to prevent interfering each other by spurious emission*13.

To achieve that, high-density BDE supports a GPS synchronization function (for synchronizing with GPS) and a Precision Time Protocol (PTP) synchronization function [4] (by which high-density BDE synchronizes to a server synchronized with GPS by the PTP). Thus, the transmission timing of the radio frame at the antenna connectors of remote radio equipment connected to high-density BDE synchronizes with Coordinated Universal Time (UTC) obtained from GPS or PTP. As for transmission timing synchronization accuracy, less than ± 1.5 μs was attained. In this way, high-density BDE meets the synchronization accuracy requirement between base stations, less than 3 μs specified by 3rd Generation Partnership Project (3GPP), and can prevent interference between our base stations and the one between our base stations and other operators' base stations.

3. Optical Remote Radio Equipment for 3.5-GHz band

Since the requirements for radio equipment differ in the cases of small cells and macrocells, SRE and RRE for 3.5-GHz band were developed with different specifications optimized to each scenario (SRE for small cells and RRE for macrocells). SRE and RRE mainly consists of a Transmitter and Receiver INterFace (TRX-INF)*14, a Transmission-Power Amplifier (T-PA)*15, a Low-Noise Amplifier (LNA)*16, a Switch*17 or CIRculator (CIR)*18, and a Band-Pass Filter (BPF)*19. The main point of difference is that in the case of FDD, a DUPlexer (DUP)*20 is used, but in the

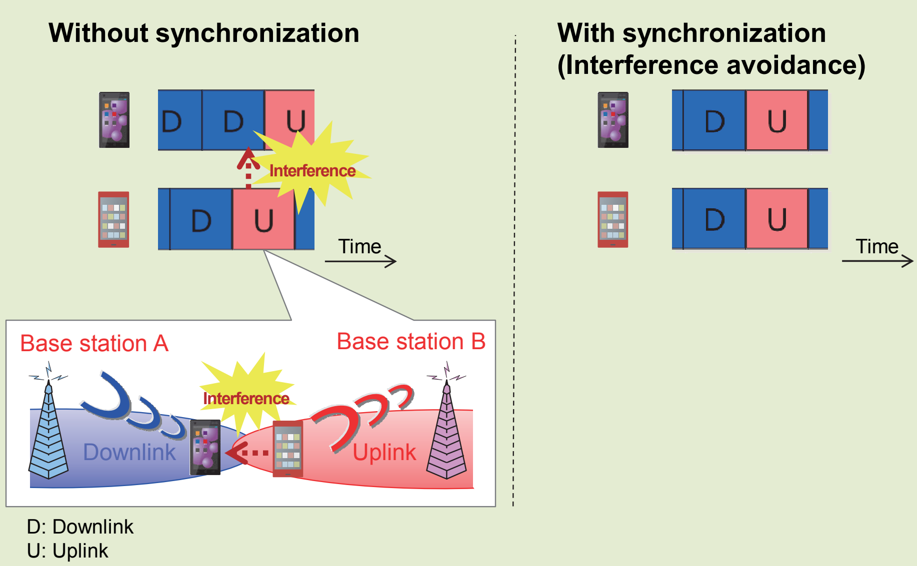

Figure 2 Avoidance of interference between uplink and downlink for TDD by synchronization between two base stations

*10 **BB:** A circuit or functional unit that performs digital signal processing.

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

*12 **Guard band:** A frequency band set between the frequency bands allocated to different wireless systems to prevent interference between the RF signals of those systems.

*13 **Spurious emission:** An unwanted emission that appears out of channel bandwidth when a signal is transmitted.

*14 **TRX-INF:** A functional unit for converting IQ signals and maintenance-monitoring signals in accordance with CPRI and transmit and receive the converted signal via optical fiber.

*15 **T-PA:** A functional unit for amplifying the power of an RF signal transmitted from a TRX to a desired level.

*16 **LNA:** A functional unit for initially amplifying the signal received by an antenna. It amplifies while adding low-noise and little signal distortion.

case of TDD, a Switch/CIR and BPF are used. The basic specifications of SRE and RRE are listed in **Table 1**, and their external appearances are shown in **Figure 3**. The main features of SRE and RRE are described in the following sections.

3.1 SRE

In places where a large number of people gather (such as city and town centers), it is suitable to cover the area by small cells to increase capacity. In comparison with macrocells, small cells have the advantage that they effectively utilize MIMO technology. Thus, the number of branches per SRE is four to achieve higher data rate by MIMO technology with one SRE. Moreover, by suppressing maximum output power per SRE as 3.84 W to optimize operating small cells, the size of the SRE could be kept below 4 ℓ.

3.2 RRE

To cover the suburbs area effectively, macrocell is suitable. In consideration that the maximum cell radius of a macrocell is about 2 km, maximum output power is specified as 19 W per 20 MHz per branch*21. In consideration of installability of RRE and antennas for macrocells, the number of branches per RRE is two. And to achieve four-branch operation, cascade connection of two RREs can be handled (see **Figure 4**).

Table 1 Basic specification of SRE and RRE for 3.5-GHz band

Item	3.5-GHz band	
	SRE	RRE
Maximum transmission power	0.48 W/20 MHz/branch	19 W/20 MHz/branch
Number of branches	4	2
Size	Less than or equal to 4 ℓ	Less than or equal to 9 ℓ
Equipment weight	Less than or equal to 4.5 kg	Less than or equal to 12 kg
Power consumption	Less than or equal to 100 W	Less than or equal to 380 W
Power source	AC 100 V/200 V	DC – 48 V

(a) SRE (b) RRE

Figure 3 External appearance of SRE and RRE compatible with 3.5-GHz band

*17 **Switch:** A circuit for switching (on a time basis) transmitting and receiving circuits connected by RF connectors.

*18 **CIR:** A circuit (with more than three terminals) for outputting the signals input from one terminal to the next terminal only.

*19 **BPF:** A filter passing only a specific frequency band.

*20 **DUP:** A device consisting of a transmitter filter and a receiver filter. It allows a single antenna transmission and reception.

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

4. FHM

A FHM has a function for distributing and combining a maximum of 16 RF signals on the fronthaul. The external appearance of a FHM is shown in **Figure 5**. By using a FHM, it is possible to operate multiple radio equipment connected to a high-density BDE as one cell (see **Figure 6**).

In this way, a greater number of radio equipment connected to a single high-density BDE can be deployed for the area where the need for wireless network capacity is low. Moreover, all remote radio equipment connected to a FHM transmit and receive RF signals as the same cell. Accordingly, it is possible to reduce the interference between remote radio equipment and suppression of frequent handover*22 when a mobile terminal moves between remote radio equipment. Still, as well as being connected to radio equipment for 3.5-GHz band, a FHM can be connected to radio equipment for the existing frequency band.

5. Conclusion

In this article, upgrade of high-density

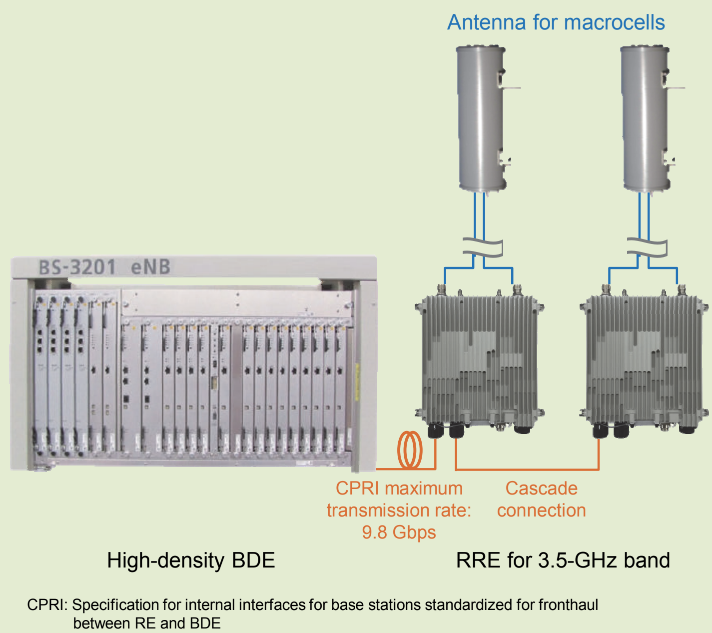

Figure 4 Cascade configuration for handling four branches

Figure 5 External appearance of FHM

*22 **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal straddles the cells operated by two base stations while moving.

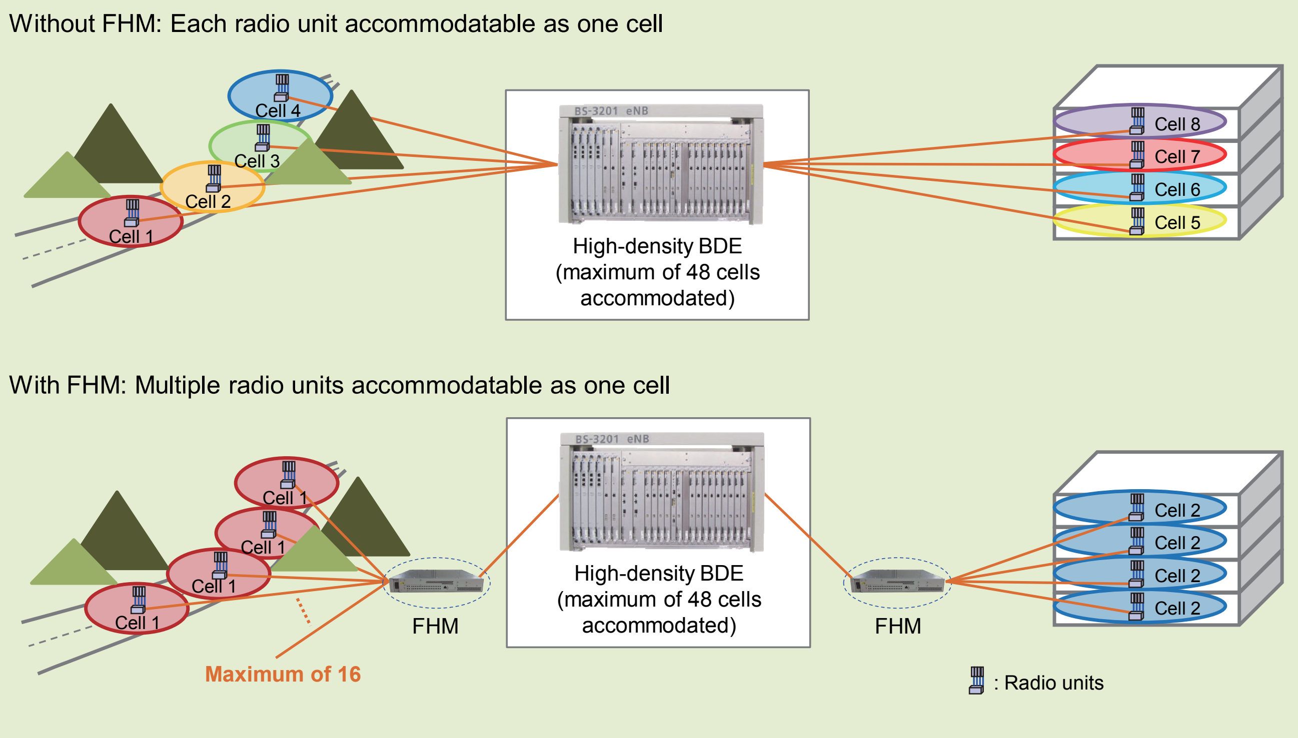

Figure 6　Accommodating radio units with a high-density BDE via a FHM

BDE for TD-LTE (targeting introduction of 3.5-GHz band), newly developed SRE/RRE for 3.5-GHz band and FHM are overviewed. From now onwards, by MIMO enhancement, further higher-order modulation, and expanding the number of frequency bands simultaneously operating CA and so on, we will continue development aimed at further enhancing our PREMIUM 4G service.

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3.5-GHz Band | Base Station Antenna | Remote Tilt

Technology Reports

Special Articles on Introducing the 3.5-GHz Band

Base Station Antennas for 3.5-GHz Band

In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. In this article, we overview new base-station antennas developed for small cells, indoor use, and macro cells to support this introduction of TD-LTE in the 3.5-GHz band.

Radio Access Network Development Department *Tatsuhiko Yoshihara*
Hiroyuki Kawai †
Sho Yoshida
Teruo Kawamura

1. Introduction

To meet the technical requirements for using frequencies in the 3.5-GHz band allocated by the Ministry of Internal Affairs and Communications in December 2014 [1], NTT DOCOMO developed new base-station antennas for small cell*1, indoor, and macro cell use, as summarized below.

(1) Small cell base stations are being rolled out in outdoor areas with high volumes of traffic such as areas surrounding train stations to provide stable communications at higher speeds. To be effective, the formation of small cell service areas must consider the purpose of use and a variety of installation conditions (building walls, rooftops, etc.). For this reason, NTT DOCOMO developed three types of compact antennas for small-cell base stations.

(2) Use of the 3.5-GHz band is also vital in indoor areas such as large-scale commercial facilities to support ever-increasing volumes of traffic. To meet this indoor need, NTT DOCOMO developed a compact antenna for mounting on ceilings to form a service area on the floor of a building.

(3) The 3.5-GHz band will also be introduced in macro cell base stations to provide high-speed communications for more than just high-traffic areas such as

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*1 **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.

train station neighborhoods. To form a broad service area with a macro cell, NTT DOCOMO developed a base-station antenna with high antenna gain*2 for installation in existing building and steel-tower base stations.

In this article, we describe the features of these new base-station antennas developed by NTT DOCOMO to meet a variety of usage scenarios and installation conditions.

2. Antennas for Small Cells

Major specifications of antennas for small cells are listed in **Table 1**. Three types of antennas were developed taking into account diverse installation platforms such as building walls and roofs and interference with adjacent small cells. These antennas have vertical/horizontal polarization*3 in common, and compared with small-cell antennas supporting the 1.5 and 1.7 GHz bands [2], they are compact in size. The following summarizes the features of each of these antennas.

1) Rod Antenna (Two Types)

This is a rod-shaped antenna that is vertically installed to form a radiation pattern with no directivity*4 (omnidirectional radiation pattern) in the horizontal plane. It can be installed on a building wall or steel pillar to form a service area in its periphery. Two types of rod antennas have been developed: one with electrical tilting*5 that can reduce interference with adjacent small cells [3], and the other with no tilting for a compact configuration.

2) Plane Antenna

This is a box-shaped antenna having a planar radiating surface and unidirectional radiation pattern. Its high antenna gain makes it applicable to forming spot-like service areas from high locations such as building roofs. In addition to mechanical tilting to reduce interference between small cells, this antenna features a low sidelobe*6 design to further reduce interference.

3. Antenna for Indoor Use

Major specifications of the antenna for indoor use are listed in **Table 2**. When forming a new service area using the 3.5-GHz band, it must be kept in mind that antenna units supporting the 1.5/1.7/2-GHz bands have already been installed indoors [4]. Installation space is therefore limited, which means that replacing existing antenna units is desirable. This newly developed antenna

Table 1 Major specifications of antennas for small cells

Antenna type	Rod antenna with tilting	Rod antenna with no tilting	Plane antenna
Appearance			
Supported frequencies	3.5-GHz band		
No. of branches	2		
Horizontal directivity	Omnidirectional		Unidirectional
Tilt support	Electrical tilting (remote control not supported)	No tilting	Mechanical tilting
Size (mm)	Under ϕ 49 × 240	Under ϕ 49 × 140	Under 150 × 150 × 60

*2 **Antenna gain:** Relative signal power in the direction of maximum radiation (main beam).

*3 **Polarization:** Direction of electric-field oscillation. Oscillation 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.

*4 **Directivity:** The property of an antenna in which signal intensity differs according to direction. An omnidirectional antenna radiates signals with the same intensity in all directions and a unidirectional antenna radiates strong signals in only one direction.

unit therefore supports the 1.5-, 1.7-, 2-, and 3.5-GHz bands in one unit with support of the 3.5-GHz band achieved through Multiple Input Multiple Output (MIMO) operation using four antenna elements. The antenna unit has the same size as existing antenna units supporting the 1.5/1.7/2-GHz bands making antenna unit replacement simple. The 3.5-GHz band can therefore be introduced without changing the overall look of indoor facilities.

The polarization configuration of the four antenna elements used for the 3.5-GHz band was studied by comparing a "vertically polarized element × 4" configuration with a "vertically polarized element × 2 and horizontally polarized element × 2" configuration. Since the size of the newly developed antenna unit is the same as existing ones, sufficient spacing between antenna elements cannot be secured, and as a result, the configuration having only vertically polarized elements exhibits high antenna correlation*7 compared with the configuration having both vertically and horizontally polarized elements. This high antenna correlation causes throughput*8 to drop. For this reason, we adopted the latter configuration providing higher throughput (low antenna correlation).

Table 2 Major specifications of antenna for indoor use

Appearance	
Supported frequencies	1.5/1.7/2/3.5-GHz bands
No. of branches	1.5/1.7/2-GHz bands: 2 3.5-GHz band: 4
Size (mm)	150 × 150 × 40

4. Antennas for Macro Cells

Major specifications of antennas for macro cells are listed in **Table 3**. Three types of antennas were developed here

Table 3 Major specifications of antennas for macro cells

Antenna type	Gain-oriented	Installation-oriented	
Appearance			
No. of sectors	3	3	6
Supported frequencies	3.5-GHz band		
No. of branches	2		
Tilt support	Electrical tilting (remote control supported)		
Size (mm)	Under ϕ 125 × 1,400	Under ϕ 125 × 600	Under ϕ 155 × 500

*5 **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 to tilt the main beam.

*6 **Sidelobe:** A weak signal radiated outside the direction of maximum radiation (main lobe). A sidelobe is generally radiated in an undesired direction and must therefore be suppressed.

*7 **Correlation:** An index expressing similarity between different signals. Expressed as a complex number, its absolute value ranges from 0 to 1. Similarity is higher for a value closer to 1, in which case signal separation at the receiver is difficult resulting in a drop in throughput.

*8 **Throughput:** Effective amount of data transmitted without error per unit time.

according to the service area to be formed: two types (gain-oriented and installation-oriented) for use with three sectors and one type (installation-oriented) for use with six sectors. To install and operate these antennas together with other base-station antennas supporting the 700- and 800-MHz bands, 1.5-, 1.7- and 2-GHz bands, etc., it may be difficult to secure space for setting up a new steel pillar for an antenna supporting the 3.5-GHz band on a building roof or elsewhere in an urban area. Accordingly, to make it easy to install a new antenna on the same steel pillar mounting existing antennas, we also developed an installation-oriented type of antenna with roughly half the volume of the gain-oriented type. In these antennas for macro cells, remote control signals can be used to drive internal phase shifter*9 devices and control tilting. We adopted the global standard specified by the Antenna Interface Standards Group (AISG)*10 as the interface here for remote control of the tilt angle.

5. Conclusion

This article described the features of new base-station antennas developed for small cell, indoor, and macro cell use to support the newly available 3.5-GHz band. Base-station antennas are important facilities closely tied to area formation in a cellular system. Going forward, NTT DOCOMO is committed to developing advanced antennas to provide users with an even better network experience including enhanced radio capacities and faster communication speeds.

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*9 **Phase shifter:** A circuit that can change the phase going to each antenna element.

*10 **AISG:** An interface standards group formulating standards for remote control and monitoring of antenna tilt angle. AISG standards have been adopted as 3GPP technical specifications.

High-precision Time Synchronization | TD-LTE | UTC

Technology Reports

Special Articles on Introducing the 3.5-GHz Band

High-precision Clock-time-synchronization Network Equipment for Introduction of 3.5-GHz band TD-LTE

In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. This article summarizes technologies and describes characteristic features in regard to high-accuracy time-synchronization networks—a required future technology—for providing services based on the TDD method (which is being introduced by NTT DOCOMO for the first time).

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Genta Nishimura
Solution Services Division, DOCOMO Technology, Inc. — *Hirotoshi Sugimoto*

1. Introduction

In December 2014, the MIC allocated the 3.5-GHz frequency band to NTT DOCOMO. In accordance with a requirement for utilization of that band, the Time Division Duplex (TDD)*1 method must be used. Accordingly, when introducing the 3.5-GHz frequency band, NTT DOCOMO adopted TD-LTE standard technology (which is one version of the LTE standard).

As for TD-LTE, the frequency band can be used to the full because the frequencies of the uplink and downlink channels do not have to be separated. On the other hand, if the signals of the uplink and downlink channels are sent at the same time, radiowave interference can be generated. Extremely accurate clock-time synchronization—between not only our base stations but also those of other communication carriers—is thus necessary.

The accuracy of that clock-time synchronization is specified in the International Telecommunication Union-Telecommunication Standardization sector (ITU-T) Recommendation G.8271*2 as a time-synchronization error between

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

base-station-equipment time and Coordinated Universal Time (UTC)*3 that must be kept to 1.5 μs or below (**Figure 1**). High-accuracy time synchronization can be achieved by directly receiving radiowaves (such as GPS signals) at base-station equipment, deriving UTC, and using that time. However, at base stations that cannot receive radiowaves like GPS signals (such as underground base stations), time-synchronization methods using Ethernet transmission are adopted.

The Network Time Protocol (NTP)*4 commonly used for time synchronization, however, it cannot be utilized as the time-synchronization method for TD-LTE, even if stratum-3*5 is applied, because time-synchronization error in relation to UTC is in the order of milliseconds, namely, time-synchronization accuracy is low. Consequently, a high-accuracy time-synchronization protocol called Precision Time Protocol (PTP) is applied (**Table 1**).

As for PTP, using a highly versatile Ethernet transmission path makes it basically possible to transmit stabilized time with high accuracy to base-station equipment without dependence on distance. Networks adopting PTP are configured with components called Grand-Master Clock (GMC)*6 and Boundary Clock (BC)*7. In this article, a high-accuracy time-synchronization network adapting TD-LTE using these components is described [1] [2].

2. Time-synchronization Method

Two kinds of time-synchronization methods using Ethernet transmission paths are specified by the ITU-T: "full-on path support" and "assisted partial timing support." Each method is summarized below (**Figure 2**).

"Full-on path support" achieves high-accuracy time transmission because all equipment on paths from GPS transmitters to base-station equipment supports BC capability (which corrects and re-sends timing errors by statistical processing) and transmits PTP packets.

"Assisted partial timing support" achieves time synchronization in a configuration including equipment in the paths that is incompatible with BC capability. While existing Ethernet networks can be utilized, the influence of factors such as processing delay of non-BC-compatible equipment is significant; therefore, it is not always possible to assure time-synchronization accuracy with this configuration. Assisted partial timing support is prescribed for use as a backup method to be used in the

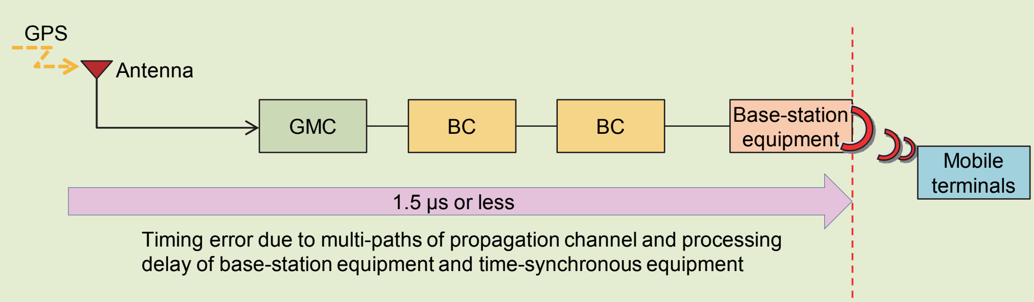


Figure 1 Condition of clock-time error in the case of TD-LTE

Table 1 Time-synchronization protocol

Protocol	Synchronization accuracy	Synchronization method
NTP	Approx.1 ms	In reference to a time standard maintained by a server, times are synchronized according to requests from clients.
PTP	1.5 μs or less	Times are synchronized by exchanging messages between equipment taking the roles of master and slave.

*2 **ITU-T Recommendation G.8271:** An ITU-T recommendation that defines clock time and phase synchronization for packet networks.

*3 **UTC:** Time on which standard time around the world is based.

*4 **NTP:** A communication protocol for correcting the internal clock of computers via networks.

*5 **Stratum-3:** Devices on the third stratum—in regard to UTC—in an NTP-hierarchical structure. Clock time is generally delivered to a client from stratum-3.

*6 **GMC:** UTC-time information is extracted from signals (such as GPS signals) and delivered to downlink equipment as packets. The GMC is located at the apex of the PTP communication structure.

case that base-station equipment receives direct radiowaves (such as GPS signals).

NTT DOCOMO is expanding TD-LTE so that it can also be used in places that cannot receive GPS signals (such as underground). Accordingly, as a time-synchronization method, full-on path support was adopted instead of assisted partial timing support—which is presupposed to be used as a backup method.

3. Mechanism of High-accuracy Time Synchronization

As shown in **Figure 3**, a time-synchronization network is configured with a GMC at its apex. In each link of this configuration, the downlink port of uplink equipment plays the role of "master," and the uplink port of downlink equipment plays the role of "slave." Messages are exchanged between the master and slave in accordance with the PTP sequence described in the following (**Figure 4**). Moreover, providing an action that cancels delay within equipment makes it possible to achieve high-accuracy time synchronization.

3.1 PTP Message Type

The PTP messages are generally classified as "announce" or "event" messages.

1) Announce Message

Announce messages are used for communication of information about session*8 establishment and time synchronization by sending messages from master to slave.

2) Event Message

- Sync: A message sent from master to slave. It records the time the message was sent from the master.
- Delay_Req: A message returned to the master from the slave that received the Sync message.
- Delay_Resp: A message sent from the master to the slave. It records the time the Delay_Req message was received by the master.

3.2 PTP Sequence

Time correction can be achieved by

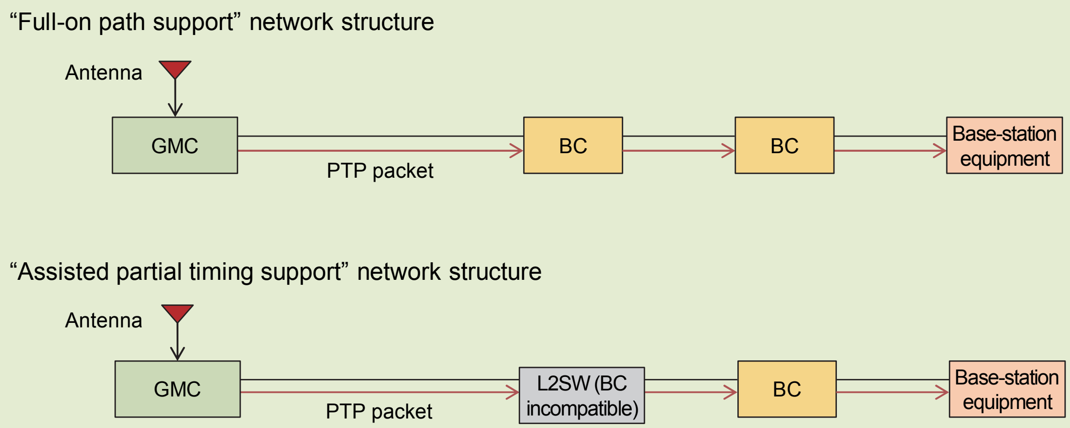


Figure 2 Time synchronization

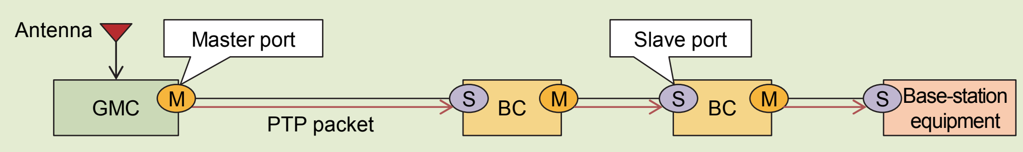


Figure 3 Configuration of time-synchronization network

*7 **BC:** A component that re-sends clock time from uplink equipment to downlink equipment after correcting it.

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

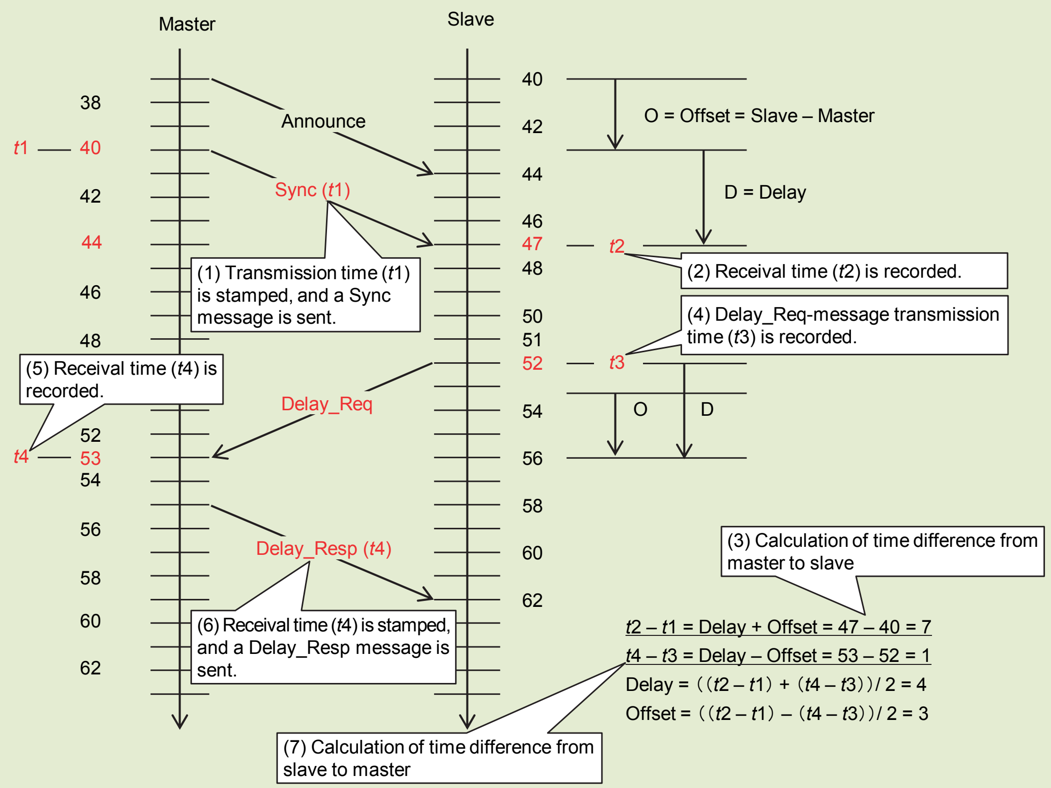


Figure 4 PTP sequence

determining the time difference between the master and slave and calculating the transmission-path delay and time lag (hereinafter referred to as "offset") between equipment (Fig. 4).

1) Calculation of Time Difference from Master to Slave

(1) The master sends a Sync message [stamped with the time it was sent ($t1$)] to the slave.

(2) The slave records the time ($t2$) that it received the Sync message.

(3) The slave determines the time difference from the master to the slave from $t1$ and $t2$ (i.e., 47 – 40 = 7, as shown in the middle of Fig. 4).

2) Calculation of Time Difference from Slave to Master

(4) The slave sends a Delay_Req message to the master, and it records the time ($t3$) that the message was sent.

(5) The master receives the Delay_Req message and records the time ($t4$) it receives the message.

(6) The master sends a Delay_Resp message (stamped with $t4$) to the slave.

(7) The slave receives the Delay_Resp message and determines the difference between $t4$ and $t3$ (i.e., $t4 - t3 = 53 - 52 = 1$, as shown in the middle of Fig. 4).

3) Calculation of Transmission-path Delay and Offset

Transmission-path delay and offset are calculated on the basis of a precondition under which the transmission-path delay time between the master and slave is symmetrical as follows:

- transmission-path delay = $\{(t2 - t1) + (t4 - t3)\}/2 = (7 + 1)/2 = 4$
- offset = $\{(t2 - t1) - (t4 - t3)\}/2 = (7 - 1)/2 = 3$

In the case that transmission-path distances from the master to the slave and from the slave to the master are symmetric, arrival times at the master and slave will be consistent. Calculating the total of the transmission-path delay and offset and dividing that value in two therefore gives the transmission-path delay time. And dividing the difference in those values in two gives the offset. The slave always performs time correction within the equipment in which it is installed on the basis of the transmission-path delay time and offset. As a result, high-accuracy time synchronization between each session of PTP equipment (GMC and BC) is accomplished.

3.3 Cancellation of Internal Equipment Delay

To correct delay occurring within equipment, a correction field*9 including PTP packets is used. Adding a correction value to the event message sent by the master allows the slave to cancel the internal delay of the master (**Figure 5**).

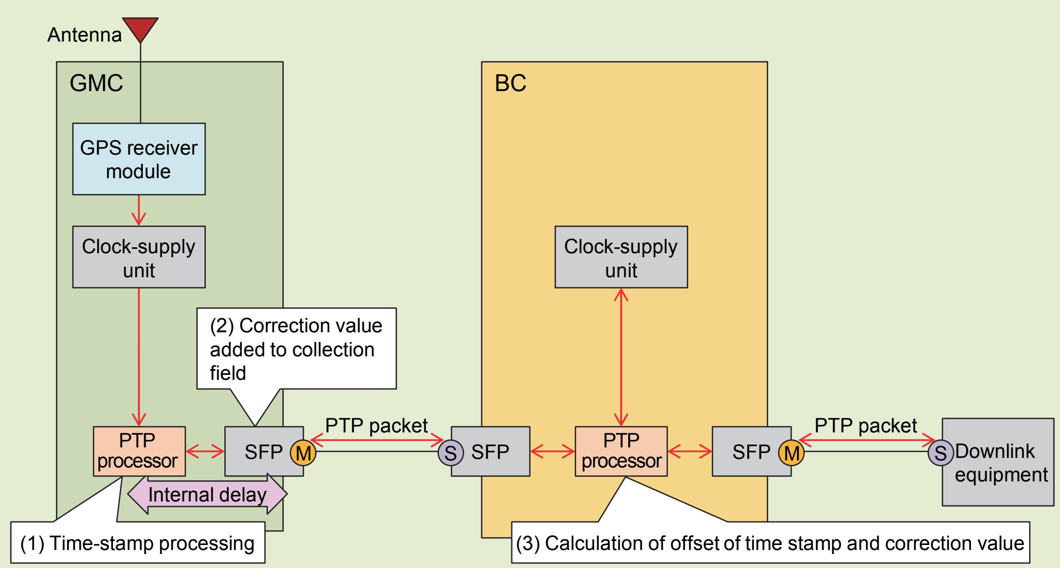
4. Outline of Functions of PTP Equipment

4.1 Functional Block

As shown in **Figure 6**, the GMC has a GPS receiver module (for receiving signals like GPS ones and extracting time information from them), a clock-supply unit (which houses a Sync-E*10 processing block) for storing that information as the system clock of the equipment in question. It also has a PTP processing block (for generating and embedding time stamps from the clock-supply block in PTP packets) and a PPS processing block for sending 1 Pulse Per Second (1PPS)*11 signals. In contrast to the functional blocks of the GMC, those of the BC do not include a GPS receiver module.

4.2 Combined Use with Sync-E

Although time synchronization is executed under the assumption that frequency synchronization*12 is imposed, frequency synchronization under PTP executed on Ethernet networks is independent in terms of each piece of equipment, and the whole network is asynchronous. On the other hand, Sync-E operates on a physical layer; therefore, frequency synchronization can be performed with high accuracy regardless of fluctuations in communication volume, and the whole network is synchronous. Under those circumstances, NTT DOCOMO judged that combined use of PTP and Sync-E would be



Small Form-factor Pluggable (SFP): A removable module that can be installed in equipment in accordance with the communication standards in use.

Figure 5 Mechanism of internal-delay cancellation for GMC and BC equipment

*9 **Correction field:** A field including PTP packets used for transmitting internal equipment delay.

*10 **Sync-E:** A method for synchronizing frequencies on the physical layer. All equipment on a transmission route performing synchronization must handle Sync-E.

*11 **1PPS:** A pulse signal sent once per second.

*12 **Frequency synchronization:** A condition under which the speed at which time is kept is consistent from one piece of equipment to the next.

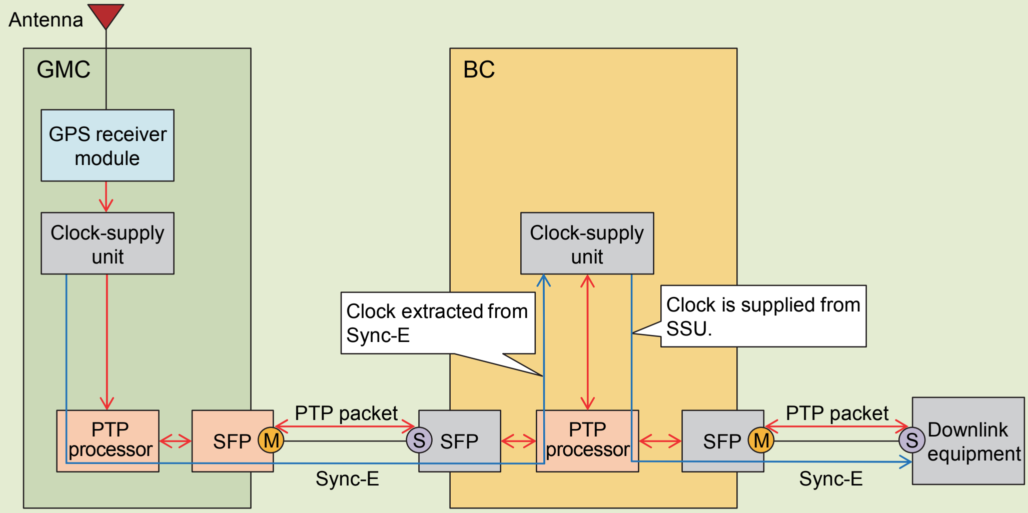


Figure 6 Functional blocks of GMC and BC

effective for the high-accuracy time synchronization required by TD-LTE, so we adopted a method combining PTP and Sync-E. Combining PTP and Sync-E in this manner for all equipment of a time-synchronization network makes it possible to improve the time-synchronization accuracy along a whole ("end-to-end") communication route because the times for processing PTP packets are consistent.

4.3 BMCA

To handle failures, BC equipment can combine a maximum of two uplink PTP units in a redundant configuration by applying a function called a Best-Master Clock Algorithm (BMCA). This function is accomplished as a result of the master recording the performance value of its own time information in the announce message and regularly communicating with the slave. The slave can receive time information from two masters, judge the masters on the basis of their performance values, and select the BMC accordingly. Which of the two pieces of received time information to use for synchronization is judged by means of a "BMCA sequence" (as shown in **Figure 7**). Furthermore, although synchronization is performed with the selected BMC, if communication with that BMC fails, time synchronization is performed with the other master. The performance value included in the time information received from the masters is classified as one of the following six kinds (and the master with the highest value is selected).

(1) Priority 1

A priority 1 value indicates the unconditional priority of GMCs. It is a set value specified in IEEE1588-2008[*13] and cannot be changed. In the case of BC, priority 1 is passed down to downlink equipment.

(2) Clock Class

"Clock Class" is a value that indicates the synchronization state between UTC and the time sent from the master (as shown in **Table 2**). In the case that the two are synchronized, a Clock Class "6" (hereinafter referred to as "CC6") is sent.

(3) Clock Accuracy

"Clock Accuracy" is a value that indicates the accuracy of time. The values handled by NTT DOCOMO's PTP equipment are shown in **Table 3**.

(4) Offset Scaled log Variance

"Offset Scaled log variance" indicates the stability of clock-synchronization accuracy as shown in **Table 4**.

(5) Priority 2

"Priority 2" is a value that indicates the unconditional priority of GMCs. However, unlike priority 1, it can be varied; that is, by setting

*13 **IEEE1588-2008:** An IEEE standard that defines a protocol for high-accuracy clock-time synchronization used for financial and communication systems.

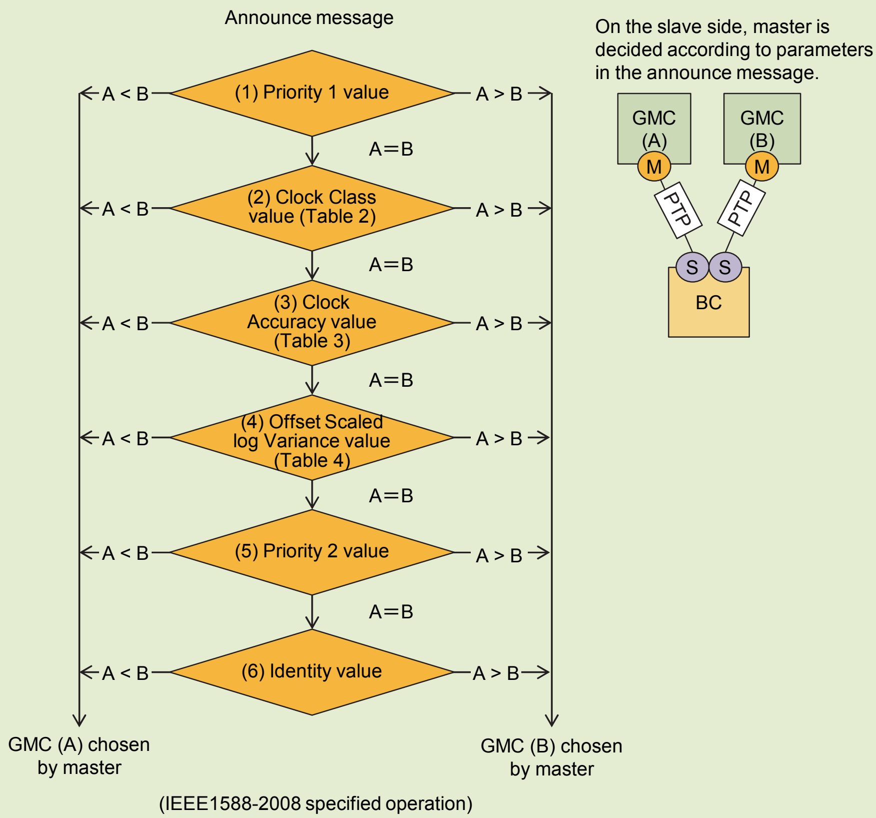


Figure 7 BMCA sequence

Priority 2, the user can select the BMC that must be synchronized.

(6) Identity

"Identity" is a value calculated from the Media Access Control (MAC) address*14 of equipment as a unique value allocated to each piece of equipment.

5. Aiming to Provide Stable Services

5.1 Improvement of Operation of PTP Equipment

When the GMC is synchronized with UTC, delivery of clock time (along with CC6) to downlinks starts.

Table 2 Clock Class

Value (hexadecimal notation)	Explanation of condition
6	Synchronization with UTC
140, 150, 160	GMC is hold over.
165	BC is not synchronized with master.
248	GMC: During initial start-up operation or hold-over BC: During initial start-up operation

Table 3 Clock Accuracy

Value (hexadecimal notation)	Explanation of condition
21	Time accuracy within 100 ns
FE	unknown

Table 4 Offset Scaled log Variance

Value (hexadecimal notation)	Explanation of condition
4E5D	Synchronization with UTC
FFFF	Not synchronized with UTC

*14 **MAC address:** A 12-digit fixed physical address allocated to an Ethernet board.

On the other hand, due to periodic failures of time-synchronization networks, even under the condition that an error between the system clock and UTC occurs, if CC6 is received, clock time is delivered to subordinate equipment. As a result, it has been typically necessary to periodically stop services delivered on the basis of TD-LTE. As a countermeasure against that necessity, by reviewing the behavior of clock-time error convergence and significantly shortening the time required for convergence, it is possible to shorten the time that failures effect services (**Figure 8**).

5.2 Influence of Multipaths

Radiowaves (like GPS signals) can be categorized as direct waves or reflected waves according to the surrounding environment (**Figure 9**). With reflected waves referred to as "multipath waves," in regard to accurate clock-time synchronization, clock-time error is increased (**Figures 10** and **11**). At present, it is impossible to completely exclude multipath waves; accordingly, at NTT DOCOMO, while considering increase in clock-time error due to the influence of multipath waves, we are

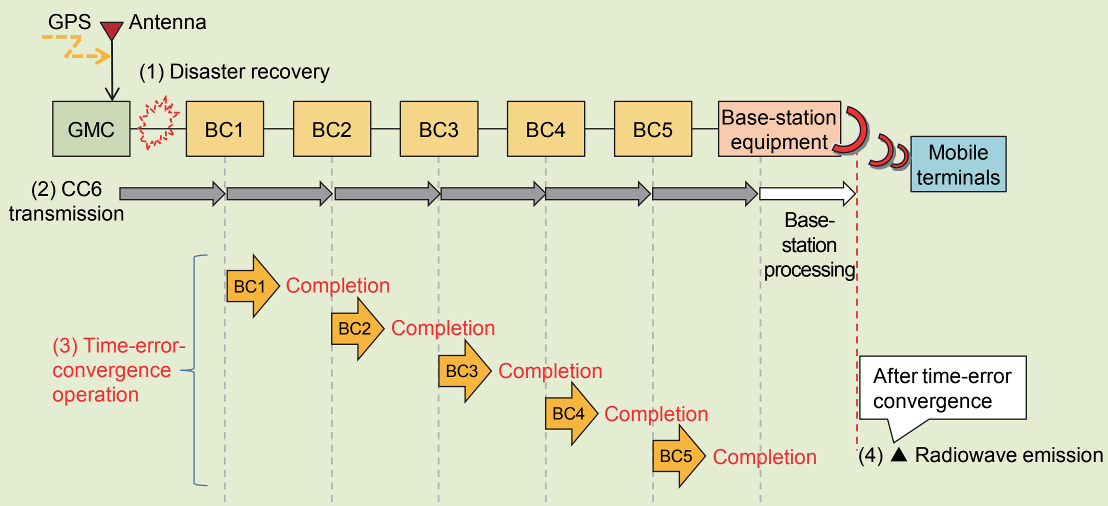


Figure 8 Convergence of time errors

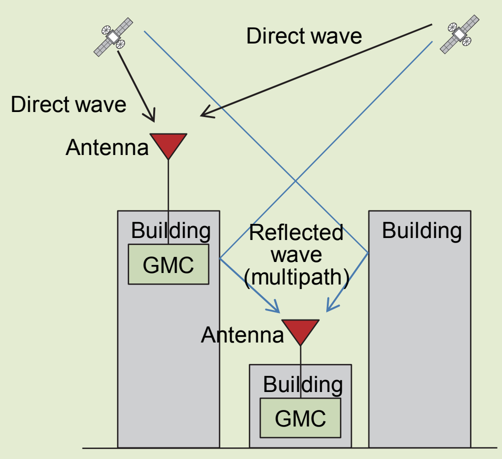


Figure 9 Direct waves and multipath waves

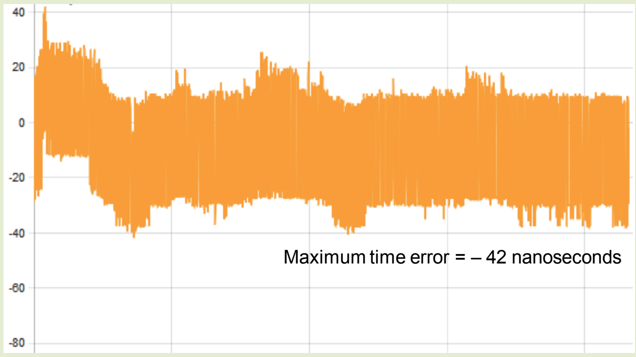


Figure 10　Maximum time error in an environment with numerous direct waves

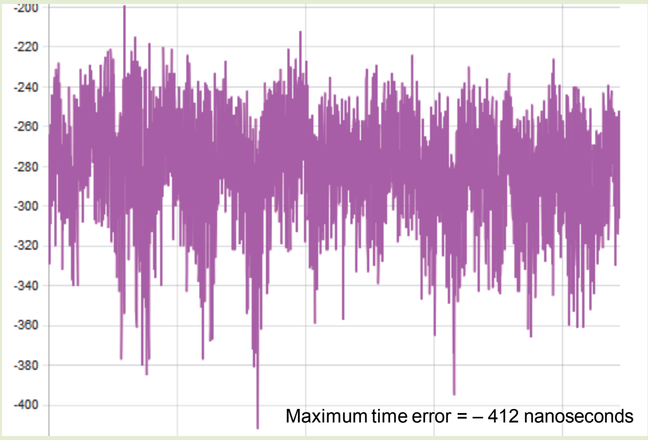


Figure 11　Maximum time error in an environment with numerous multipaths

building networks with a limited number of BC stages connected to downlink equipment of GMC.

6. Conclusion

In this article, standard specifications and operations in regard to equipment composing high-accuracy time-synchronization networks targeting introduction of 3.5-GHz-band TD-LTE are explained. At present, standardization of, for example, operation during failures is progressing, and while considering this trend, we will continue to apply this standardized technology to NTT DOCOMO networks as necessary.

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3.5-GHz Band | TD-LTE | 3DL CA

Technology Reports

Special Articles on Introducing the 3.5-GHz Band

Router-type Mobile Terminal for TD-LTE in 3.5-GHz Band

In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. This article provides an overview of a router-type mobile terminal supporting a maximum downlink data rate of 370 Mbps using TD-LTE and 3DL CA technologies. It also describes 3.5-GHz band standardization activities and presents the results of laboratory and field experiments for downlink data rates.

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1. Introduction

The dramatic increase in mobile data traffic in recent years and growing demand for ultra-high-speed data communications is driving the need for greater capacities in new frequency bands.

The 3.5-GHz band has been newly allocated as a frequency band that can provide wide bandwidths. In 3rd Generation Partnership Project (3GPP), it has been specified as band 42 [1] for use with the Time Division Duplex (TDD)*1 transmission method, and it is expected to be used globally in the future. In the development of this standard, NTT DOCOMO promoted specifications that would facilitate the early implementation of low-cost mobile terminals, and these efforts have resulted in the recent launch of commercial services applying TDD-based LTE (hereinafter referred to as "TD-LTE").

In this article, we describe an NTT DOCOMO router-type mobile terminal that achieves high transmission speeds by performing Carrier Aggregation (CA)*2 between the TDD frequency band and existing Frequency Division Duplex (FDD)*3 frequency bands in a scheme called 3DownLink CA (3DL CA)*4.

*1 **TDD:** A signal transmission method that allocates different time slots on the uplink and downlink using the same carrier frequency and frequency band.

2. Categories and Overview of TD-LTE-capable Mobile Terminal in 3.5-GHz Band

1) Mobile Terminal Categories

The newly developed mobile terminal supports 3DL CA that includes two 20-MHz frequency blocks in the 3.5-GHz band each serving as a Component Carrier (CC)*5. This makes for a total bandwidth of 60 MHz resulting and a maximum downlink data rate of 370 Mbps. The terminal supports mobile terminal category 9, which is necessary to achieve downlink data rates in excess of 300 Mbps. Mobile terminal categories are compared in **Table 1** [2].

2) Overview

The appearance of the mobile terminal developed by NTT DOCOMO is shown in **Photo 1** and its basic specifications are listed in **Table 2**. This terminal (HW-01H) is a mobile Wi-Fi®*6 router that achieves high-speed communications by supporting the 3.5-GHz band in addition to the existing 2-GHz, 1.7-GHz, 1.5-GHz, and 800-MHz bands.

It also supports a maximum downlink data rate of 370 Mbps by applying CA between the 3.5-GHz band and either the 2-GHz band or 1.7-GHz band (3.5 GHz + 3.5 GHz + 2 GHz or 3.5 GHz + 3.5 GHz + 1.7 GHz).

The HW-01H terminal targets users in need of a Wi-Fi router while on the go. In addition to offering high-speed communications, it features a 4,750 mAh large-capacity battery for extended usage time. It also supports the USB 3.0 SuperSpeed standard to enable high-speed communications during USB tethering*7 in addition to high-speed Wi-Fi communications. It is equipped with an extra function for waking up from sleep mode, which is enabled through Bluetooth®*8 communications via a dedicated mobile app on a smartphone or tablet. For example, this convenient function can be used to wake up a sleeping HW-01H terminal inside the user's bag or briefcase without having to remove the terminal from the bag.

3. Standardization Activities toward Development of Radio Part in 3.5-GHz Terminal

There were two main issues to be resolved in developing the radio part of a terminal supporting the 3.5-GHz band:

Table 1 Maximum data rates for each mobile terminal category

Terminal category	Max. downlink data rate (Mbps)	Max. uplink data rate (Mbps)	No. of MIMO layers
4	150	50	2
6	300	50	2 or 4
9	450	50	2 or 4

Photo 1 Appearance of HW-01H

*2 **CA:** An LTE-Advanced technology enabling high-speed communications by bundling multiple frequency bands on the uplink or downlink.

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

*4 **3DL CA:** An LTE-Advanced technology enabling high-speed communications by bundling three frequency bands on the downlink.

*5 **CC:** A term indicating a frequency band targeted for bundling in CA.

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

*7 **Tethering:** A function which enables a mobile terminal to be used as an external modem, so that Wi-Fi devices such as game machines or PCs can connect to the Internet through the mobile phone's connection.

Table 2 Basic specifications of HW-01H terminal

			HW-01H	L-01G (Ref.)
Max. data rate	LTE-Advanced	3CA	DL: 370 Mbps UL: 50 Mbps	–
		2CA	DL: 262.5 Mbps UL: 50 Mbps	DL: 262.5 Mbps UL: 50 Mbps
	LTE		DL: 150 Mbps UL: 50 Mbps	DL: 150 Mbps UL: 50 Mbps
	HSDPA		DL: 14.4 Mbps	DL: 14.4 Mbps
	HSUPA		UL: 5.7 Mbps	UL: 5.7 Mbps
Dimensions			64 × 100 × 22 mm	107 × 65 × 20 mm
Weight			Approx. 173 g	Approx. 186 g
Wi-Fi (LAN side)			11a/b/g/n (2.4/5 GHz) /ac	11a/b/g/n (2.4/5 GHz) /ac
Battery capacity			4,750 mAh	4,880 mAh

- Method for developing a 3.5-GHz band filter
- Method for developing CA combinations to include the 3.5-GHz band

Studies were conducted on each of these issues, as described below.

3.1 Achieving a 3.5-GHz Band Filter

Mobile communications make use of a component called a "Radio Frequency (RF) filter" for extracting electrical signals in a specific frequency band. When developing the HW-01H terminal, potential filter technologies to the 3.5-GHz band were evaluated. There are three main types of filter technologies used in mobile terminals: Surface Acoustic Wave (SAW) filter*9, Bulk Acoustic Wave (BAW) filter*10, and LC filter. The SAW filter, which is widely used today in mobile terminals, is achieved by an interdigital transducer*11 having a width proportional to the target wavelength. However, the higher frequencies of the 3.5-GHz band compared with existing FDD frequency bands creates new issues, such as the need for fine processing to fabricate narrower electrodes and for electrical power resistance to withstand the transmission power output from the power amplifier. In contrast, the BAW filter, which uses a thin piezoelectric film, is known to be advantageous for high-frequency use because it has a device structure requiring no fine patterns while featuring good out-of-band attenuation characteristics. On the other hand, signal loss in the 3.5-GHz band is large at the moment, and attempts to reduce such losses have revealed that a long development time may be needed to do so. The LC filter, meanwhile, is existing technology that can accommodate higher frequencies and broader bandwidths while maintaining low-loss and low-cost characteristics. At present, this type of filter is the most appropriate for the 3.5-GHz band. However, its attenuation characteristics with respect to interference signals outside the 3.5-GHz band are poor compared with that of the other two filters. Consequently, when applying this filter to the 3.5-GHz band, there is concern that a receiver specification in the 3GPP radio standard with respect to out-of-band interference will not be able to be satisfied. Thus, given that this standard applies specifications for existing frequency bands to the 3.5-GHz band too, it was decided to optimize a 3.5-GHz band specification taking into account the increase in path loss accompanying high frequencies. As a result, the LC filter as well can now meet the 3GPP receiver requirement, thereby enabling the development of low-cost, low-loss mobile terminals with a shortened development period.

*8 **Bluetooth®:** A registered trademark of Bluetooth SIG Inc. in the United States.

*9 **SAW filter:** An electrical device for extracting signals in a specific frequency band using surface acoustic waves.

*10 **BAW filter:** An electrical device for extracting signals in a specific frequency band using bulk acoustic waves.

*11 **Interdigital transducer:** Comb-shaped electrodes formed by depositing thin metallic film on the surface of a piezoelectric substrate.

3.2 Achieving CA That Includes 3.5-GHz Band

It is known that one method of achieving CA combining the 3.5-GHz band and existing frequency bands is to use a triplexer that separates an incoming signal into three frequency ranges with low loss, as shown in **Figure 1** (a). A triplexer is a filter device that has a function for extending a conventional diplexer to three-times signal branching. When including the 3.5-GHz band, however, there are concerns not just about insertion loss in the 3.5-GHz band but also about an increase in side loss of existing frequency bands. With the aim of resolving this issue, studies were performed with various filter vendors on achieving a low-loss triplexer. These studies resulted in standardizing TDD-FDD CA for the frequency-band combinations of 800 MHz + 3.5 GHz, 1.5 GHz + 3.5 GHz, 1.7 GHz + 3.5 GHz, and 2 GHz + 3.5 GHz while minimizing as much as possible the increase in loss in existing frequency bands. Another method of achieving CA combining the 3.5-GHz band and existing frequency bands is to use separate antennas for the 3.5-GHz band and existing frequency bands, as shown in Fig. 1 (b). The radio part configurations shown in Fig. 1 (a) and (b) are just examples, and what type of configuration to use in developing a mobile terminal depends on the design ideas offered by various terminal vendors. At this time, the implementation should not be limited in specifications that do not include antenna aspects. For this reason, specifications were defined that enable any radio part configuration to be achieved taking as a precondition the configuration of Fig. 1 (a) that takes into account filter insertion loss in the 3.5-GHz band.

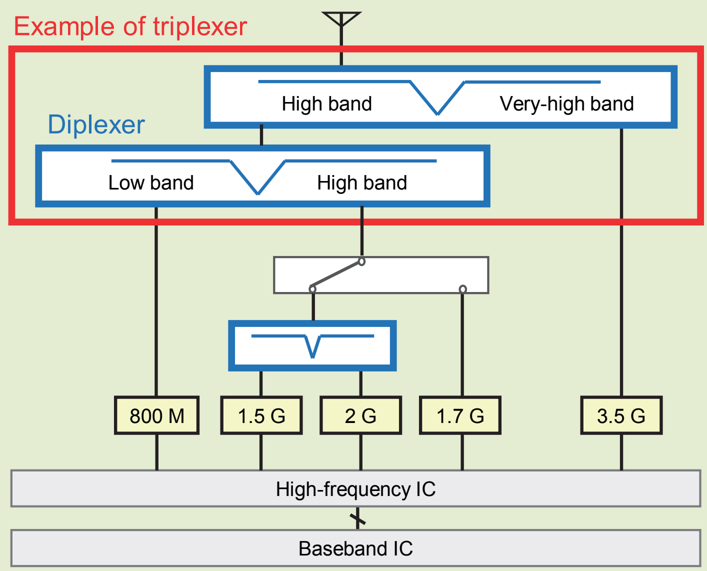

Figure 1 (a) Example of triplexer configuration

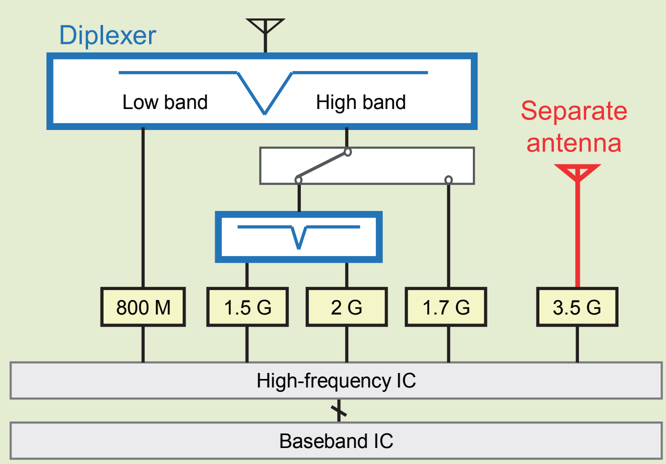

Figure 1 (b) Example of separate antenna configuration

4. Results of Laboratory and Field Experiments on Downlink Data Rates

We evaluated downlink data rates of this 3.5-GHz TD-LTE-capable terminal through laboratory and field experiments.

First, we measured the maximum downlink data rate in a laboratory environment using commercial mobile terminal and base station equipment. In the experiment, we connected the base station and mobile terminal by cable to create an ideal environment with no interference or fading of radio quality. The frequency bands used in the experiment consisted of one 1.7-GHz CC with a bandwidth of 20 MHz and two 3.5-GHz CCs each with a bandwidth of 20 MHz for a total bandwidth of 60 MHz. We transferred data to the mobile terminal and measured downlink data rate including the IP layer*12 header. Results are shown in **Table 3**. A maximum downlink data rate of 343 Mbps was observed compared with a theoretical value of 370 Mbps.

Next, we measured the downlink data rate in a field experiment. For this experiment, we checked signal propagation conditions in the 3.5-GHz band and selected a location having good downlink quality in the range covered by the base station. The base station and mobile terminal were connected by a radio link thereby creating an environment closer to that of commercial services compared with the laboratory experiment. The total frequency bandwidth was the same as that used in the laboratory experiment. The measurements were carried out at a location with good downlink radio quality in a static state. We observed a high-speed downlink data rate of 340 Mbps, which was almost the same as that observed in the laboratory. These results demonstrate that the newly developed router-type mobile terminal can contribute to higher data rates in commercial services.

Table 3 Theoretical and measured values for downlink data rate (60-MHz bandwidth)

Theoretical value	Measured value (laboratory)	Measured value (field)
370 Mbps	343 Mbps	340 Mbps

5. Conclusion

In this article, we described our development of a router-type mobile terminal that makes use of the newly allocated 3.5-GHz band and performs CA combining the FDD and TDD transmission methods. We also presented an overview of the HW-01H mobile terminal and its features, described standardization activities, and presented the results of field experiments on downlink data rates. At NTT DOCOMO, we are committed to developing advanced technologies with the aim of achieving even higher communication speeds for our customers.

References

[1] 3GPP TS36.101 V12.10.1: "Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio transmission and reception," Jan. 2016.

[2] 3GPP TS36.306 V12.7.0: "Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio access capabilities," Jan. 2016.

*12 **IP layer:** The third layer in the OSI reference model performing routing, relaying, etc. Headers on this layer include source/destination IP addresses.

3GPP Release 13 LTE/LTE-Advanced

Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

LTE-Advanced Release 13 Standardization Technology Overview

The international standards organization, 3GPP, introduced the LTE-Advanced standard for extending and expanding LTE in their Release 10 specification. Since then, it has continued to specify extensions to the standard to further advance the elemental technologies of LTE/LTE-Advanced. In this article, we describe the main functions specified in Release 13 that was completed in March 2016.

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1. Introduction

The 3rd Generation Partnership Project (3GPP), which developed the specifications for Wideband Code Division Multiple Access (W-CDMA)*1, High-Speed Packet Access (HSPA)*2, and the LTE standard, established the Release 10 specification for LTE-Advanced to extend and expand LTE. This was done to meet the growing needs of smartphone users and support increasingly diversified services. NTT DOCOMO, for its part, launched its PREMIUM 4G service using LTE-Advanced technology in March 2015, and services using LTE-Advanced technology are now being rolled out in various countries around the world. Following the Release 10 specification, 3GPP continued to update specifications for extending the functionality and enhancing the performance of LTE/LTE-Advanced, and it completed its Release 13 specification in March 2016. In this article, we explain the background to the formulation of Release 13 and describe newly introduced functionality.

2. Background to Release 13 Studies

Release 10, the first specification for the LTE-Advanced standard, introduced technologies such as Carrier Aggregation (CA)*3, which increases bandwidth up to 100 MHz while maintaining backward compatibility with LTE, and advanced multi-antenna technology, which supports up to eight transmission layers on the downlink and four transmission layers on the uplink [1].

This was followed by Release 11

*1 **W-CDMA:** A third-generation mobile communications system specified by 3GPP.

and Release 12 specifications to expand LTE-Advanced functionality. In addition to band-expansion and multi-antenna technologies for conventional mobile phones, these releases included extensive specifications for terminals equipped with communication modules such as smart meters (electricity and gas meters) [2] [3].

In a similar manner, studies for Release 13, which got under way in 2014, considered a wide range of market trends and needs beyond the domain of conventional mobile phones. As shown in **Figure 1**, the scope of study in Release 13 can be broadly divided into (1) new technologies for creating new services, (2) new technologies for increasing user throughput and capacity, and (3) improved functionality based on network operations experience.

3. New Functionality in Release 13

3.1 New Technologies for Creating New Services

Market expectations of the Internet of Things (IoT)*4 have been increasing, and to meet these expectations, 3GPP has developed specifications to provide IoT-oriented devices with communications capability. The Device-to-Device (D2D)*5 function specified in Release 12 has also been extended.

1) Machine Communication (Category M1 and NB-IoT)

A variety of organizations have been studying terminals oriented to machine communication for smart meters (electricity and gas meters) and other services. In Release 12, 3GPP specified low-price machine-communication terminals as LTE terminal Category 0. These terminals feature (1) a maximum data rate limited to 1 Mbps, (2) support for

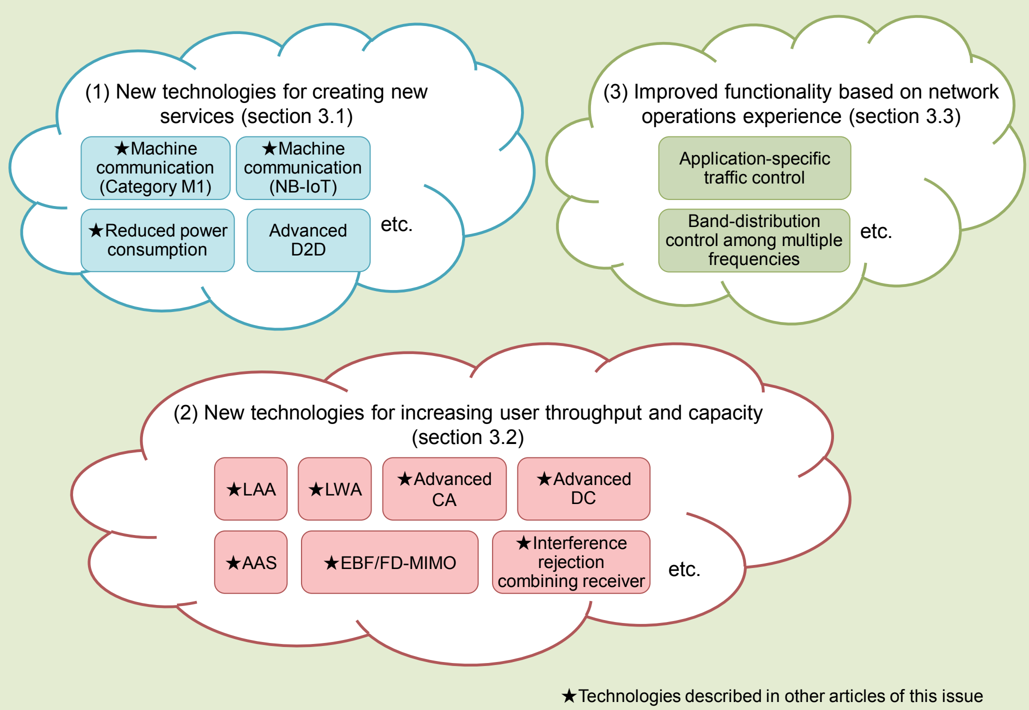

Figure 1 Main functionality in Release 13

*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).

*3 **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.

*4 **IoT:** General term for a style of control and communication where various "things" are connected via the Internet or cloud services.

*5 **D2D:** A technology enabling direct communications between terminals. It supports both autonomous-type direct communications between terminals when outside of base station coverage and direct communications between terminals when inside of base station coverage based on control information from the base station.

Frequency Division Duplex (FDD)*6 and Half Duplex*7, and (3) support for single-antenna reception. Release 13, in turn, supports two new terminal categories to further lower terminal price and extend coverage, as described below.

(a) Category M1

In addition to the features provided by Category 0, Category M1 features (1) transceiver bandwidth limited to 1.08 MHz and (2) support for coverage extension of approximately 15 dB. This limitation of transceiver bandwidth is expected to have a significant cost-reduction effect and to reduce the price of the terminal chip by approximately 50% compared with Category 0.

(b) NB-IoT

Although specification studies for machine communication originally targeted the frequency bands of the Global System for Mobile communications (GSM)*8, NarrowBand (NB)-IoT has been common to studies aimed at enabling use of LTE frequency bands too. This NB-IoT category features (1) tranceiver bandwidth limited to 180 kHz and (2) support for coverage extension greater than 20 dB. Compared with Category M1, NB-IoT is inferior in data rate and spectrum efficiency*9, but the use of an even narrower band is expected to reduce the price of the terminal chip by approximately 25%.

2) Reduced Power Consumption

The Release 12 specification provided for Power Saving Mode (PSM), a technology for reducing power consumption in machine-communication terminals. This technology can greatly reduce power consumption by turning nearly all radio functions OFF without performing intermittent reception. On the other hand, an incoming call to such a terminal can only be received at the time of location registration, that is, during a tracking area update in LTE, which is performed periodically (normally every 54 min). To deal with this issue, Release 13 provides for extended Discontinuous Reception (DRX)*10 as a technology for shortening the call-receiving interval. This technology can greatly increase the intermittent reception period during standby from the existing maximum of 2.56 s to a maximum of 43 min.

3) Advanced D2D

Release 13 enhanced the D2D specifications established in Release 12 to expand the scope of D2D application to services. For example, in a public safety application to provide communications in times of an emergency, it specifies a User Equipment (UE)-to-network relay function that enables a UE within coverage to serve as a relay station to relay data of a UE outside of coverage to a base station. Providing network connectivity in this way by supplementing base-station coverage for public safety purposes can reduce investment costs. Also specified by Release 13 is D2D discovery*11 technology that can be applied, for example, to the discovery of such relay stations when a UE is outside of coverage.

Release 13 also specifies D2D discovery between carriers and between operators for commercial applications. It specifies, in particular, the use of resident cell*12 information to notify a UE of D2D settings for use with other carriers, and it specifies control procedures for switching transceiver functions in D2D discovery.

3.2 New Technologies for Increasing User Throughput and Capacity

New technologies for increasing user throughput and capacity are being established at 3GPP. A key feature of Release 13 is the specification of technologies for using LTE in unlicensed spectrum, as described below.

1) LAA

The explosive increase in data traffic in recent years is producing a serious shortage of available frequencies allocated for operator use (licensed spectrum). Under these conditions, some telecom operators are working to improve quality by using frequency bands not requiring a radio station license (unlicensed spectrum) to offload data in an area in which licensed spectrum is scarce. To meet the demand for improving capacity using unlicensed spectrum,

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

*7 **Half Duplex:** A communications method whereby signals can be transmitted in only one direction at a time; when transmission (reception) is being performed in one direction (by the base station, for example), reception (transmission) is being performed in the other direction (by the mobile terminal, for example).

*8 **GSM:** A second-generation mobile communications system used by digital mobile phones.

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

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

*11 **D2D discovery:** Technology for discovering a nearby terminal.

*12 **Cell:** The smallest area unit for sending and receiving radio signals between a cellular mobile communication network and mobile terminals.

3GPP specified Licensed-Assisted Access (LAA) to promote a more effective use of unlicensed spectrum compared with the above offloading technology. This LAA technology enables aggregation of unlicensed spectrum in the 5-GHz band as a dedicated Secondary Cell (SCell)*13 with existing licensed spectrum as CA in the downlink, and performs simultaneous communications over both carriers. Additionally, as a result of studies on technologies for achieving a fair coexistence with other systems using the same frequencies, such as existing wireless LAN systems and LAA of other operators, Release 13 specifies channel access technology based on Listen-Before-Talk*14 while also establishing signal configurations for efficient transmission and reception of data on unlicensed spectrum. Moreover, for Release 14, studies are being performed on using unlicensed spectrum as a SCell in both the uplink and downlink of LTE CA.

2) LWA

Also specified in Release 13 is LTE-WLAN Aggregation (LWA) that bundles LTE and wireless LAN radio signals as a technology for increasing user throughput and capacity using unlicensed spectrum. In this regard, some telecom operators are working to enhance transmission speeds by providing Internet connections via wireless LAN using an existing wireless LAN access point*15. Here, the LTE base station and wireless LAN access point may be implemented in physically different equipment or in the same equipment, and the LWA function supports either scenario.

3) Advanced CA

(1) Extension of maximum number of LTE carriers

The CA function enables simultaneous communications over a maximum of five aggregated LTE carriers. It was originally specified in Release 10 and enhanced in various ways through Release 12, but the maximum number of carriers remained the same. However, the actual number of LTE carriers used in CA specified for various combinations of frequency bands has been approaching that upper limit. In addition, the LAA function described above is expected to use the 5-GHz unlicensed spectrum enabling the use of frequency bandwidths in excess of 100 MHz. The need was therefore felt for extending the number of LTE carriers that can be simultaneously used in CA so that even higher peak data rates could be achieved. In light of this need, Release 13 extended the maximum number of LTE carriers that can be simultaneously used to 32.

(2) New PUCCH format and functions

Conventional CA allowed uplink control signals to be transmitted to the base station from only the Primary Cell (PCell)*16. However, as the number of simultaneously usable LTE carriers increase, the number of uplink control signals that would have been handled by the PCell would likewise increase. To address this issue, Release 13 specifies a new Physical Uplink Control CHannel (PUCCH)*17 format that can accommodate large-capacity uplink control signals. Furthermore, considering that simply extending the PUCCH payload*18 will concentrate the load on the PCell, Release 13 also introduces a function that enables PUCCH to be transmitted from a SCell too as a solution based on load distribution. This is a general-purpose function that can be applied regardless of the number of LTE carriers that are being used at the time of CA. It is expected to help improve quality in CA not only when the number of LTE carriers increases beyond the present limit but also in a Heterogeneous Network (HetNet)*19 that overlays multiple instances of a small cell*20 on a macro cell*21 area.

4) Advanced DC

Dual Connectivity (DC), which enables data requiring the same Quality of Service (QoS) to be received from two different base stations, was originally specified in Release 12. That specification, however, supported simultaneous reception only on the downlink, so for Release 13, it was decided to support simultaneous transmission of data to two

*13 **SCell:** In CA, a cell that provides radio resources in addition to the PCell.

*14 **Listen-Before-Talk:** A mechanism that enables a terminal to check whether another terminal is transmitting data before transmitting data over the air.

*15 **Wireless LAN access point:** A connection control node for adding a WLAN terminal to a network. It serves as intermediary for terminal communication, corresponding to a cell phone base station.

*16 **PCell:** In CA, a cell that maintains connectivity between the UE and network.

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

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

*19 **HetNet:** A network configuration featuring an overlay of nodes having different power attributes; a network in which pico base stations, femto base stations and Wi-Fi hotspots having transmit-power levels smaller than conventional base stations coexist, interface and integrate.

different base stations on the uplink as well. Additionally, a mechanism has been achieved for asynchronous DC operation (that performs no time synchronization between the base stations) to enable the terminal to report the inter-base-station System Frame Number (SFN) and inter-base-station error, the latter in radio subframe*22 units. In Release 12, it was assumed that some sort of mechanism would be used on the network side to determine inter-base-station error. In contrast, introducing this new mechanism of UE-based reporting in Release 13 makes it possible to gauge inter-base-station error without having to perform measurements on the network side.

5) AAS

Specifications studies on an Active Antenna System (AAS) that integrates the transceiver and antenna at the base station have resulted in the completion of Radio Frequency (RF)*23 specifications in Release 13 following a feasibility study (Study Item: Release 11–12) and specifications study (Work Item: Release 12–13). In addition to downsizing equipment, AAS negates the need for a coaxial cable between the transceiver and antenna. This means reduced cable loss and more efficient use of power.

(a) Features from an operation viewpoint

In terms of operation, AAS enables the direction of the main beam to be varied in the horizontal and vertical directions by adjusting signal amplitude and phase between multiple antenna elements. This makes for more flexible area construction. In addition, formation of multiple beams in directions different from that of the main beam enables the creation of a multi-cell area with the same equipment.

(b) Features from a specifications viewpoint

In terms of specifications, RF specifications for conventional base stations and RF specifications for AAS differ greatly in the following two points.

(1) Specification point*24: In conventional specifications, there is only one specification point, namely, the connector that serves as the boundary between the transceiver and antenna. In AAS specifications, however, there are two specification points. The first is the antenna connector, which is called a Transceiver Array Boundary (TAB) Connector in AAS specifications, and the second is the space through which signals are radiated from the antenna. Application of the latter, however, is limited to only some characteristics. Additionally, in specifications using this specification point, provisions that include antenna radiation characteristics (hereinafter referred to as "Over The Air (OTA)*25 specifications") can be established enabling characteristics of the entire base station including the antenna to be evaluated.

(2) Specification unit in conducted specification (characteristics of input/output signals between the transceiver and antenna): In conventional specifications, radio characteristics are specified per connector. In AAS, they are specified per TAB connector or, in some cases, as a sum total of multiple TAB connectors.

Work Item discussions for stipulating all AAS RF specifications in terms of OTA have begun for Release 14. This should simplify testing and make it easier to guarantee total base station characteristics.

6) EBF/FD-MIMO

In conjunction with progress in AAS technology, the number of Multiple Input Multiple Output (MIMO)*26 antennas have been increasing and the accuracy of calibrating antennas and RF circuits has been improving. Envisioning that a maximum of 16 antennas will be arranged on a plane in the horizontal and vertical directions at a base station, Release 13 specifies Elevation Beam Forming/Full Dimension-MIMO (EBF/FD-MIMO) technology that achieves precoding control in the horizontal and vertical directions. This technology can

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*20 **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.

*21 **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.

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

*23 **RF:** Frequency used in radio communications or the frequency used for the carrier wave of radio signals.

*24 **Specification point:** A point specified by base station RF specifications.

*25 **OTA:** Specifications and measurement method that establishes a specification point in signal radiation space from the antenna and in signal reception space to the antenna and that includes radiation characteristics from the antenna and reception characteristics to the antenna.

control the directivity*27 of a formed beam within a Cartesian coordinate system in three dimensions, which is why it is sometimes called three dimensional precoding. Additionally, envisioning an increase in the number of simultaneously multiplexed layers in Multi User (MU)-MIMO*28 transmission as well as system operation by Time Division Duplex (TDD)*29, Release 13 specifies technology for expanding the capacity of reference signals used for propagation-path assessment in the uplink.

7) Interference Rejection Combining Receiver on the Uplink

Release 13 specifies technology for suppressing interference and improving the quality of reception even on the uplink. This is achieved by using multiple receiving antennas mounted on the receiver to orient the antenna gain "drop points" in the direction of any interface signals arriving from adjacent cells.

3.3 Improved Functionality Based on Network Operations Experience

In the footsteps of previous releases, Release 13 continues to improve functionality based on network operations experience.

1) Application-specific Traffic Control

In traffic control technology up to Release 12, control was performed in units of specific packet services, such as voice calls, video calls, and emergency calls delivered by the IP Multimedia Subsystem (IMS)*30. Release 13 builds upon these specifications by establishing Application specific Congestion control for Data Communication (ACDC), a technology enabling application-specific traffic control. Compared with conventional technology that performed traffic control uniformly across a service requiring the same QoS, ACDC can perform different traffic control for different applications requiring the same QoS. For example, given a group of applications all of which perform packet communications, a telecom operator could give priority to those having a high degree of urgency, such as a disaster message board.

2) Band-distribution Control among Multiple Frequencies

(1) Inter-frequency cell reselection

As the migration from W-CDMA/HSPA to LTE continues in countries around the world, an increasing number of telecom operators are providing LTE over multiple frequency bands. However, when doing so, situations can occur in which traffic does not distribute uniformly among different frequency bands and instead comes to concentrate in a particular frequency band. To resolve this issue, Release 13 specifies technology for performing cell reselection between different frequency bands according to a probability value set in system information*31 while the UE is in idle mode. In this way, UEs can be idling under each of the target frequencies according to a probability value set by the telecom operator, which means that traffic at the time of actual communications should end up being distributed over those frequencies.

(2) RS-SINR

As a new index of signal quality to be measured by the UE, Release 13 specifies Reference Signal-Signal to Interference plus Noise power Ratio (RS-SINR) using cell-unique reference signals. It also specifies a mechanism for reporting this index from the UE. Given that terminal communications are distributed among different frequencies by handover*32 operations, RS-SINR is used as an index to predict the throughput that can be provided at a handover destination. Compared with the conventional Reference Signal Received Quality (RSRQ)*33 index, RS-SINR enables more accurate selection of a handover candidate cell that can achieve high throughput even in an area with relatively good signal quality.

4. Conclusion

In this article, we explained the background to Release 13 specification studies and described newly introduced functionality. Among the main Release 13 functions introduced in this article, category M1, NB-IoT, reduced power con-

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

*27 **Directivity:** An antenna radiation characteristic indicating the directional characteristics of radiation strength (or reception sensitivity) from the antenna.

*28 **MU-MIMO:** Technology that uses MIMO transmission over the same time and frequency for multiple users.

*29 **TDD:** A single transmission method that allocates different time slots on the uplink and downlink using the same carrier frequency and frequency band.

*30 **IMS:** A 3GPP standardized call control procedure that realizes multimedia communications by consolidating fixed and mobile network communication services with Session Initiation Protocol (SIP), which is a protocol used on the Internet and with Internet phones.

sumption, LAA, LWA, advanced CA/DC, AAS, EBF/FD-MIMO, and the interference rejection combining receiver are described in other articles of this issue [4]–[6]. Please refer to those articles for detailed descriptions of these functions. Formulation of the Release 14 specification has already begun at 3GPP. The plan going forward is to develop specifications for enhancing the functionality of IoT and unlicensed-spectrum technologies.

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*31 **System information:** Various types of information broadcast from each cell, such as the location registration area number required for judging the need for location registration in a mobile terminal, adjacent cell information and radio-signal quality for camping in that cell, and information for restricting and controlling outgoing transmissions.

*32 **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal straddles two base stations while moving.

*33 **RSRQ:** Indicates the ratio of the power of the cell-unique reference signal to total power within the receive bandwidth.

M1 | NB-IoT | eDRX

Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

New Technologies for Achieving IoT in LTE Release 13

As IoT services grow, elemental UE technologies and network control technologies have been intensively studied specifically for IoT. In contrast to past trends in high-speed data communications, UE in the IoT era has distinct requirements such as lower costs suitable for mass production and mass introduction and a battery replacement period of more than ten years. Against this background, 3GPP has formulated new specifications for IoT in LTE Release 13. This article describes key technologies for achieving low costs, wide coverage, and low power consumption in IoT terminals and optimization of the core network for IoT services as introduced in LTE Release 13.

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1. Introduction

In addition to achieving high-speed, large-capacity radio access in LTE to meet the needs of smartphone users, the 3rd Generation Partnership Project (3GPP) has been studying elemental technologies and network control technologies specifically for the Internet of Things (IoT)*1 as extensions to LTE. Release 13 specifications, in particular, involved extensive studies on elemental technologies for achieving low costs, wide coverage, and low power consumption in terminals and on optimization of the core network to meet the high market demand for IoT services. In this article, we describe new technologies for IoT specified by Release 13.

2. UE Categories for IoT in Release 13

2.1 Overview

1) Category 0

Recently, a variety of organizations have taken up the study of terminals (hereinafter referred to as "User Equipment (UE)") for IoT services such as smart meters (electricity and gas meters

*1 **IoT:** General term for a type of control and communication where various "things" are connected via the Internet or cloud services.

with communication functions). In LTE, Release 12 specifications supported a low-price UE category for IoT (Category 0) featuring (1) a maximum data rate of up to 1 Mbps, (2) support for Frequency Division Duplex (FDD) Half Duplex*2, and (3) support for single-antenna reception.

2) Category M1 and NB-IoT

Release 13 specifications support two new terminal categories to further lower UE price and provide extended coverage (**Table 1**).

- The first is Category M1 that supplements Category 0 features with (1) reduced UE transmission bandwidth of 1.08 MHz and (2) coverage extension by approximately 15 dB compared to Category 1. This limitation of transmission bandwidth results in a significant cost reduction for the UE chip [1].
- The second category is Narrow-Band (NB)-IoT. Although the studies originally targeted the frequency bands of the Global System for Mobile communications (GSM)*3, NB-IoT has been specified so that LTE frequency bands could be used as well. This category features (1) UE transmission bandwidth of 180 kHz and (2) coverage extension by approximately 20 dB compared to Category 1. Compared with Category M1, NB-IoT is inferior in data rate and spectrum efficiency*4, but the use of an even narrower band is expected to further reduce the price of the UE chip. The following provides an overview of the functions supported by UE Category M1 and NB-IoT.

2.2 Category M1

Category M1 features the transmitting and receiving of signals using a 1.08-MHz portion of the LTE transmission bandwidth, as shown in **Figure 1** (a). The frequency location for Category M1 can be flexibly changed within the LTE system band, and operation using another 1.08-MHz segment is also possible as long as that segment is within the LTE system band.

However, in terms of the Physical Resource Block (PRB)*5, Category M1 UE can only receive downlink signals within six PRBs corresponding to 1.08 MHz, which means that it cannot receive signals transmitted over a bandwidth

Table 1 UE categories for IoT

	Category 1	Category 0	Category M1	NB-IoT
Release	Release 8	Release 12	Release 13	Release 13
Operating band	LTE band in use (if using a dedicated frequency band, an area for dedicated-frequency use must be constructed.)			
				Outside of LTE band (in guard band)
Transmission bandwidth	20 MHz	20 MHz	1.08 MHz	180 kHz
Spectrum efficiency	Same as existing LTE	Same as existing LTE	Less than Category 1 (due to single antenna reception, limited bandwidth)	Less than Category M1 (due to further bandwidth limitation)
Coverage	Same as existing LTE	Same as existing LTE	Category 1 + 15 dB	Category 1 + 20 dB
Mobility	Same as existing LTE	Same as existing LTE	Same as existing LTE (slower under coverage extension)	Handover non-supported Mobility in idle mode supported
Power consumption	Same as existing LTE	Same as existing LTE	(less than Category 1 and 0)	
Transmission power	Same as existing LTE	Same as existing LTE	Less than 3 dB	Less than 3 dB (under study)

*2 **FDD Half Duplex:** A method for transmitting signals using different carrier frequencies and bands in the uplink and downlink. Simultaneously transmitting and receiving signals on different frequencies is called FDD Full Duplex and temporally switching transmission and reception on different frequencies is called FDD Half Duplex.

*3 **GSM:** A second-generation mobile communications system used by digital mobile phones.

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

*5 **PRB:** A unit for allocating radio resources consisting of one subframe and 12 subcarriers.

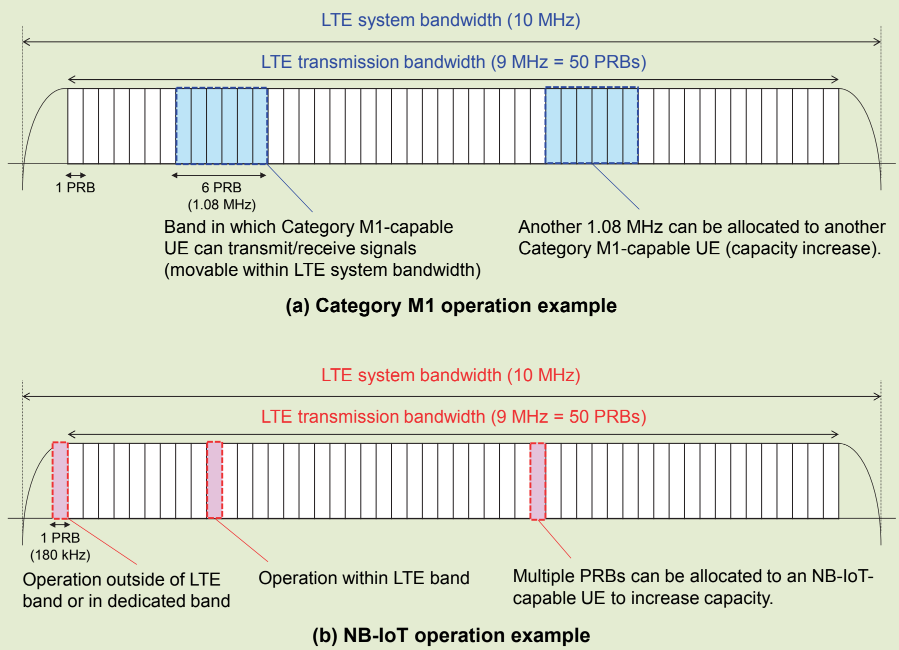

Figure 1 Operation example of Category M1 and NB-IoT in LTE

greater than six PRBs on the LTE system band. Specifically, this prevents reception of the Physical Downlink Control CHannel (PDCCH)*6, which is used for allocating the Physical Downlink Shared CHannel (PDSCH) consisting of data and the System Information Block (SIB)*7. As a result, the UE cannot receive LTE system information, as shown in **Figure 2** (1).

1) Newly Specified M-PDCCH and SIB

Taking the characteristics of Category M1 UE into account, Release 13 specifies Machine Type Communication (MTC)*8 -PDCCH (M-PDCCH) as a physical downlink control channel mapped within six PRBs to allocate SIB, etc. as well as a new SIB specific to Category M1 UE. Introducing a new downlink control channel and upper layer signals confined to six PRBs in this way makes it possible to limit the Category M1 transmission band to 1.08 MHz and lower the price of the module. Because of this bandwidth limitation, as only six PRBs are available, PDSCH is allocated using an M-PDCCH in a different subframe*9, as shown in Fig. 2 (2). Moreover, as described above, the Category M1 transmission band is flexibly changed within the LTE transmission band, so PDSCH (or Physical Uplink Shared CHannel (PUSCH)) can be allocated to a different set of six PRBs in a different subframe, as also shown in Fig. 2 (2). This scheme enables PDSCH and PUSCH to be transmitted and received using a set of six PRBs with good receiving quality.

2) Newly Specified Power Class

Additionally, as a method for achieving low-price modules, Release 12 specifies a new transmission power class that is 3 dB lower than the power of existing LTE modules.

3) New Function for Coverage Extension

As shown in Fig. 2 (3), Release 13 also specifies a function for extending coverage by repeating the transmission of the same signal using multiple subframes. This type of repeated transmission enables Category M1 UE to transmit

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

*7 **SIB:** Various types of information broadcast from base stations to surrounding cells, such as the location code required for judging whether location registration is needed for a mobile terminal, surrounding cell information, and information for restricting and controlling outgoing calls.

*8 **MTC:** A collective term for 3GPP machine communication with no intervening communication operations performed by humans.

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

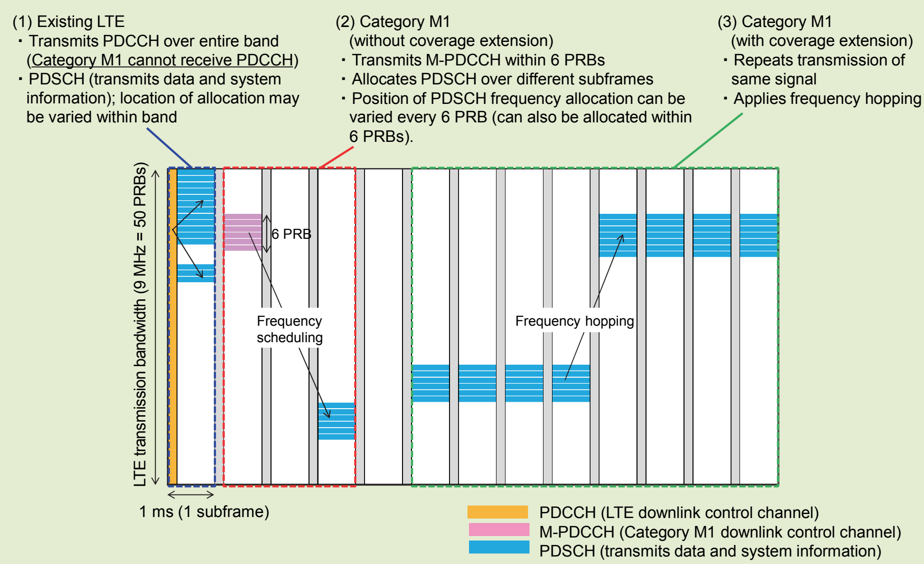

Figure 2 Configuration of Category M1 physical layer channel

and receive signals for MTC purposes even in an environment with low Signal-to-Interference plus Noise power Ratio (SINR)[*10]. On the other hand, the same signal would have to be transmitted over 100 subframes to achieve coverage extension of about 15 dB, which would significantly degrade throughput[*11] and spectrum efficiency. For this reason, Release 13 also supports frequency hopping[*12] that transmits the same signal using a different set of six PRBs within the LTE transmission band. Again, referring to Fig. 2 (3), having the frequency of the transmission signal hop at fixed intervals (for example, every four subframes) can exploit a frequency diversity[*13] effect, which means that throughput and spectrum efficiency can be greatly improved while improving received SINR and extending coverage.

2.3 NB-IoT

In contrast to Category M1 UE that operates within the LTE transmission band, the NB-IoT category supports UE operation outside the LTE band (hereinafter referred to as “guard band[*14]”) and in a dedicated “standalone” frequency band for only NB-IoT UE. It also supports the coexistence of NB-IoT UE and existing LTE UE (such as smartphones) within the LTE band. Here, operation within the LTE band requires that physical layer signals be designed taking into account PDCCH and other signals transmitted for LTE use as described above. However, operation in the guard band or in a dedicated frequency band differs in that there is no need to transmit LTE physical layer signals.

1) Newly Specified NB-PSS/SSS and NB-PBCH

To further reduce costs compared with Category M1, the NB-IoT category transmits and receives signals using a narrow 180-kHz band (corresponding to one PRB) as shown in Fig. 1 (b). As a result, this category can receive neither control signals such as PDCCH or the Primary Synchronization Signal/Secondary Synchronization Signal (PSS/SSS)[*15] and Physical Broadcast CHannel (PBCH)[*16] transmitted over six PRBs for LTE and Category M1. To resolve this issue, Release 13

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

*11 **Throughput:** Effective amount of data transmitted without error per unit time.

*12 **Frequency hopping:** A transmission method using a different frequency or frequency resource for each transmission.

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

*14 **Guard band:** A frequency band set between the signal frequency bands of systems to prevent radio signal interference between systems.

*15 **PSS/SSS:** A synchronization channel for performing cell detection, time/frequency synchronization, etc.

*16 **PBCH:** A physical channel for broadcasting main radio parameters such as downlink system bandwidth and system frame number.

newly specifies NB-PSS/SSS and NB-PBCH that can be transmitted within one PRB for the NB-IoT category.

2) Enhanced Functionality for Coverage Extension

Functions for the uplink, which has even stricter requirements, have been enhanced for extending coverage. To begin with, Release 13 specifies transmission in subcarrier*17 (15 kHz) units smaller than one PRB (one PRB consists of 12 subcarriers) (hereinafter referred to as "single tone transmission"). Given that UE transmission power is limited in the uplink, single tone transmission can improve receive SINR by concentrating transmission power in one subcarrier at the expense of data rate. Release 13 also supports a 3.75-kHz subcarrier interval that narrows down the 15-kHz subcarrier even further.

3) Support of π/4-QPSK and π/2-BPSK Modulation

With the aim of reducing the Peak-to-Average Power Ratio (PAPR)*18, Release 13 adds phase rotation to conventional Quadrature Phase Shift Keying (QPSK)*19 modulation by supporting π/4-QPSK modulation and π/2-Binary Phase Shift Keying (BPSK)*20 modulation. Adding phase rotation in this way can avoid a zero point in the amplitude of the modulation signal and suppress amplitude fluctuation thereby reducing PAPR.

3. eDRX Technology for Power Savings

One of the key requirements in IoT scenarios is a battery replacement period of at least ten years for IoT modules [2]. There is therefore a need for technology that can provide a high battery-saving gain compared to the power consumption of conventional LTE UE.

Discontinuous Reception (DRX) has been specified as a power saving technology since 3GPP Release 8. Making use of intermittent signal reception, DRX minimizes power consumption by shutting down the Radio Frequency (RF) function*21 and putting the UE into a sleep state during the period of no reception. DRX is applied when receiving the PDCCH signal intermittently in Radio Resource Control (RRC)_IDLE*22 and RRC_CONNECTED*23. Pre-Release 13 specifications specify a maximum DRX cycle of 2.56 s. In order to satisfy battery requirements in IoT scenarios, the DRX cycle needs to be extended on the order of minutes or even hours, so Release 13 specifies extended DRX (eDRX) that greatly extends the period of DRX cycle.

3.1 eDRX Operation Overview

The eDRX function specified in Release 13 improves the battery-saving gain by lengthening the sleep state. In RRC_CONNECTED, a maximum eDRX cycle can be extended up to 10.24 s. In RRC_IDLE, the maximum eDRX cycle is extended up to 43.96 min for Category M1 and up to 2.91 h for NB-IoT, respectively. The state of a UE applying the eDRX function is called the eDRX state. A UE in eDRX state attempts to receive signals every eDRX cycle as configured by the network. Many IoT scenarios have the following communication pattern: small amounts of data transmission, long intervals (e.g., once every 24 hours) between outgoing calls, small number of incoming calls compared with ordinary smartphones, and infrequent updating of system information. In such a communication pattern, the RRC_CONNECTED period is extremely short compared to that of smartphones. It is therefore considered that the operation of eDRX during RRC_IDLE can make a greater contribution to the battery-saving effect than eDRX during RRC_CONNECTED. In addition, different IoT scenarios may have different requirements in terms of paging*24 response time. Consequently, even in an IoT scenario with infrequent outgoing calls (e.g., once every 24 hours), it is necessary to set an eDRX cycle of a certain time to ensure that the UE can satisfy the paging response time requirements. For example, given a paging response requirement within 2 min, an appropriate eDRX cycle value of around 2 min may be set.

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

*18 **PAPR:** Ratio of peak power to average power used as an index for evaluating performance and power consumption of a power amplifier.

*19 **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.

*20 **BPSK:** A digital modulation method that allows transmission of 1 bit of information at the same time by assigning one value to each of two phrases.

*21 **RF function:** The functional section that transmits and receives radio signals.

*22 **RRC_IDLE:** A RRC state in an LTE UE in which the UE is not known on cell level within the eNB, the eNB stores no UE context, and the MME stores UE context.

*23 **RRC_CONNECTED:** A RRC state in an LTE UE in which the UE is known on cell level within the eNB and the eNB stores UE context.

*24 **Paging:** A procedure and signal for calling a UE while camped in a cell in standby mode at time of an incoming call.

1) Definition of H-SFN

In LTE, System Frame Number (SFN)*25 is defined as a time reference for synchronization between the UE and evolved Node B (eNB)*26. The UE obtains SFN from the eNB when it camps into the eNB's cell and uses that information to synchronize with the eNB. For eDRX, the concept of a Hyper SFN (H-SFN) is introduced based on the abovementioned legacy SFN. As in the case of SFN, H-SFN is provided via system information.

In this regard, an SFN is defined as having a length of 10 ms with SFN numbering running from 0 to 1023, so the length of a total SFN cycle is 10.24 s. Consequently, to specify a long-term eDRX cycle, a single H-SFN is defined as having a length equivalent to that of an SFN cycle (10.24 s) with H-SFN numbering likewise running from 0 to 1023.

2) Setting of eDRX Cycle

The network can set an eDRX cycle for each UE. An eDRX cycle consists of a sequence of H-SFN frames, which means that the length of the cycle is an integral multiple of the length of a single H-SFN. A Mobility Management Entity (MME)*27 determines the eDRX cycle of each UE and notifies the eNB of that value via the S1 interface. Since the UE attempts to receive paging in every eDRX cycle, the network transmits paging signals according to that cycle.

3.2 Receiving Paging Message during RRC_IDLE

1) UE Operation

The method for receiving a paging message during RRC_IDLE is shown in **Figure 3**. The eNB and UE is synchronized at the SFN level. Additionally, to achieve eDRX, synchronization must be performed among MME, eNB, and UE at the H-SFN level (within several seconds). As a result, the H-SFN start time may have an offset by several seconds between the MME and UE and between the MME and eNB, but the MME, eNB, and UE will all have the same H-SFN number.

The UE attempts to receive paging during a specific H-SFN in every eDRX cycle. This H-SFN is called a Paging Hyperframe (PH)*28. Here, the UE uses the International Mobile Subscriber Identity (IMSI)*29 and the eDRX cycle to calculate which H-SFN number should become the PH to receive paging. Then, within that PH, the UE attempts to receive the paging message during the period of a Paging Time Window (PTW)*30. Furthermore, to increase the probability of receiving paging, the MME or eNB can repeat paging transmissions within the PTW. The PTW start timing can be distributed over four starting times within the H-SFN corresponding to that PH. The MME determines the PTW and signals it to the eNB together with the eDRX cycle via the S1 interface.

Within the PH, taking into account the PTW start timing, paging reception follows the legacy mechanism. That is, the UE uses the Default Paging DRX cycle to calculate which SFN number will be the Paging Frame (PF)*31 to receive paging and which subframe within that PF qualifies as a Paging Occasion (PO)*32. The UE then attempts to receive the paging message accordingly.

In addition, a UE that applies the coverage extension function will repeatedly transmit and receive the same signal. If eDRX operation is also being performed, the UE will begin receiving a repetition of paging messages from the first PO/PF subframe determined by the above calculations.

2) MME and eNB Operation

The MME and eNB calculates the H-SFN number that corresponds to the PH for each UE using a method similar to the PH calculation method in the UE as described above. The MME transmits the paging message to the eNB via the S1 interface before the timing of that H-SFN so that the eNB can transmit the paging message based on that timing. The eNB transmits the paging message received via the S1 interface to the UE in the relevant H-SFN number and PO/PF subframe. To enable the above operation, it is recommended that the MME and eNB be synchronized on the H-SFN

*25 **SFN:** Reference time in a UE and eNB in LTE.
*26 **eNB:** A base station for the LTE radio access system.
*27 **MME:** A logical node accommodating a base station (eNB) and providing mobility management and other functions.
*28 **PH:** The H-SFN in which a UE in eDRX attempts to receive a paging message.
*29 **IMSI:** A number used in mobile communications that is unique to each user and stored on a User Identity Module (UIM) card.
*30 **PTW:** Length of time that a UE in eDRX will attempt to receive a paging message.
*31 **PF:** The SFN in which a UE in DRX will attempt to receive a paging message when in IDLE mode.
*32 **PO:** The subframe within the SFN in which a UE in DRX will attempt to receive a paging message when in IDLE mode.

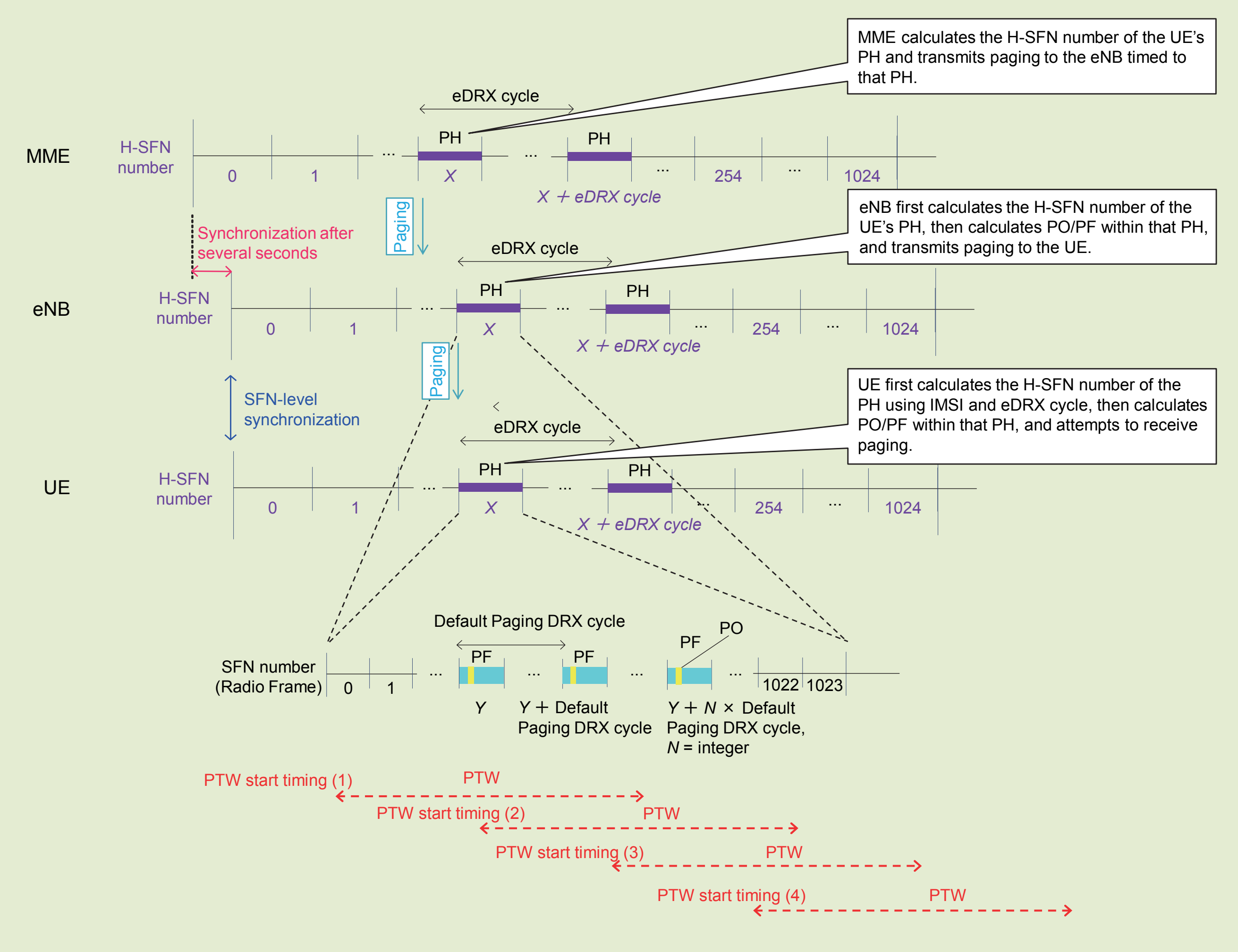

Figure 3　Method for receiving paging message during RRC_IDLE

level (several seconds). On receiving a paging message from the MME, the eNB needs to store that message until the H-SFN for transmitting the message begins. If the synchronization precision between the MME and eNB is high, the time difference of the H-SFN in the eNB and in the MME is short and the buffer capacity*33 needed for storing the paging message in the eNB until the relevant H-SFN timing occurs will be small.

3.3 HLCom

Functional extensions to the MME and upper-layer core network*34 nodes to support eDRX are specified as High Latency Communication (HLCom) functions. In HLCom, these functions are used to process paging for incoming data, SMS*35, and LoCation Service (LCS)*36. In this article, we focus on and describe HLCom functions for paging of incoming data.

As described above, the MME knows the PH of each UE. When the Serving GateWay (S-GW)*37 indicates that incoming data is received, the MME, which is aware that the target UE is in eDRX state and therefore not reachable,

*33 **Buffer capacity:** Size of the location for temporarily saving user data, signaling, etc.

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

*35 **SMS:** A service for sending/receiving short text-based messages mainly between mobile terminals.

*36 **LCS:** A service that determines the location of a mobile terminal.

*37 **S-GW:** A packet switch on the LTE network for sending/receiving user data to/from P-GW (see *56).

understands that a paging message cannot be transmitted to the UE. It therefore estimates the time until a bearer*38 connection can be made between the UE and the network and requests the S-GW to buffer the message for as long as the estimated time. The MME stores the buffering time requested to the S-GW for the UE, and if MME is aware that the UE accessed the network within that time, it establishes a User Plane (U-Plane)*39 Data. Furthermore, if during the estimated timing the UE moves and relocates to another MME, the estimated buffering time information is forwarded from the old MME to the new MME so that the new MME can preserve the timer and perform the above operation. The S-GW, in turn, will store the incoming data for as long as the buffering time requested by the MME.

4. Optimization of Core Network for IoT

The NB-IoT category is specified as radio technology for intermittent transmission of small amounts of data. On the other hand, the Evolved Packet System (EPS)*40 in the core network is applicable to the transmission of large amounts of data. There is therefore a need for optimizing EPS for NB-IoT applications, and this topic was discussed at the 3GPP Service and System Aspects (SA) Plenary*41 meeting in March 2015. As a result of these discussions, an architecture study on optimizing EPS for Cellular IoT (CIoT) got under way in July 2015 at SA2. The following describes the specifications resulting from this study for CIoT EPS optimization.

4.1 Overview of CIoT EPS Optimization

1) Features

CIoT EPS optimization supports the features listed below.

- Ultra-low UE power consumption
- Large number of devices per cell
- Narrowband spectrum Radio Access Technologies (RATs)
- Enhanced coverage level

2) Two Methods of CIoT EPS Optimization

Two methods of CIoT EPS optimization have been standardized [3].

(1) The first is Control Plane (C-Plane)*42 CIoT EPS optimization, in which user data is subjected to encapsulation*43 in C-Plane signaling messages in the form of a Non-Access Stratum Protocol Data Unit (NAS PDU)*44.

(2) The second is U-Plane CIoT EPS optimization. Here, while the user data transmission method uses a U-Plane bearer the same as EPS, efficient U-Plane bearer control applicable to the intermittent transfer of user data can be achieved by introducing Suspend and Resume as new states on the RRC layer and having the NB-IoT UE, eNB, and MME store connection information.

An architecture overview of each method is shown in **Figure 4**. At SA2, it was decided that support for method (1) would be mandatory while support for method (2) would be optional on NB-IoT UEs.

3) Selecting Method of CIoT EPS Optimization

An NB-IoT UE must determine which CIoT EPS optimization method to use with the core network. For this reason, the NB-IoT UE first sends information on the methods it supports to the core network by including that information in the Attach*45/Tracking Area Update (TAU)*46/Routing Area Update (RAU)*47 Request signals. Then, based on that information, the core network returns information on the method it has selected to the NB-IoT UE by including that information in the Attach/TAU/RAU Accept signals. However, if the NB-IoT UE should request connection by a method not supported by the core network, the core network sets an appropriate code and performs an Attach/TAU/RAU Reject operation.

4) Function for Allocating UEs to Core Network

CIoT EPS optimization is being specified with the objective of making data

*38 **Bearer:** In this article, the path taken by user data packets.

*39 **U-Plane:** The transmission path of user data, in contrast to the C-Plane, the transmission path of control signals.

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

*41 **SA Plenary:** The highest level of 3GPP TSG SA meetings.

*42 **C-Plane:** A sequence of exchanged control processes for establishing communications, etc.

*43 **Encapsulation:** Technology for embedding data in a different protocol so that communications can be performed even in a network with limited protocol.

*44 **NAS PDU:** The functional layer between the mobile terminal and core network located above the Access Stratum (AS) (see *62).

*45 **Attach:** A process for registering a mobile terminal with the network such as when turning the terminal's power on.

*46 **TAU:** Process for changing network equipment to reregister or register a mobile terminal with the network when the mobile terminal moves into LTE.

*47 **RAU:** Process for changing network equipment to reregister or register a mobile terminal with the network when the mobile terminal moves into 3G.

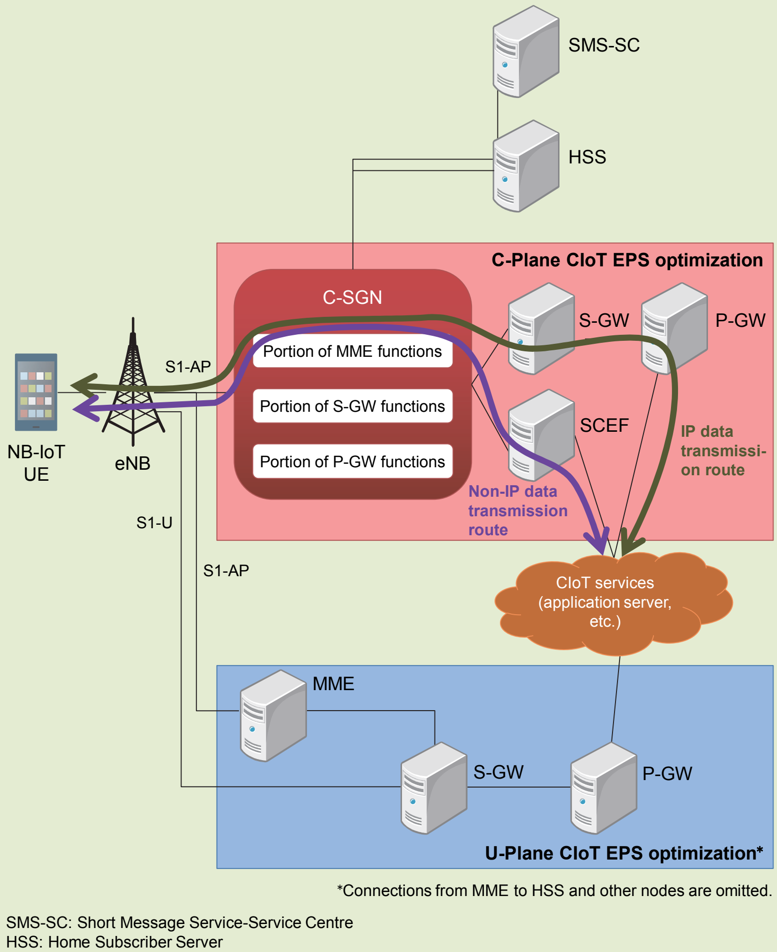

Figure 4 Architecture overview of CIoT EPS optimization

transfer from NB-IoT UEs as efficient as possible. The assumption here is that NB-IoT UEs do not connect to the existing EPS. For this reason, a function is implemented whereby the eNB discriminates between existing EPS and EPS optimized for CIoT and allocates conventional UEs to existing EPS and NB-IoT UEs to EPS optimized for CIoT. This function is linked to the RRC signal. We note here that this function is achieved by a mechanism different from the allocation of a Dedicated Core Network (DCN)*48 [4] specified in Release 13 the same as this function. However, a core network with EPS optimized for CIoT may also be deployed as a DCN.

5) Unsupported Functions

At the same time, considering that NB-IoT UEs and CIoT EPS optimization were developed with function simplification in mind, they do not support some of the functions provided by existing UEs and EPS. Some examples are given below.

- Emergency call services are not provided.
- Offload technologies such as Local IP Access (LIPA)*49 and Selected IP Traffic Offload (SIPTO)*50

*48 **DCN:** A dedicated core network separate from the core network that groups together mobile terminals having the same terminal identifier indicating the type of mobile terminal.

*49 **LIPA:** A type of offload technology specified by 3GPP. A method for connecting to the Internet and sending/receiving certain types of packets via a wireless access network without having to pass through the core network.

*50 **SIPTO:** A type of offload technology specified by 3GPP. A method for connecting to the Internet and sending/receiving certain types of packets via a wireless access network using only part of the core network.

cannot be applied.

- Only mobility in EPS Connection Management (ECM)_IDLE*51 mode is supported; handover*52 in ECM_CONNECTED*53 mode is not.
- Establishment of a Guaranteed Bit Rate (GBR) bearer*54 and a dedicated bearer*55 is not supported.

4.2 C-Plane CIoT EPS Optimization

1) Features

As described above, C-Plane CIoT EPS optimization is a method for transferring encapsulated user data via C-Plane messages. This method decreases the number of C-Plane messages when transferring small amounts of data, and as a result, it can be expected to contribute to ultra-low UE power consumption and reduction of bands for use by narrowband devices. This method supports the following functions the same as existing EPS (with the exception of non-IP data transfer):

- Transport of user data (IP and Non-IP)
- Local mobility anchor point
- Header compression (for IP user data)
- Ciphering and integrity protection of user data
- Lawful interception of user traffic

2) C-SGN

The CIoT Serving Gateway Node (C-SGN) is specified as a new node for the C-Plane CIoT EPS optimization (see Fig. 4). This node consolidates a minimum of functions from C-Plane node MME and from U-Plane nodes S-GW and Packet data network GateWay (P-GW)*56 in existing EPS and is defined as a single logical entity*57. C-SGN functions may also be deployed in the MME of existing EPS.

Transfer of user data by this method can be performed via C-SGN using the S1-AP interface. This means that there is no need to establish a U-Plane bearer by the S1-U interface between the eNB and S-GW in relation to IP data transfer. As a result, the NB-IoT UE can set dummy data in the EPS Session Management (ESM) container*58 of the Attach Request and omit establishment of a U-Plane bearer by the S1-U interface. However, if U-Plane CIoT EPS optimization to be described in section 4.3 is simultaneously supported, a U-Plane bearer can also be established by the S1-U interface and IP data transferred as usual.

3) Application of HLCom

In IoT communications, we can envision the application of intermittent reception through the joint use of functions such as Power Saving Mode (PSM)*59 and eDRX. In this case, as well, HLCom functions can be applied to C-Plane CIoT EPS optimization. In other words, incoming IP data can be buffered at the S-GW. First, the S-GW sends a Downlink Data Notification message to the C-SGN on receiving downlink packets. Next, the C-SGN sends a response signal to the S-GW indicating the length of time until the NB-IoT UE enters the ECM_CONNECTED state. This information enables the S-GW to extend buffer capacity (time and quantity of packets). It is also shared between C-SGNs when a TAU occurs. In the case of non-IP data, the Service Capability Exposure Function (SCEF)*60 can be used to buffer incoming and outgoing data, but we omit description of this function in this article.

4.3 U-Plane CIoT EPS Optimization

As shown in Fig. 4, U-Plane CIoT EPS optimization uses the same architecture and control/data-transfer methods as existing EPS. However, in terms of RRC connections and bearer control, it also provides for the storage of state information on the NB-IoT UE and various nodes to make RRC reconnection and bearer reestablishment quick and efficient. With this method, a bearer can be established in an on-demand manner, so we can expect positive effects such as ultra-low UE power consumption and a large number of devices per cell. In addition to functions supporting existing EPS, this method can support the

*51 **ECM_IDLE:** State in which resources between the mobile terminal and radio network have been released.

*52 **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal straddles two base stations while moving.

*53 **ECM_CONNECTED:** State in which resources between the mobile terminal and radio network are secured and data can be sent and received.

*54 **GBR bearer:** A bearer established for providing a bandwidth guaranteed service.

*55 **Dedicated bearer:** The second or later bearer established at each APN. In IMS-APN, this type of bearer is used for sending/receiving data in Realtime Transport Protocol (RTP) or RTP Control Protocol (RTCP).

*56 **P-GW:** A gateway acting as a point of connection to a PDN, allocating IP addresses and transporting packets to the S-GW.

*57 **Entity:** A constituent element providing a function in logical architecture.

*58 **ESM container:** An area containing a message related to bearer construction, modification, and disconnection in session management (ESM), as in mobility (EMM) messages Attach and TAU.

transfer of non-IP data via the P-GW.

As described above, U-Plane CIoT EPS optimization introduces Suspend and Resume as two new states in RRC control [5]. The state-transition procedure for each of these is described below (**Figure 5**).

1) RRC Suspend Procedure

This procedure, activated by the eNB,

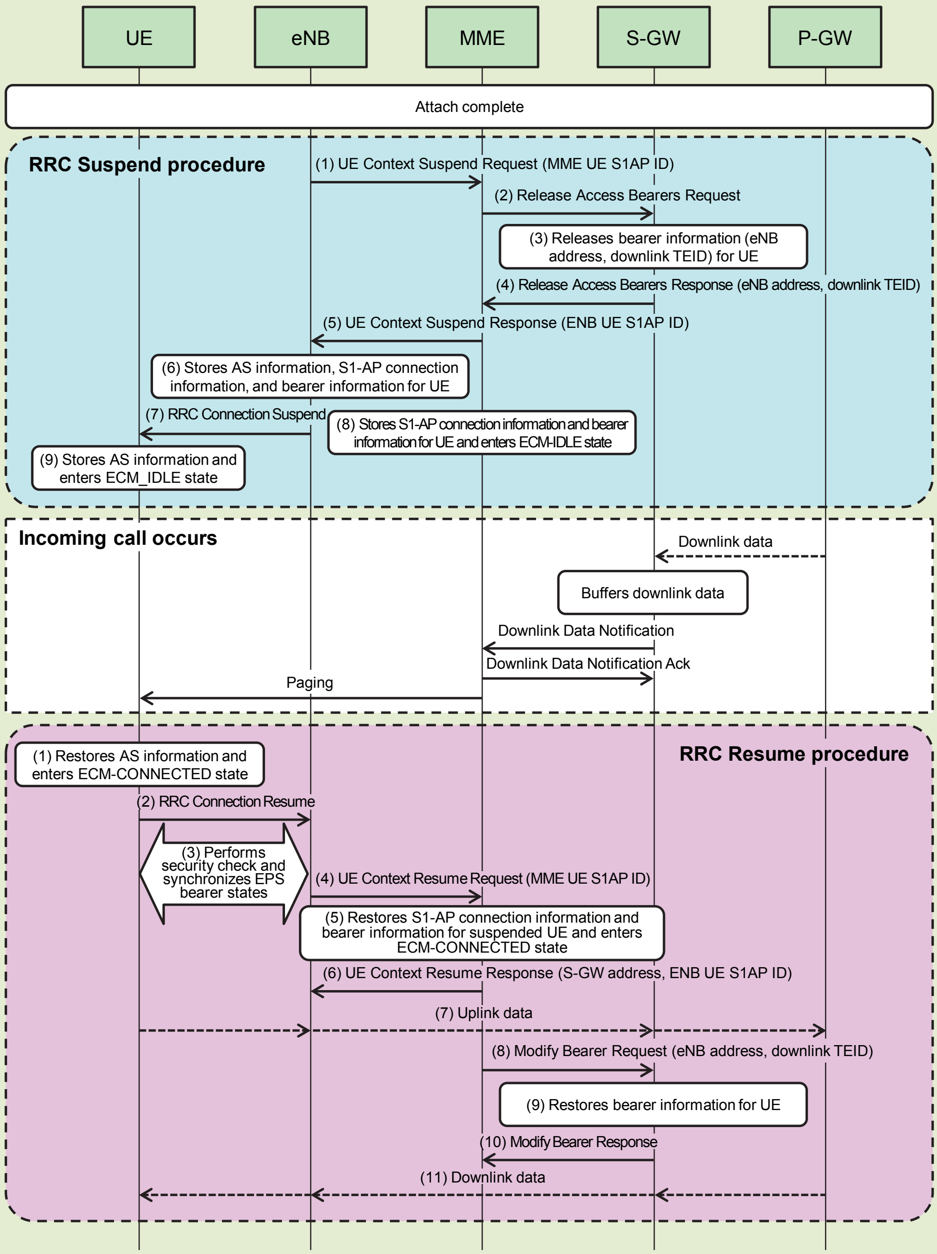

Figure 5 Overview of RRC Suspend/Resume procedures in U-Plane CIoT EPS optimization

*59 **PSM:** A type of low power consumption technology. While maintaining registration with the network, the UE enters a pseudo power cutoff state for a certain period of time.

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

releases the RRC connection between the target NB-IoT UE and eNB and the S1-U bearer between the eNB and S-GW. To begin with, the eNB sends a UE Context Suspend Request and releases bearer information related to the NB-IoT UE at S-GW via MME (steps (1) and (2) in Fig. 5). Next, the S-GW releases the S1-U bearer with the eNB related to the NB-IoT UE. Specifically, the S-GW releases only the eNB address and downlink Tunnel Endpoint IDentifier (TEID)*61 and continues to store other information (step (3)). On completion of S1-U bearer release at the S-GW, the eNB receives notification of that by a UE Context Suspend Response via MME (steps (4) and (5)). The eNB then stores Access Stratum (AS)*62 information, S1-AP connection information, and bearer information for that NB-IoT UE and sends a RRC Connection Suspend message to the UE (steps (6) and (7)). The MME also stores S1-AP connection information and bearer information for that NB-IoT UE and enters the ECM_IDLE state (step (8)). Finally, on receiving the RRC Connection Suspend message from the eNB, the NB-IoT UE stores AS information and likewise enters the ECM_IDLE state ((step (9)).

2) RRC Resume Procedure

This procedure reestablishes (resumes) the RRC connection between the NB-IoT UE and eNB in Suspend state and the released S1-U bearer between the eNB and S-GW. When resuming a connection at UE startup, the NB-IoT UE activates this procedure. It begins by resuming the connection with the network using the AS information stored by the RRC Suspend procedure (steps (1) and (2) in Fig. 5). At this time, the eNB performs a security check on the NB-IoT UE to resume the RRC connection. It also provides a list of resumed radio bearers to the NB-IoT UE and synchronizes the EPS bearer state between the NB-IoT UE and eNB (step (3)). If the above process completes normally, the eNB sends a UE Context Resume Request to the MME to notify it that the connection with the NB-IoT UE has safely resumed (step (4)). On receiving this resumption notification from the eNB, the MME restores the S1-AP connection information and bearer information for the suspended NB-IoT UE, enters the ECM_CONNECTED state, and sends to the eNB a UE Context Resume Response that includes the S-GW address and related S1-AP connection information for the NB-IoT UE (steps (5) and (6)). Uplink data transfers can now take place from the NB-IoT UE toward the S-GW (step (7)). The MME, in turn, sends the eNB address and downlink TEID to the S-GW by a bearer correction request to reestablish (resume) the S1-U bearer between the NB-IoT UE and S-GW on the downlink (steps (8) and (9)). Once this resumption completes, the S-GW sends a bearer correction request to MME enabling downlink packet transfers to the eNB to start immediately (steps (10) and (11)).

In the event that downlink packets are received at the S-GW while the NB-IoT UE is in Suspend state, the S-GW buffers the downlink packets and initiates a Downlink Data Notification procedure between the S-GW and MME the same as in existing EPS. The MME can now page the NB-IoT UE thereby activating the connection resume procedure by UE startup (see "Incoming call occurs" in Fig. 5).

3) Deletion of S1-AP Connection Information

To minimize the effects of inter-cell movement by an NB-IoT UE, AS information is transferred between eNBs [5] [6]. Thus, in the case that the eNB changes, the suspended connection established by procedure (1) above by the old eNB can be resumed by procedure (2) by the new eNB. However, if any of the following events should occur while the MME is in a state storing S1-AP connection information related to a certain NB-IoT UE, the MME and related eNB will delete the stored S1-AP connection information by a S1 release procedure [3] [7].

- MME receives a new EPS Mobility Management (EMM)*63 procedure via a different logical S1 connection related to that NB-IoT UE.

*61 **TEID:** A connection path identifier used in GRPS Tunneling Protocol (GTP).

*62 **AS:** The function layer between the mobile terminal and radio network.

*63 **EMM:** Management information used in LTE on UE location state, concealment, authentication, connection, etc. or processes related to the registration, modification, or deletion of that information.

- A TAU procedure is activated in conjunction with a MME change.
- A UE capable of 3G/LTE connections with NB-IoT ability receives a Context Request from a Serving General packet radio service Support Node (SGSN)*64 when reattaching by 3G and making a transition to LTE by TAU.
- UE performs a Detach*65.

4) Application of HLCom

If, in communications using intermittent reception functions such as PSM and eDRX, the S-GW receives downlink packets while the NB-IoT UE is in Suspend state, the S-GW can extend buffer capacity by the same type of method as used in C-Plane CIoT EPS optimization described above. Furthermore, if a TAU occurs, that time-related information is shared between MMEs.

5. Conclusion

In this article, we described new technologies for IoT services as specified in LTE Release 13. These technologies satisfy core service requirements, and we expect them to be introduced in earnest as those services began to spread. Going forward, 3GPP intends to further enhance Release 13 specifications, and NTT DOCOMO plans to be actively involved in standardization activities for other technologies that need to be provided to further promote the proliferation of IoT services.

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*64 **SGSN:** A logical node in 3GPP standard specifications providing functions such as packet switching and mobility management for mobile terminals performing packet communications.

*65 **Detach:** Procedure to remove registration of a terminal from the network at certain times such as when its power is switched off.

CA | DC | Unlicensed Frequency Utilization

Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

Broadband Frequency Technologies in LTE-Advanced Release 13

To accommodate the surge in traffic, the key LTE-Advanced technologies such as CA and DC were specified in 3GPP up to Release 12. CA achieves broadband communication by utilizing multiple LTE carriers simultaneously, while DC enables UE to connect with multiple eNBs simultaneously utilizing multiple LTE carriers. This article describes new technologies defined in 3GPP Release 13 including advanced CA and DC technologies, and LAA and LWA technologies that utilize unlicensed frequency bands.

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1. Introduction

In recent years, there have been growing demands for higher speed and larger capacity networks to cope with the rapid increase in mobile data from services such as high-definition video and video calling accompanying the spread of smartphones and tablet devices. The 3rd Generation Partnership Project (3GPP) Release 10 specifies Carrier Aggregation (CA) technologies that achieve high data rates utilizing multiple LTE carriers simultaneously. These technologies have already been deployed by many mobile network operators all around the world. In March 2015, NTT DOCOMO launched LTE-Advanced services based on CA technologies called PREMIUM 4G. These services offered a maximum downlink speed of 300 Mbps in October of that year, which rose to 375 Mbps in June 2016. In 3GPP standardization, NTT DOCOMO has been proactive in studying further expansion of high-speed CA data communications with other participating companies such as telecommunication operators and vendors. 3GPP discussed enhanced technologies to enable higher-speed communications with multiple LTE carriers and more flexible operations in recent releases, and specified Time Division Duplex (TDD)*1-Frequency Division Duplex (FDD)*2 CA technologies that aggregate multiple LTE carriers with different duplex modes

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*1 **TDD:** A scheme for transmitting signals using the same uplink and downlink carrier frequency. It switches time slots for uplink and downlink.

*2 **FDD:** A scheme for transmitting signals using different uplink and downlink carrier frequencies.

and Dual Connectivity (DC) technologies that enable simultaneous communications with multiple evolved Node B (eNB)*3 in Release 12.

Then, 3GPP Release 13 specified advanced CA technology for higher throughput*4 by aggregating even more LTE carriers, and advanced DC technology for enhancing uplink throughput. In addition, Release 13 also specifies Licensed Assisted Access (LAA) and LTE Wireless Local Area Network (LTE-WLAN) Aggregation (LWA) technologies to enhance throughput by utilizing conventional LTE and unlicensed frequency bands*5 simultaneously. This article describes these Release 13 technologies.

2. Advanced CA Technologies

2.1 CC Number Extension

Up to Release 12 CA, a maximum of 5 LTE carriers called "Component Carriers" (CCs)*6 could be configured for a User Equipment (UE) [1] - [3]. This enables a maximum 100 MHz bandwidth for data communications, which achieves a theoretical peak data rates of approximately 4 Gbps, assuming eight Multiple Input Multiple Output (MIMO) layers*7 and 256 Quadrature Amplitude Modulation (QAM)*8 for downlink, and 1.5 Gbps assuming four MIMO layers and 64QAM*9 for uplink.

In Release 13, the maximum number of CCs that can be configured for a UE simultaneously was increased to 32 to archive higher data transmission rates with wider bandwidths. This enables a maximum 640-MHz bandwidth for data transmission, achieving peak data rates of approximately 25 Gbps for downlink with 8 MIMO layers and 256QAM, and 9.6 Gbps for uplink with 4 MIMO layers and 64QAM.

2.2 PUCCH on SCell

Since CA aggregates multiple independent LTE carriers for parallel and simultaneous communications, scheduling and data transmission/reception are done independently by each CC. Hence, most of the conventional and non-CA LTE functions can be reused for each CC. On the other hand, in Release 12 CA, only the Primary Cell (PCell)*10 supports the Physical Uplink Control CHannel (PUCCH)*11 that transmits Uplink Control Information (UCI)*12 such as ACKnowledgement (ACK)*13/Negative ACK (NACK)*14 for all the downlink CCs and Channel State Information (CSI)*15 for all the downlink CCs, and Scheduling Requests (SR)*16 for uplink. This is to avoid mandating more than one uplink CC in CA. Furthermore, having PUCCH on PCell only allows UE to use the unified UCI transmission framework regardless of its uplink CA capability. However, if a certain LTE carrier is used as the PCell for many UEs configured with CA, there can be a shortage of uplink radio resources*17 due to the increased PUCCH load on that carrier. A typical example is CA operating on heterogeneous networks*18 where many small cells*19 are deployed in the coverage of a macro cell. The relatively low-powered small cells are deployed in high traffic areas with different frequencies from that of the macro cell. In areas where these small cells are overlaid on the macro cell, UE can be configured with CA for the small cells and the macro cell (**Figure 1**).

In order to solve this issue, Release 13 introduced the new function to enable PUCCH configuration for a Secondary Cell (SCell)*20 in addition to the PCell in uplink CA. When CA is performed with this function, CCs are grouped together either with the PCell or SCell with PUCCH (PUCCH-SCell). UE sends UCI for CCs within each group by using the PCell or PUCCH-SCell. With this new function, uplink radio resource shortages can be resolved by offloading UCI from macro cell to the small cells while keeping the macro cell as the PCell.

2.3 Two Types of PUCCH Formats

Up to Release 12, different PUCCH formats were designed to suit numbers of CCs or multiplexed UCI classes/payloads*21. All of these formats use Code Division Multiplexing (CDM)*22

*3 **eNB:** A base station in LTE radio access systems.
*4 **Throughput:** The effective amount of data received without error per unit time.
*5 **Unlicensed frequency band:** A frequency band usable without the need for an official license and not limited to a particular telecommunications operator.
*6 **CC:** A term denoting each of the carriers in CA.
*7 **MIMO layer:** In MIMO, the multiplex number when multiplexing different signals with spatial multiplexing on the same radio resources with different antennas.
*8 **256QAM:** A type of modulation scheme. 256QAM modulates data bits through 256 different amplitude and phase signal points. A single modulation can transmit 8 bits of data.
*9 **64QAM:** A type of modulation scheme. 64QAM modulates data bits through 64 different amplitude and phase signal points. A single modulation can transmit 6 bits of data.
*10 **PCell:** The carrier essential to keep the connection with multiple carriers in CA. Also referred to as the primary cell.
*11 **PUCCH:** The physical channel used to send and receive UCI.
*12 **UCI:** A term denoting uplink control information such as ACK/NACK, CSI and SR.
*13 **ACK:** A reception confirmation signal to notify the transmitting node that the receiving node has received (decoded) the data correctly.

to multiplex different users on PUCCH into a single Physical Resource Block (PRB)*23 to suppress overheads. However, to achieve CA with maximum 32 CCs, UCI with size of tens to hundreds of bits need to be accommodated on PUCCH. For this reason, two types of new PUCCH formats (PUCCH formats 4 and 5) were introduced in Release 13 (**Table 1**, **Figure 2**).

(1) The PUCCH format 4 can accommodate very large payloads without any spreading (no CDM support). Furthermore, it enables setting more than one PRB to further increase payloads.

(2) Applying the spreading factor 2 to PUCCH format 5 enables CDM for up to two users on PUCCH, which supports larger payloads than the conventional PUCCH formats.

Apart from the CDM supporting and

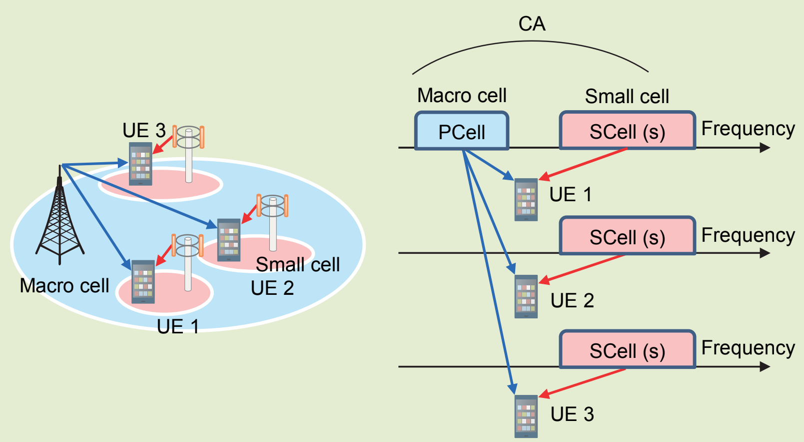

Figure 1 CA operations with macro and small cells

Table 1 Structure of PUCCH formats 4 and 5

	PUCCH format 4	PUCCH format 5
Spreading factor	1 (no spreading)	2
No. of PRBs	1 - 8	1
No. of bits per PRB	288	144
UCI classes	Any combination of ACK/NACK, SR, CSI measurement information	
No. of CRC bits	8	
Encoding scheme	Tail biting convolutional coding	
Frequency hopping	Yes	

Tail biting convolutional coding: A type of convolutional coding. These encoders match the initial shift register state with the end. Convolutional coding is a type of error correction encoding. Consisting of a shift register and a bit adder, these encoders use input bits and internal state of the shift register to produce an output. Maximum likelihood decoding based on the Viterbi algorithm is known as a decoding method.

*14 **NACK:** A reception confirmation signal to notify the transmitting node that the receiving node was unable to receive (decode) the data correctly.

*15 **CSI:** The channel state information of the radio channel.

*16 **SR:** A signal from the user to the base station requesting radio resource allocation for uplink.

*17 **Radio resources:** A general term for resources needed to allocate radio channels (frequencies).

*18 **Heterogeneous network:** In this article, a network configuration that overlays nodes of different power, which typically includes picocell and/or femtocell base stations whose transmit power is smaller than that of ordinary base stations.

*19 **Small cell:** A general term for cells that transmit with lower power than macro cells.

*20 **SCell:** Carriers other than the PCell with multiple carriers in CA. Also referred to as the secondary cell.

*21 **Payload:** In this article, this denotes the number of UCI data bits transmitted on a PUCCH.

*22 **CDM:** Multiplexing signals using mutually different orthogonal spreading sequences when transmitting multiple signal sequences on the same radio system band.

*23 **PRB:** A unit for allocating radio resources consisting of one subframe and 12 subcarriers.

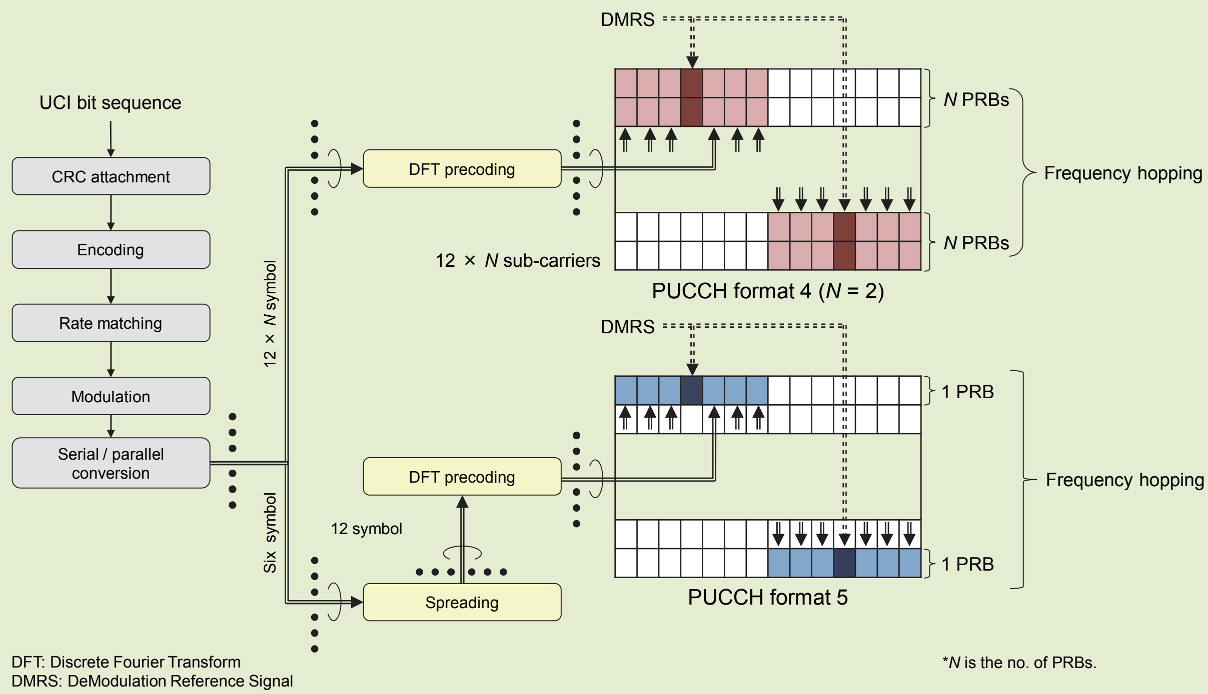

Figure 2 Structure of PUCCH formats 4 and 5

the number of PRBs, these two PUCCH formats have many commonalities in the physical layer, such as the number of Cyclic Redundancy Check (CRC) bits, encoding scheme, and multiplexed UCI classes.

3. Advanced DC Technologies

Release 12 designed DC to achieve user throughput comparable with that of CA by aggregating multiple CCs across two eNBs. In release 13, DC was further enhanced with higher uplink throughput and more flexible deployment.

3.1 Uplink Throughput Improvements

1) DC Uplink Resource Allocation Issues

In DC, separate eNBs allocate uplink resources independently for a UE. Hence, Release 13 addresses how to allocate adequate uplink resources on multiple CCs for UE.

Typically, eNB calculates the required uplink resources based on the uplink buffer amount reported from UE. In DC, since both eNBs calculate the amount of uplink resources based on the report and allocate them to the UE independently, excess uplink resource allocation over actual amount of remaining data will occur. In particular, with small data packets, if resources are allocated by both eNBs, the UE may send all data to only one of them, and send padding (meaningless bit strings) to the other eNB, which wastes radio resources.

2) Data Amount-based Buffer Size Report/Uplink Data Transmission Control

To prevent the excess uplink resource

allocation for the small data packets described above, new uplink transmission control methods were introduced. In Release 13 DC, UE buffer status reporting and uplink data transmission are controlled based on the amount of uplink data buffered in the UE. As shown in **Figure 3**, if the amount of the buffered data is smaller than the threshold configured by the eNB, the UE performs buffer status reporting and uplink data transmission only to one of the eNBs, just like DC in Release 12. In contrast, if the amount of the buffered data is larger than the threshold, the UE transmits to both eNBs. This buffer size-based mechanism solves the uplink resource over-allocation problem since only one eNB is aware of the buffered data and allocates resources when the amount of the buffered data is small.

3.2 Controls for More Flexible Operations

1) The Issue of Acquiring Difference Information for SFN/Subframe Numbers between eNBs

Release 12 specifies two kinds of DC operation - synchronous DC (requiring synchronization between eNBs), and asynchronous DC (not requiring synchronization between eNBs). When DC is deployed on an unsynchronized NW where each eNB manages System Frame Number (SFN)*24/subframe numbers*25 independently, UE is configured with the multiple CCs of which SFN/subframe numbers are not aligned. In this case, both eNBs must control the UE considering the SFN/subframe number differences (e.g. measurement gap control*26) (**Figure 4**).

In Release 12 DC, it was assumed that the difference information of SFN/subframe numbers between eNBs would be acquired by Operation, Administration and Management (OAM)*27. However, several potential issues were identified with this assumption in 3GPP standardization. Specifically, this OAM based acquisition is hard to apply to eNBs operating under separate OAMs. Another issue is the increased operational workload such that when an eNB is newly installed, the operator needs to obtain and set the difference information for every neighboring eNB. Consequently,

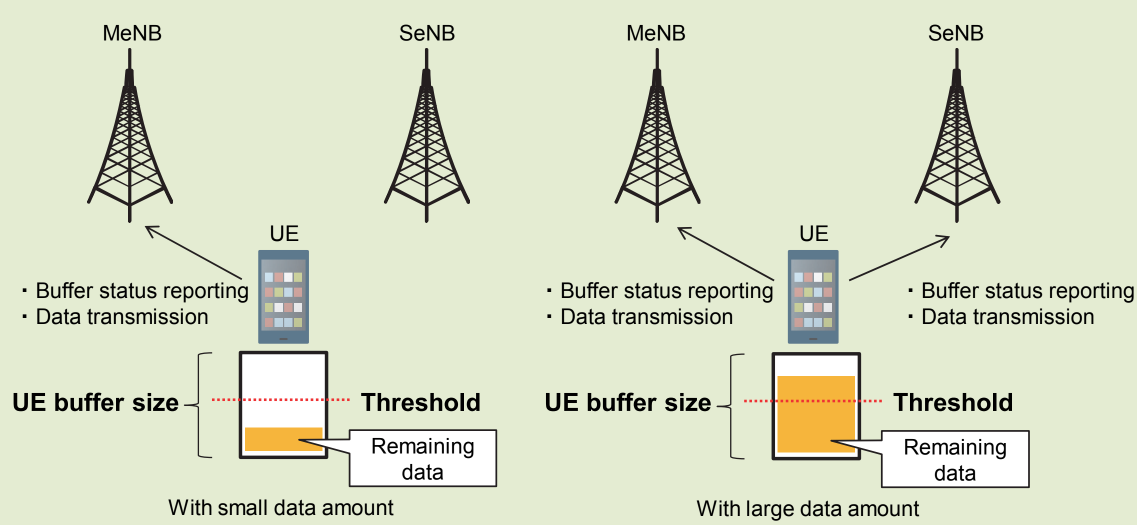

Figure 3 Uplink data amount-based buffer size report & transmission controls in DC

*24 **SFN:** The number allocated to each radio frame. Values are from 0 to 1,023.

*25 **Subframe number:** The number allocated to each subframe. Values are from 0 to 9.

*26 **Measurement gap control:** Management control in periods for measuring frequencies other than the serving frequency.

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

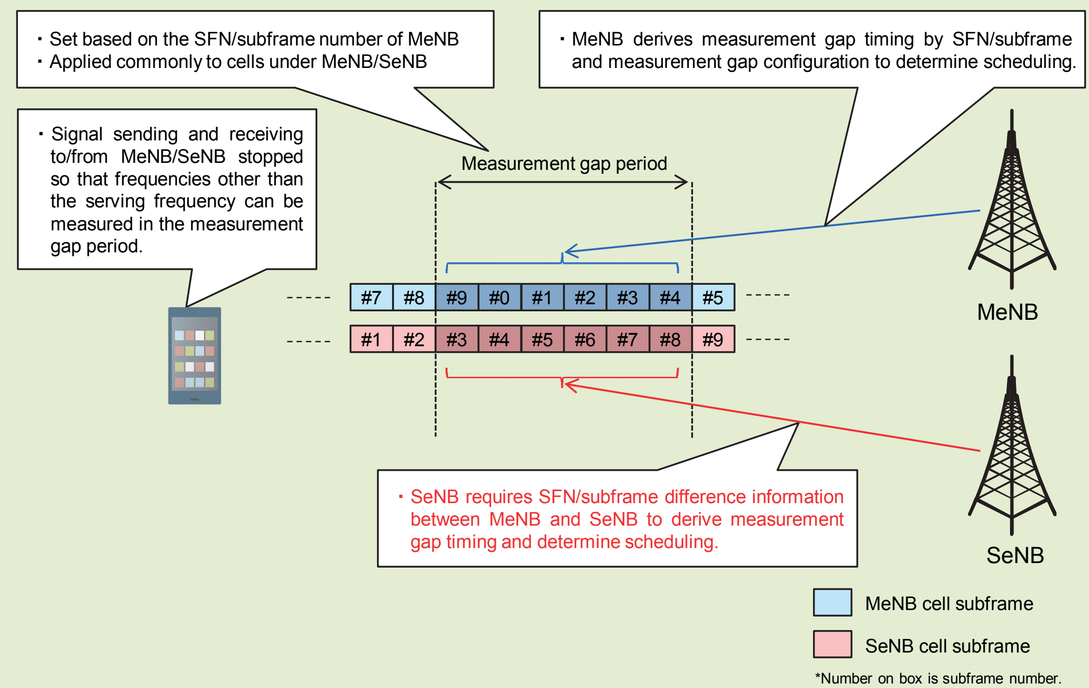

Figure 4　Example of SFN/subframe number differences necessity in asynchronous DC (measurement gap control)

DC deployment is limited to certain areas.

2) UE Measuring and Reporting of SFN/Subframe Number Difference

To solve the issues above, Release 13 specified UE-based acquisition of the difference information of SFN/subframe numbers. Specifically, UE calculates the differences of SFN, subframe numbers and subframe start timing between Master eNB (MeNB)*28 and Secondary eNB (SeNB)*29 cells, and then reports the information to the eNB as measurement result. With this new UE based acquisition mechanism, operators can deploy DC more flexibly, i.e., regardless of OAM implementation and without increasing operational load.

4. Unlicensed Frequency Band Technologies

In hot spot areas where high data traffic can be expected, many telecommunications operators are providing WLAN services using Wi-Fi®*30 with unlicensed frequency bands in addition to their cellular communication services such as 3G/LTE provided on specially allocated frequencies (licensed frequency bands). Unlicensed frequency bands in hot spot areas can greatly improve the quality of the user experience. However, using two different Radio Access Technologies (RAT)*31, i.e. LTE with licensed frequency bands and Wi-Fi with unlicensed frequency bands, could inconvenience users, since RAT switching, re-connection and re-authentication would be necessary as users move to different coverage areas. Hence, 3GPP studied and specified LAA and LWA technologies to eliminate this inconvenience and facilitate efficient use of unlicensed frequency bands. LAA enables users to use unlicensed frequency bands without any

*28 **MeNB:** eNB in DC that manages UE-network connectivity.

*29 **SeNB:** eNB in DC that provides radio resources in addition to MeNB.

*30 **Wi-Fi®:** The name used for devices that interconnect on a wireless LAN using the IEEE802.11 standard specifications, as recognized by the Wi-Fi Alliance. A registered trademark of the Wi-Fi Alliance.

*31 **RAT:** Radio access technologies such as LTE, 3G, GSM and Wi-Fi.

inconvenient operations by using a single LTE-based RAT for both licensed and unlicensed frequency bands. On the other hand, LWA utilizes DC designed to enhance user throughput by adding WLAN connections while maintaining mobility with connection to LTE.

4.1 LAA Technology

Release 13 defines LAA technologies for LTE carriers using a 20-MHz bandwidth on the 5-GHz unlicensed band as a supplemental downlink SCell in CA. Essential channel access technologies for unlicensed frequency bands are described below.

1) Channel Access Based on LBT

Since radio stations using unlicensed frequency bands can be set up by any operator or user, interference from the radio stations in the vicinity could degrade the quality of data communications. For this reason, Japan and Europe require Listen-Before-Talk (LBT) mechanisms in radio systems working on the 5-GHz unlicensed band. These mechanisms prevent interference by allowing transmission only when it is confirmed as result of carrier sensing*32 that the channel is unused by the other systems in the vicinity, and limiting the transmission period to a predetermined amount of time (4 ms in Japan) [4] [5].

3GPP specifies LBT mechanisms as LAA downlink channel access methods (**Figure 5**) for fair coexistence with WLAN. LAA base stations use collision avoidance mechanisms similar to those of WLAN, which are based on random back-off*33 and Contention Window Size (CWS)*34 adjustment with variable length. Carrier sensing is performed and the back-off counter is decremented when the channel is idle. Then, when the back-off counter reaches 0, channel access opportunity for transmission can be obtained. Furthermore, there is a low power detection threshold in LAA for

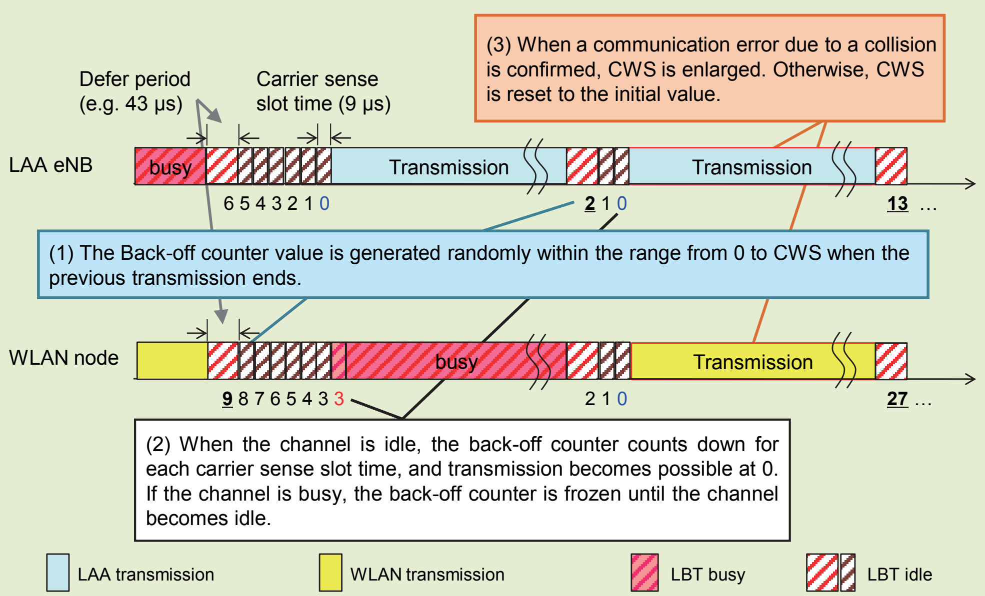

Figure 5 LAA and WLAN coexistence based on LBT

*32 **Carrier sensing:** Technology to confirm that a frequency carrier is not in use by another communication before commencing transmission.

*33 **Random back-off:** Technology to prevent collisions due to multiple simultaneous transmissions that uses periods of randomly set length in which it must be confirmed that a frequency carrier is not used before transmitting.

*34 **CWS:** The range of values that can be set randomly in random back-off technology.

coexistence with WLANs so that other nearby WLAN performance is not degraded [6]. There is also a set of configurations (LBT priority class) for the combination of LBT parameters and maximum transmission time, which are described in **Table 2**. For example, to send a small amount of data with minimum delay, the LBT time can be shortened with LBT priority class 1 in exchange for decreasing the maximum transmission time (Maximum Channel Occupancy Time (MCOT)).

2) Partial Subframe Transmission

In LTE, subframes with length of 1 ms are used as the basic Transmission Time Interval (TTI)*35 for data transmission and reception. Therefore, radio signal transmission or reception is performed for 1 ms from the beginning of the subframe. However, with the LAA channel access method, when transmission or reception becomes possible, i.e. when the back-off counter is at 0, in most cases the corresponding timing does not match the beginning of the subframe, which may limit opportunities for sending or receiving data.

Here, in LAA, initial partial subframe and ending partial subframe transmissions are supported as functions to enable transmission of control and data signals in start and stop positions other than the subframe boundaries. The initial partial subframe is the data transmission structure from the middle to the end of the subframe, while ending partial subframe is the data transmission structure from the beginning to the middle of the subframe. This function improves LAA transmission efficiency and throughput by increasing the amount of data sent in the same transmission time. Furthermore, since the LAA transmission time for a certain traffic amount is reduced, the time spent competing for channels with other systems is reduced, which enables improved coexistence with other systems in neighboring LAA areas [7].

Also, UE can identify normal subframes or partial subframes and recognize continuous transmission (bursts*36) cut-off points by decoding common control information from eNB to get the number of valid Orthogonal Frequency Division Multiplexing (OFDM) symbols in the subframe.

4.2 LWA Technology

In addition to LAA technology, Release 13 also specifies LWA technologies that enhance user throughput by utilizing LTE and WLAN radio resources simultaneously.

Figure 6 describes LWA network architecture and LTE/WLAN protocol stack*37 adaptation.

1) LWA Network Architecture

LWA network architecture is based on the DC architecture defined in Release 12. LWA achieves radio capacity improvements without degrading UE mobility performance by utilizing LTE eNB as the MeNB due to its more reliable transmissions while using WLAN-AP (Access Point)*38 as SeNB for more capacity. Also, LWA utilizes the user plane data transmission paths defined for DC in Release 12, as shown in Fig. 6 (a). Release 13 specifies an interface (Xw IF) between eNB and WLAN-AP and inter-node procedures for this architecture.

Table 2 LBT parameter set in LAA

LBT priority class	Defer period	CWS set (underlined is initial CWS value.)	MCOT
1	16 + 9 × 1 = 25 μs	{<u>3</u>, 7}	2 ms
2	16 + 9 × 1 = 25 μs	{<u>7</u>, 15}	3 ms
3	16 + 9 × 3 = 43 μs	{<u>15</u>, 31, 63}	8 or 10 ms*
4	16 + 9 × 7 = 79 μs	{<u>15</u>, 31, 63, 127, 255, 511, 1,023}	8 or 10 ms*

*10 ms is applied if RAT other than LAA is guaranteed not to coexist on the same frequency by regulations etc. In other cases, 8 ms is applied.

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

*36 **Burst:** Temporally successive transmissions based on one LBT.

*37 **Protocol stack:** Protocol hierarchy.

*38 **WLAN-AP:** Nodes that transmit and receive using WLAN radio resources.

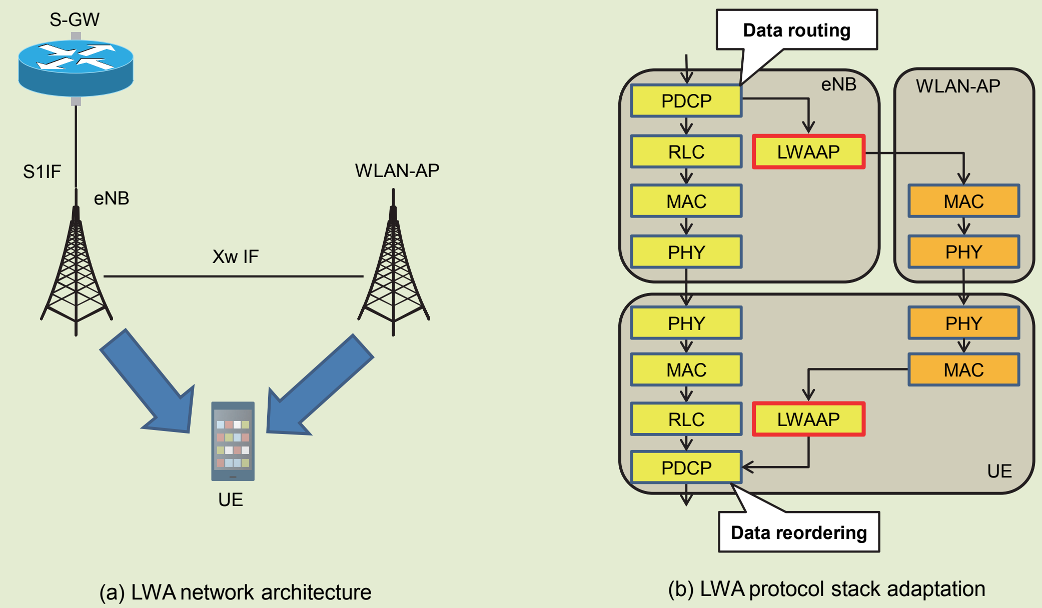

Figure 6 LWA network architecture and protocol stack adaptation

2) LTE/WLAN Protocol Stack Adaptation

In the same way as DC, the LWA protocol stack is split under the Packet Data Convergence Protocol (PDCP)*39 layer. Downlink data from Serving Gate-Way (S-GW)*40 arriving at eNB via S1 interface is processed in the PDCP layer in eNB, then either passed to LTE Radio Link Control (RLC)*41 layer to be sent to UE using LTE radio resources, or transferred to WLAN-AP to be sent to UE using WLAN resources.

However, because bearer*42-aware (de-) multiplexing is not done in WLAN as it is in LTE, if data of multiple bearers are sent via WLAN, the receiving UE is not be able to identify which received data belongs to which bearer, and consequently is not be able to perform reordering with the data received via LTE.

In order to solve this problem, a new adaptation layer (LWAAP, LTE-WLAN Aggregation Adaptation Protocol) is introduced under the PDCP layer in LWA, as shown in Fig. 6 (b). LWAAP layer performs capsuling on PDCP Protocol Data Units (PDUs)*43, and attaches the identity of the corresponding bearer to the header to enable the UE to identify the data.

5. Conclusion

This article has described the functional characteristics and basic operations specified in 3GPP Release 13 including advanced CA technologies for expanding maximum bandwidth and offloading uplink control information, advanced DC technologies for high uplink throughput and operational flexibility, and LAA/LWA technologies for communications on unlicensed bands. These functions enable further broadband communications, higher user throughput, and more flexible operations. To accommodate further traffic increases, Release 14 is studying enhanced LAA for higher uplink throughput and next-generation radio technologies with even wider bandwidths.

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

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

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

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

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

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EBF/FD-MIMO | AAS | BS IRC

Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

LTE-Advanced Release 13 Multiple Antenna Technologies and Improved Reception Technologies

To respond to the traffic increases of recent years, 3GPP has been studying further enhancements for radio base stations. LTE-Advanced Release 13 specifies technologies to achieve two-dimensional radio base station antenna port mapping and increase the number of ports, radio performance requirements for AAS for more flexible area construction with combined antenna-transmission/reception functions, as well as performance requirements for interference suppression enabled by interference rejection combining receivers to minimize uplink interference from neighboring cells. This article describes the technical characteristics of these, and 3GPP standardization trends.

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1. Introduction

With the spread of terminals such as smartphones and tablets, and the advanced functions of these terminals in recent years, traffic has dramatically increased due to use of high-volume content such as high-definition video services and video calling. For this reason, The 3rd Generation Partnership Project (3GPP) is studying further enhancements to radio base stations to enable services with larger volumes and higher speeds.

LTE-Advanced*1 Release 13 specifications (hereinafter referred to as "Release 13") prescribe Elevation Beam-Forming/Full Dimension-Multiple Input Multiple Output (EBF/FD-MIMO*2) to expand antenna port mapping on base stations from one dimension to two dimensions, and increase port numbers. These can be achieved using Active Antenna System (AAS) technology in which antennas are combined with transceiver units to make base stations that are more compact, more energy efficient, and that enable greater flexibility in configuring coverage areas. 3GPP also prescribes requirements for AAS, and requirements for Minimum Mean Squared Error-Interference Rejection Combining (MMSE-IRC) receivers, which use advanced signal processing to suppress uplink interference from neighboring cells*3.

This article describes implementation of these new technologies and equipment, an overview of their requirements, and the future outlook in 3GGP.

*1 **LTE-Advanced:** A developmental radio interface in LTE (Releases 8, 9), standardized as a specification from Release 10 onward.

2. EBF/FD-MIMO

LTE has been continuing downlink MIMO technical enhancements through successive releases. **Table 1** and **Figure 1** briefly describe Releases 12 and 13 downlink MIMO technologies and closed-loop*4 precoding MIMO multiplexing transmission, respectively. Release 13 prescribes EBF/FD-MIMO functions, which enable control of vertical and horizontal transmission beams using two-dimensional base station antenna ports arranged in the horizontal and vertical directions.

2.1 Downlink MIMO Technology in Release 12

Release 12 supports a maximum of eight transmission antenna ports for downlink MIMO. This enables different data streams*5 to be simultaneously transmitted from each antenna port, which maximizes the peak data rate (MIMO spatial multiplexing). In addition, multiplying different complex weights*6 with combination data stream/transmission antennas enables precoding transmission which gives directionality*7 to transmission signals. Release 12 achieved horizontal precoding transmission using MIMO antenna ports arranged in the horizontal direction. For appropriate precoding control, Channel State Information (CSI)*8 has to be acquired by the transmitter. Two methods are adopted in LTE for this purpose.

(1) CSI-RS-based method

The first method uses feedback information from terminals. In this method, the base station sends a CSI-Reference Signal (CSI-RS)*9

Table 1 Release 12 and 13 downlink MIMO technologies

	Release 12	Release 13
Number of transmission antenna ports	1, 2, 4, 8	1, 2, 4, 8, 12, 16
Transmission antenna configuration	One dimension (horizontal direction arrangement)	Two dimension (horizontal and vertical direction arrangement)
Number of SU-MIMO streams	Max. 8	Max. 8
Number of MU-MIMO streams	Max. 4 (Max. 4 mobile terminals, max. 2 streams per mobile terminal)	Max. 8 (Max. 8 mobile terminals, max. 2 streams per mobile terminal)

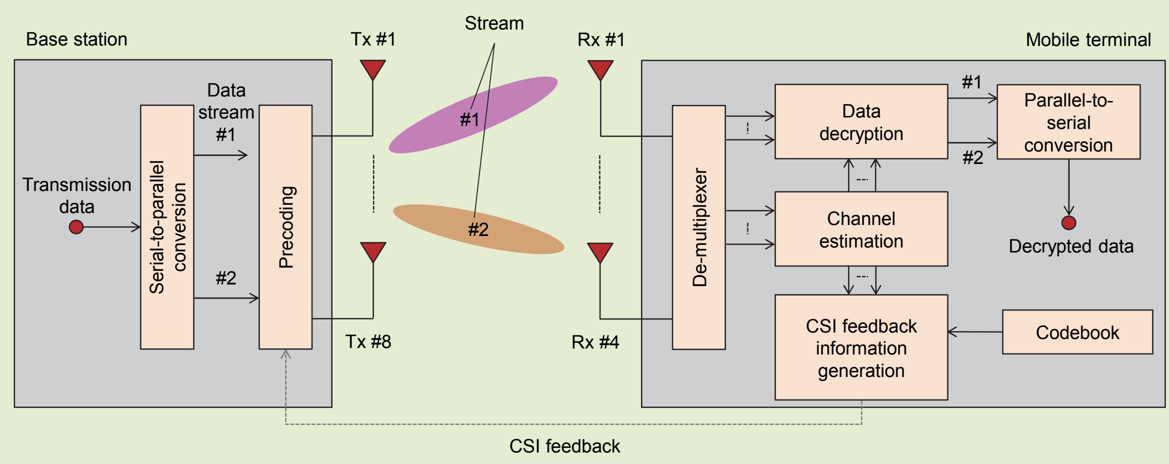

Figure 1 Closed-loop precoding MIMO multiplexing (e.g. 8 × 4 MIMO, 2 stream transmission)

*2 **MIMO:** Technology to improve data rate and reception quality by using more than one transmitter (transmission antenna) and receiver (reception antenna).

*3 **Cell:** The smallest area unit for sending and receiving radio signals between a mobile communication network and mobile terminals.

*4 **Closed-loop:** A method of using feedback information from receivers.

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

*6 **Complex weight:** Complex signals multiplied with transmission signals for the purpose of obtaining a precoding gain.

*7 **Directionality:** A radiation characteristic of data streams.

*8 **CSI:** Information describing the state of the radio channel.

from each antenna port. The terminal then estimates the channel state information based on the received CSI-RS and selects a suitable precoding weight from predetermined candidates (Codebook*10), and then feeds back the selected index as a Precoding Matrix Indicator (PMI)*11. In addition to PMI, CSI feedback information consists of the Rank Indicator (RI)*12 that controls the number of transmission streams, and a Channel Quality Indicator (CQI)*13 for applied modulation encoding.

(2) SRS-based method

This method is based on the physics of channel reciprocity, which assumes that the uplink and downlink channel states are the same in principle. The base station can estimate downlink CSI from the received Sounding RS (SRS)*14, which is an uplink reference signal for channel sounding. This method is particularly effective with Time Division Duplex (TDD)*15, which uses the same frequency band for uplink and downlink, but requires accurate calibration of antennas and Radio Frequency (RF)*16 circuits.

There are two types of LTE MIMO transmission schemes - Single-User MIMO (SU-MIMO) and Multi-User MIMO (MU-MIMO). For SU-MIMO, multiple data streams are transmitted towards a single terminal, whereas data streams are spatially multiplexed to multiple terminals in MU-MIMO. Release 12 supported up to eight and four data streams for SU-MIMO and MU-MIMO, respectively.

2.2 Three-dimensional Beamforming

1) Overview

In recent years, enhancements in active antenna technology has enabled increases in the number of MIMO transmission antennas, and improved calibration accuracy of antennas and RF circuits. Particularly with precoding control in the vertical direction, it is necessary to calibrate vertical circuits with high accuracy to prevent unexpected interference from neighboring cells. Hence, Release 13 specifications enable horizontal and vertical precoding control using two-dimensional horizontal and vertical base station antenna ports. This technology controls beam direction in three dimensions in a rectangular coordinate system, and is referred to as three-dimensional beamforming.

2) Two CSI Report Methods

Release 13 specifications introduce two CSI report methods (called Class or eMIMO-Type) in which CSI-RS transmission method and CSI feedback information are different (**Figure 2**).

(1) Class A reporting method

The Release 13 Class A CSI reporting method supports up to 16 CSI-RS antenna ports two-dimensional CSI feedback. This method assures 12 or 16 CSI-RS resources (mapping in time and frequency domains) as multiple Release 12 CSI-RS resources, and adopts a two-dimensional codebook for CSI feedback in the horizontal and vertical directions. This codebook follows the double codebook structure*17

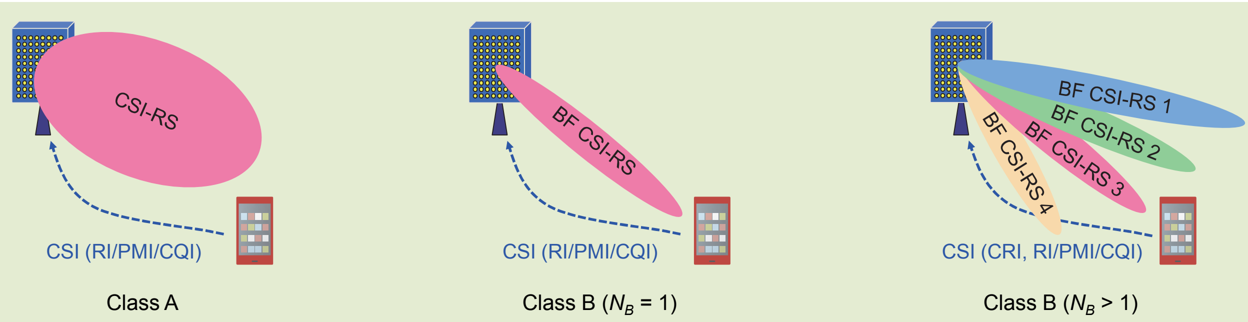

Figure 2 Release 13 CSI report method

*9 **CSI-RS:** A signal transmitted to measure CSI.

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

*11 **PMI:** Information fed back from the mobile terminal to specify a suitable downlink precoder. Notifies the index selected from the codebook.

*12 **RI:** Information returned from the mobile terminal to specify a suitable number of transmission streams.

*13 **CQI:** An index of reception quality measured at the mobile terminal indicating downlink channel reception conditions.

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

adopted in Releases 10 and 12 [1]. Also, this codebook is designed to notify antenna configurations with higher layer signaling to enable application to various antenna configurations (different numbers of horizontal/vertical antenna ports, and antenna spacing etc.) and deployment environments. For the Class A report method, CSI-RS overhead increases in proportion to the number of antenna ports. In addition, if the total base station transmission power is constant, transmission power for each CSI-RS antenna port is reduced correspondingly with the increase in the number of antenna ports.

(2) Class B reporting method

The Class B reporting method assumes beamformed CSI-RS to reduce CSI-RS overhead and expand CSI-RS coverage. This technology is presumed to have two major applications to suit the number of CSI-RS beams (N_B).

- If $N_B = 1$, it is possible to transmit CSI-RS with mobile terminal-specific beamforming. For example, based on preliminary CSI by channel reciprocity, the base station applies beamforming to CSI-RS. The mobile terminal measures CSI based on the beamformed CSI-RS and returns the CSI to the base station. In this way, CSI-RS overhead is reduced in the subsequent Class B report method ($N_B = 1$).
- On the other hand, when N_B is greater than 1, CSI feedback is performed for CSI-RS beam selection. Specifically, the base station transmits multiple CSI-RSs with different beams applied. The terminal selects a suitable CSI-RS beam from among those, and returns its index as a CSI-RS Resource Index (CRI). In addition, the terminal also returns CSI for the selected CSI-RS beam. In this method, even though there are overhead increases with multiple CSI-RS transmissions, beamforming suppresses those increases.

Release 13 specifications support Class B CSI reporting with a maximum N_B of 8. The Class B reporting method holds promise as a more effective technology in dealing with potential 5G (5th generation mobile communications systems) coverage issues, as it uses higher frequency.

2.3 Advanced MU-MIMO

Release 13, which improves precoding control flexibility, promises high spatial separation capacity between transmission beams, and hence enables more useful MU-MIMO operations. Release 13 expands the downlink data DeModulation Reference Signal (DM-RS)*18 functions to support MU-MIMO with up to eight streams (max. eight terminals, two streams per terminal). Specifically, it ensures up to four orthogonal layers by using a code multiplexing sequence length of four for DM-RS.

2.4 Technical Enhancements for TDD Systems

As described above, one of the CSI acquisition schemes is channel reciprocity using SRS. SRS is mainly designed for link adaptation applied to uplink data transmission, however higher accuracy channel estimation and high reference signal density is required if this reference signal is used for CSI acquisition for downlink precoding. Also with dense SRS scheduling, there is a concern that the SRS interference level from adjacent cells will rise and channel estimation accuracy will deteriorate. For this reason, Release 13 involved discussions on increasing SRS capacity to prevent insertion density expansion and overly dense scheduling. More specifically, Release 13 increases the number of SRS symbols*19 and enhances SRS multiplex technologies in TDD systems.

2.5 Future Outlook

While Release 13 studied EBF/FD-MIMO assuming operations below 6 GHz, wide bandwidth above 6 GHz will be crucial for future cellular networks including 5G, and there are demands for further advancements to MIMO beamforming and diversity*20 technologies for high frequency bands where radio wave propagation loss is large.

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

*16 **RF:** The frequencies used in radio communications, and frequencies used for radio signaling channels.

*17 **Double codebook structure:** A codebook structure designed to express radio channels as combinations of long-cycle, wide-band data and short-cycle, narrow-band data.

*18 **DM-RS:** A known signal transmitted to measure the state of a radio channel for data demodulation.

*19 **Symbol:** A time unit of transmitted data, consisting of multiple sub-carriers with Orthogonal Frequency Division Multiplexing (OFDM). Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK)) are mapped to each sub-carrier.

Achieving surface and distance coverage for sharing signals such as control signals in cells could also present a new challenge. The difficulty of RF circuit implementation for enlarged bandwidth is also a known issue. Studies are also required for high-gain MIMO equipment configurations and transmission technologies with low-cost RF circuitry (e.g. the number of RF circuits).

3. AAS

3.1 Requirements for AAS

To achieve beam control employed in EBF/FD-MIMO, AAS which integrates multiple transceiver units and a composite antenna including a radio distribution network and an antenna array is considered to be an effective way. However, since the composite antenna characteristics are not included in existing 3GPP base station RF specifications that are for their transceiver unit performance, AAS RF specifications have been specified in Release 13 [2] as new antenna-integrated 3GPP base station RF specifications.

Figure 3 shows configurations and scopes covered by RF specifications for existing base stations and AAS. AAS is expected to operate with higher power efficiency compared to existing base stations because of decreasing power loss by removing coaxial cables connected between transceiver units and the composite antenna. Furthermore, as shown in **Figure 4**, AAS also enables more flexible coverage area construction because it is possible to steer a main beam direction in the horizontal and vertical directions by adjusting the amplitude and phase of transmission/

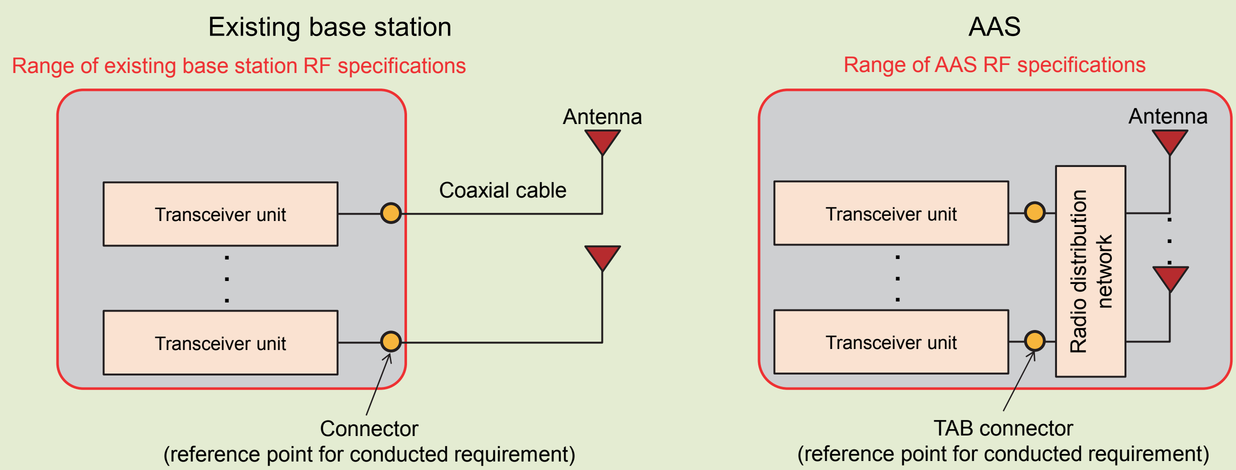

Figure 3 Configurations and scopes covered by RF specifications for existing base stations and AAS

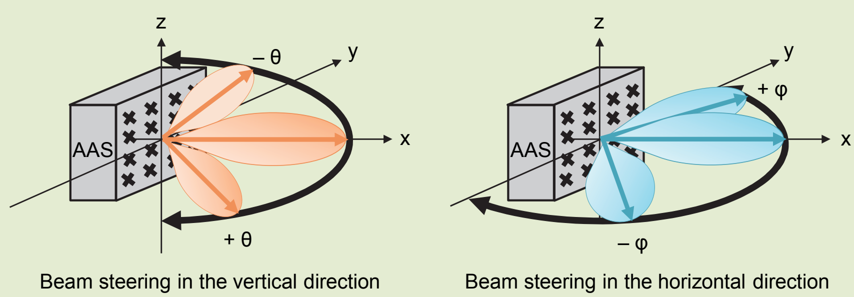

Figure 4 Steering main beam directions with AAS

*20 **Diversity:** A general name for technologies designed to improve the quality and reliability of communications using MIMO antennas. In particular, non-closed loop types.

reception signals. In addition, AAS can form multiple beams with different main beam directions simultaneously to cover multiple cell areas. As just described, AAS can offer functions not available with existing base stations.

3.2 AAS Specification Characteristics

Compared to existing base station RF specifications, there are two notable differences in AAS RF specifications in Release 13.

- Firstly, requirement reference point*21 is different. In existing base station specifications, the conducted requirement reference point (hereinafter requirements at this point referred to as "conducted requirements") is specified at a physical connector existed between the transceiver unit and the composite antenna, which is called as a Transceiver Array Boundary (TAB) connector. Then, antenna I/O signal characteristics at the conducted requirement reference point are also specified. In AAS specifications, in addition to the conducted requirement reference point, a new radiated requirement reference point (hereinafter requirements at this point referred to as "Over The Air (OTA) requirements") is specified in the antenna radiation space. Then some combined antenna radiation characteristics at the radiated requirement reference point are also specified. In particular, (1) radiated transmit power accuracy requirement*22 and (2) OTA sensitivity requirement*23, are specified as OTA requirements. OTA requirements enable evaluation on some performances of base stations that integrate the transceiver units and the composite antenna.
- Secondly, the specified unit is extended for some conducted requirements. In existing base station specifications, all radio requirements are specified at each conducted requirement reference point. In contrast, in AAS RF specifications, some radio requirements are specified not only for the amount at each TAB connector but also for the total amount of some TAB connectors.

1) OTA Requirement Details

(1) Radiated transmit power accuracy requirement

Radiated transmit power accuracy is considered to be the OTA requirement corresponding to the transmit power accuracy in the conducted requirements. To make these two accuracies equivalent, the antenna gain and its deviation*24 must be taken into account in the radiated transmit power accuracy requirement. For this reason, Equivalent Isotropic Radiated Power (EIRP)*25 [2] [3] is used as an evaluation indicator. The OTA requirement for the radiated transmit power accuracy is applied to the maximum value of EIRP. A beam direction achieving the maximum EIRP is referred to below as "beam peak direction." **Figure 5** shows examples of EIRP and deviation corresponding to various beam peak directions. Radiated transmit power accuracy is specified as the allowable deviation of EIRP in the beam peak direction. The specified range of accuracy is +/− 2.2 dB as indicated in Fig. 5. Also, each AAS has a different beam peak direction with its inherent antenna gain and deviation. Therefore, AAS vendors also declare the range of directions that satisfy radiated transmit power accuracy requirements. Here, the declared range is called as "EIRP accuracy directions set," and is shown in **Figure 6**. Radiated transmit power accuracy must be within the specified range. Testing to confirm the specified accuracy is performed in the representative five directions, namely one direction in which the absolute EIRP value is at its maximum and four directions in which θ or φ becomes the maximum or minimum within EIRP accuracy directions set because it is impractical to test for every point within the EIRP accuracy directions set. The specifications cover all AAS configurations that can steer the beam peak direction in both θ and φ directions,

*21 **Reference point:** Point locations for prescribing base station RF specifications. Measuring the characteristics of I/O signals to/from the antenna and characteristics of the radio radiation/reception space at the reference point confirms whether the base station satisfies 3GPP specifications.

*22 **Radiated transmit power accuracy requirement:** The requirement for transmission power accuracy at the radiated requirement reference point in antenna radio radiation space.

*23 **OTA sensitivity requirement:** The requirement for reception sensitivity at the radiated requirement reference point in antenna radio reception space.

*24 **Deviation:** An indication of variation in antenna gain.

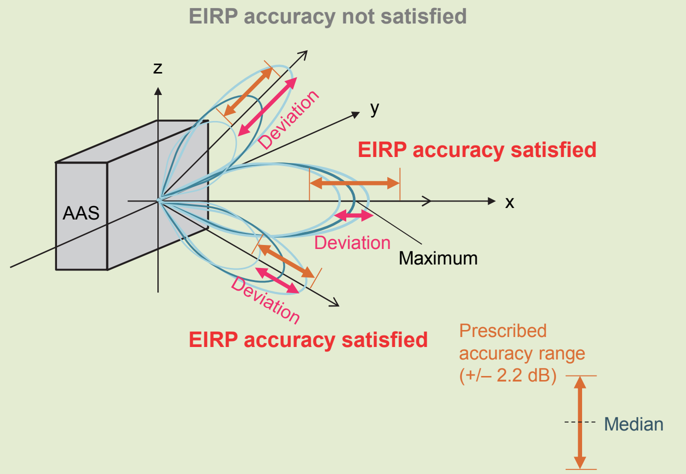

Figure 5　EIRP accuracy corresponding to steered beam peak directions

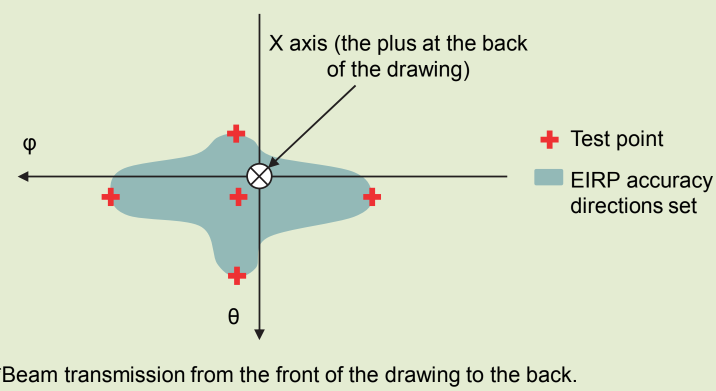

Figure 6　Range satisfying EIRP accuracy and test points

either θ or φ direction, and neither θ nor φ direction. Fig. 6 shows an EIRP accuracy directions set for a general AAS with beam peak directions steered in both θ and φ directions.

(2) OTA sensitivity requirements

Equivalent Isotropic Sensitivity (EIS)*26 [2] is used as an indicator for OTA sensitivity for similar reasons as radiated transmit power accuracy. The beam direction in which the receiving antenna gain is at its maximum is referred to below as the "OTA sensitivity direction". OTA sensitivity is specified as the minimum received power which throughput*27 of signals received from terminals achieves 95% of the maximum. Whether this requirement is satisfied is dependent on the relationship between the received beam direction and the actual arrival direction of signals from terminals and the EIS value. AAS vendors declare the EIS value, and the receiver target redirection range where the OTA sensitivity is achievable with the declared EIS value. **Figure 7** shows an example. The sensitivity Range of Angle of Arrival (RoAoA) is defined as OTA sensitivity directions that satisfy OTA sensitivity requirements. The receiver target redirection range is defined as the collective sensitivity RoAoA when changing the OTA sensitivity direction. Because it is impractical to test at every point, testing is performed in the five representative directions in the receiver target redirection range, similar to the test of radiated transmit power accuracy.

These two OTA requirements specify radio characteristic requirements which include composite antenna characteristics and enable evaluation of the requirements, but are not in existing specifications.

2) Requirements for the Total Amount at Multiple TAB Connectors

Allowable values for unwanted emission requirements (unwanted power radiated outside the desired frequency range) are specified as the total amount at multiple TAB connectors. In existing base station specifications, unwanted emission requirements are defined for each connector as discussed above. In

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

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

*27 **Throughput:** The amount of data transmitted without error per unit time.

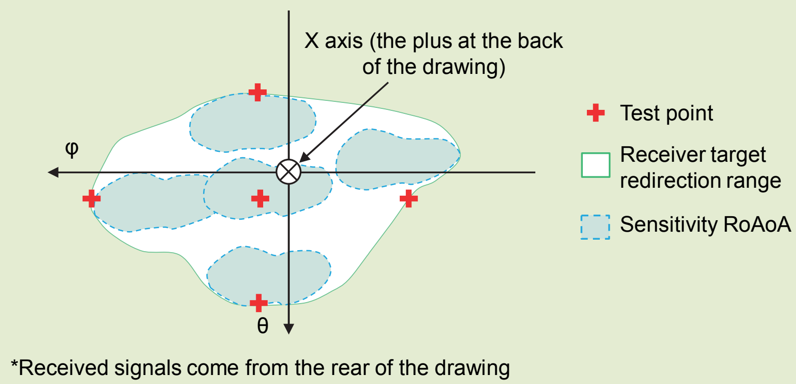

Figure 7 Range satisfying OTA sensitivity requirements and test points

contrast, for AAS, since multiple TAB connectors are implemented, there is a concern that applying the existing requirements defined for each TAB connector would result in large increases of total allowable unwanted emissions. Thus, requirements state that (1) total unwanted emission level for AAS shall not exceed the allowable amount for eight antenna ports, which is equivalent to the total amount of unwanted emission level for the maximum number of streams that can be simultaneously transmitted in existing specifications, and (2) if one AAS covers more than one cell, unwanted emission requirements are to be specified per cell to prevent bias in the amount of unwanted emissions between cells.

These requirements are described below.

- To be the number of transceiver units or the number of cells × 8 as $N_{TXU, counted}$, whichever is smaller (the latter to be the maximum if the number of transceiver units is larger than cells × 8).
- $N_{TXU, countedpercell}$ to be $N_{TXU, counted}$/ the number of cells
- Multiple TAB connectors which transmit and receive for a cell are to be grouped, and the allowable amount of unwanted emissions is then the existing allowable amount of unwanted emissions × $N_{TXU, countedpercell}$ for that group.

3.3 Future Work

The OTA requirements and the total amount requirements at multiple TAB connectors have been newly included in AAS RF specifications. However, as mentioned above, OTA requirements are only for radiated transmit power accuracy and OTA sensitivity. Because there are other requirements for TAB connectors between transceiver units and composite antennas, Physical TAB connectors must be installed and measurements at these connectors are required with AAS RF specifications. On the other hand, super multi-element AAS is considered to be an effective approach to construct commercial massive MIMO base stations being developed for 5G etc. In this kind of AAS, implementing physical TAB connectors with all transceiver units would not be practical. Furthermore, since removing physical TAB connectors promises to make AAS equipment more compact, the needs of AAS RF specifications with only OTA requirements are growing. There are ongoing discussions on the OTA requirements in Release 14.

4. Uplink MMSE-IRC Receiver

To handle the increase in traffic due to the rise in smartphone popularity of recent years, cells are becoming denser, especially in urban areas, which means interference from neighboring cells is increasing. In these areas, the power of interference from neighboring cells is larger than noise power*28, and has the potential to degrade throughput.

3GPP has been studying a variety of technologies in recent years to reduce the abovementioned neighboring cell interference at receiver side. In particular with downlink, advanced radio signal processing for terminals has been studied, and Release 11 specified performance requirements for MMSE-IRC receiver based on Minimum Mean Square Error (MMSE) criteria*29 with the aim of suppressing neighboring cell interfer-

*28 **Noise power:** The noise power in the receiver. This consists of the sum of thermal noise power originating in the mobile terminal, and the small power that comes from afar due to interference signals between cells.

*29 **MMSE criteria:** A method of calculating antenna combination weight. A standard requiring the minimum mean square error of the received signal after antenna combination, so that the reception SINR after combination can be maximized.

ence [5] [6]. In Release 12, the Network Assisted Interference Cancellation and Suppression (NAICS) receiver, a further enhancement of the interference reduction process for mobile terminals based on some control information about neighboring cell interference (e.g. transmission power) signaled from serving base station, was studied and the performance requirements for the receiver were specified [5] [7].

In contrast, advance radio signal processing for uplink has been considered in Release 13 for the first time. Specifically, the performance requirements for base station were specified with the assumption that the MMSE-IRC receiver studied in Release 11 is deployed in base stations [8].

4.1. MMSE-IRC Receiver Characteristics

1) MMSE Receiver Issues

In LTE Release 8 specifications, the uplink performance requirements for base station were specified assuming the MMSE receiver as radio signal processing technology [3]. The MMSE receiver detects desired signal according to the MMSE criteria, but it assumes that interference signals from neighboring cells are equivalent to white noise*30 in the radio signal process. Thus, since neighboring cell interference cannot be realistically suppressed, uplink throughput will be limited due to neighboring cell interference in areas where base stations are densely positioned.

2) MMSE-IRC Receiver Installation in Base Stations

Here, as discussed above, Release 13 considered the inclusion of MMSE-IRC receivers in base stations with the aim of suppressing neighboring cell interference. The MMSE-IRC receiver entails multiple reception antennas in base stations, and received signals at each antenna are combined so that neighboring cell interference is suppressed in base station radio signal processing. More specifically, an uplink reference signal (DM-RS) is used to estimate not only the channel matrices of the desired signal but also statistical characteristics of neighboring cell interference. Both these pieces of information are used to adjust the phase of received signals at each antenna and combine it to generate a null*31 point (where antenna gain drops) in the direction of the incoming neighboring cell interference (**Figure 8**). Refer to [6] for more details about the MMSE-IRC receiver reception algorithm. Orienting a null toward main interference signals, in other words interference signals that particularly degrade throughput, improves the Signal to Interference plus Noise power Ratio (SINR)*32 in receivers and thus improves throughput. This receiver also offers another advantage of being relatively easy to deploy in base stations already in service, because it uses technology that only improves radio signal processing.

4.2 Uplink Throughput Improvement Effects

Figure 9 shows the uplink throughput improvement effects of the MMSE-IRC receiver. This is a simulation of a macro base station environment in which two reception antennas are deployed, and in which two high-power interference waves arrive from two interfering mobile terminals in neighboring cells. The simulation also assumes that each mobile terminal is fitted with one transmission antenna, and that the optimal MCS (Modulation and Coding Scheme) of the desired signal is adaptively selected to suit the reception environment.

From this simulation, we found that the MMSE-IRC receiver promises a 1.5

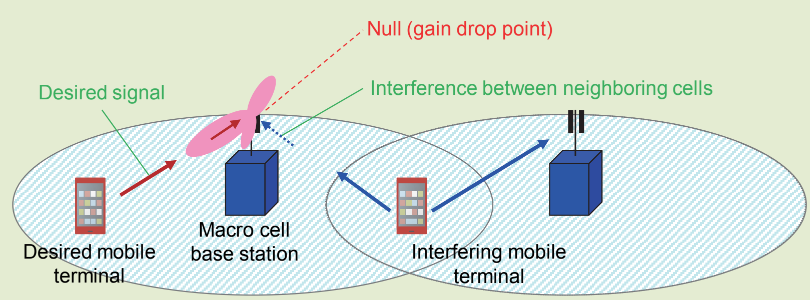

Figure 8 MMSE-IRC receiver operations

*30 **White noise:** A noise component in the receiver. White noise is characterized by constant power spectral density across the entire frequency spectrum.

*31 **Null:** A direction in the beam pattern in which the antenna gain is at a local minimum.

*32 **SINR:** The ratio of desired-signal reception power to the sum of power of all other interference-signals and noise. However, in this article, the power of minor interference signals arriving from afar is regarded as a noise.

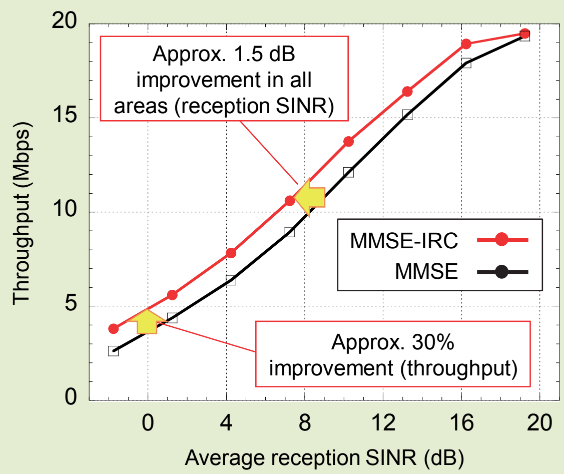

Figure 9 Throughput improvements with the MMSE-IRC receiver

dB (SINR conversion) improvement in all SINR areas compared to existing MMSE receivers, and particularly, with an average reception SINR of 0 dB, it also promises a 30% throughput improvement.

4.3 Future Outlook

Aiming for further performance improvements from Release 14 onward, it was proposed that receivers equivalent to Release 12 NAICS be deployed in base stations. While further performance improvements can be expected with these receivers, continued discussions are required as base station reception loads and installation costs could increase.

5. Conclusion

This article has described the advances in base station equipment technologies introduced with LTE-Advanced Release 13 specifications. Aiming to provide high-quality service areas into the future, we will continue to drive standardization of technologies to further improve base station equipment.

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Improving IP-based OSS Reliability During Large-scale Disasters

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The IP-based Operation Support System (OSS)*1 monitors the large-scale routers and switches that form the backbone IP network and also monitors pieces of peripheral IP network equipment that carry communications via these routers and switches. This is a large-scale monitoring system that covers approximately 30,000 units. As shown in **Figure 1**, the old IP-based OSS was a dual-system redundant

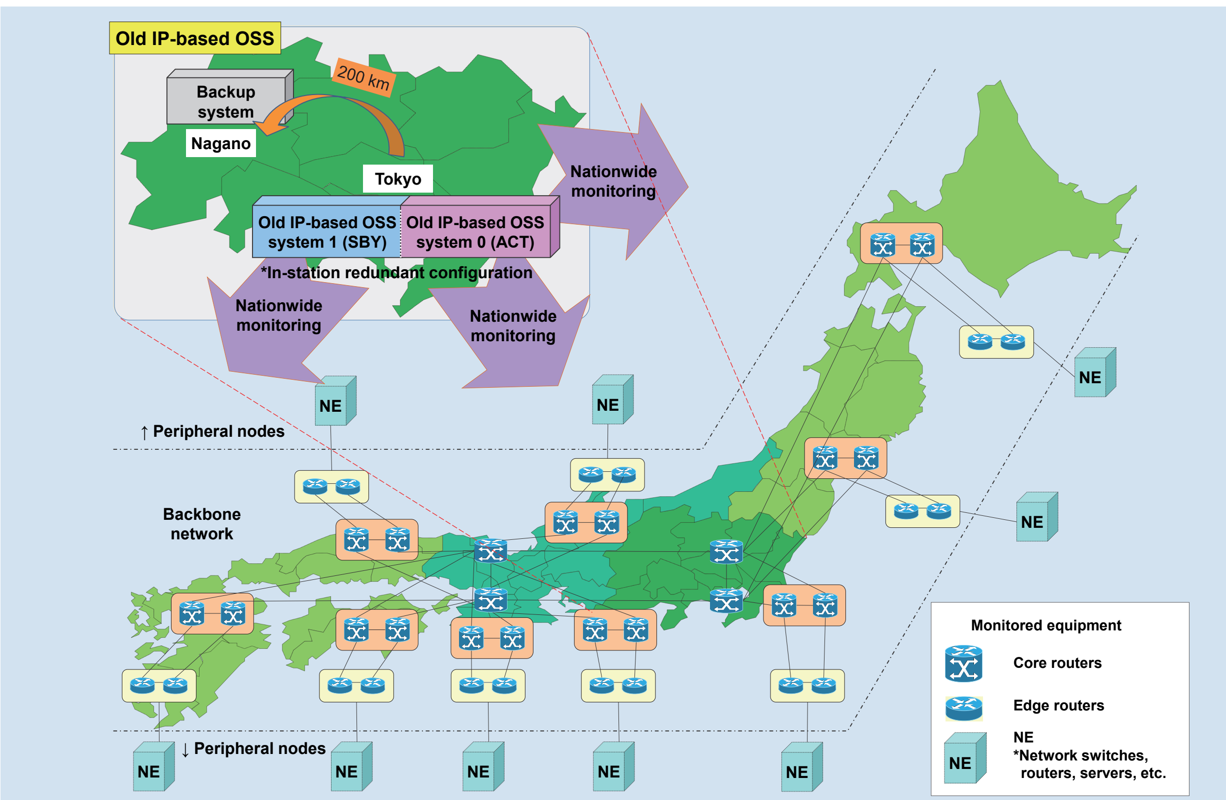

Figure 1　Old IP-based OSS monitoring system configuration

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*1 **OSS:** A system for discovering failures and congestion in the mobile communications network and performing appropriate control functions or measures in response to such problems.

configuration located in a building in Tokyo for monitoring nationwide Network Elements (NE)*2 with Simple Network Management Protocol (SNMP)*3/Syslog*4. In addition, a third backup system was set up in Nagano that could be manually switched on if the two Tokyo systems simultaneously failed.

The OSS had continued stable operation without major malfunctions that disabled monitoring since its introduction in 2002. Therefore, it was considered that the OSS had thorough disaster countermeasures. However, due to the Great East Japan Earthquake of 2011, it became necessary to assume two new potential scenarios, since the impacts of that disaster were more far-reaching than anyone had expected.

(1) In the first scenario, since Tokyo and Nagano are only 200 km apart, in the worst case both bases could be destroyed. Also, even if the Nagano backup system survived the direct impacts of a disaster, ensuring availability of maintenance personnel would be difficult due to lifeline and transport paralysis, meaning systems launch would be greatly delayed (**Figure 2** (a)).

*2 **NE:** A functional block that achieves a necessary function in the provision of telecommunication services. Specifically, a unit of telecommunication equipment such as a switch, transmitter or radio station.

*3 **SNMP:** Protocol for communicating information for monitoring and controlling network equipment on IP networks. Can receive TRAP and acquire MIB information.

*4 **Syslog:** A protocol for recording system operation conditions and error messages and exchanging the data with other computers via a network.

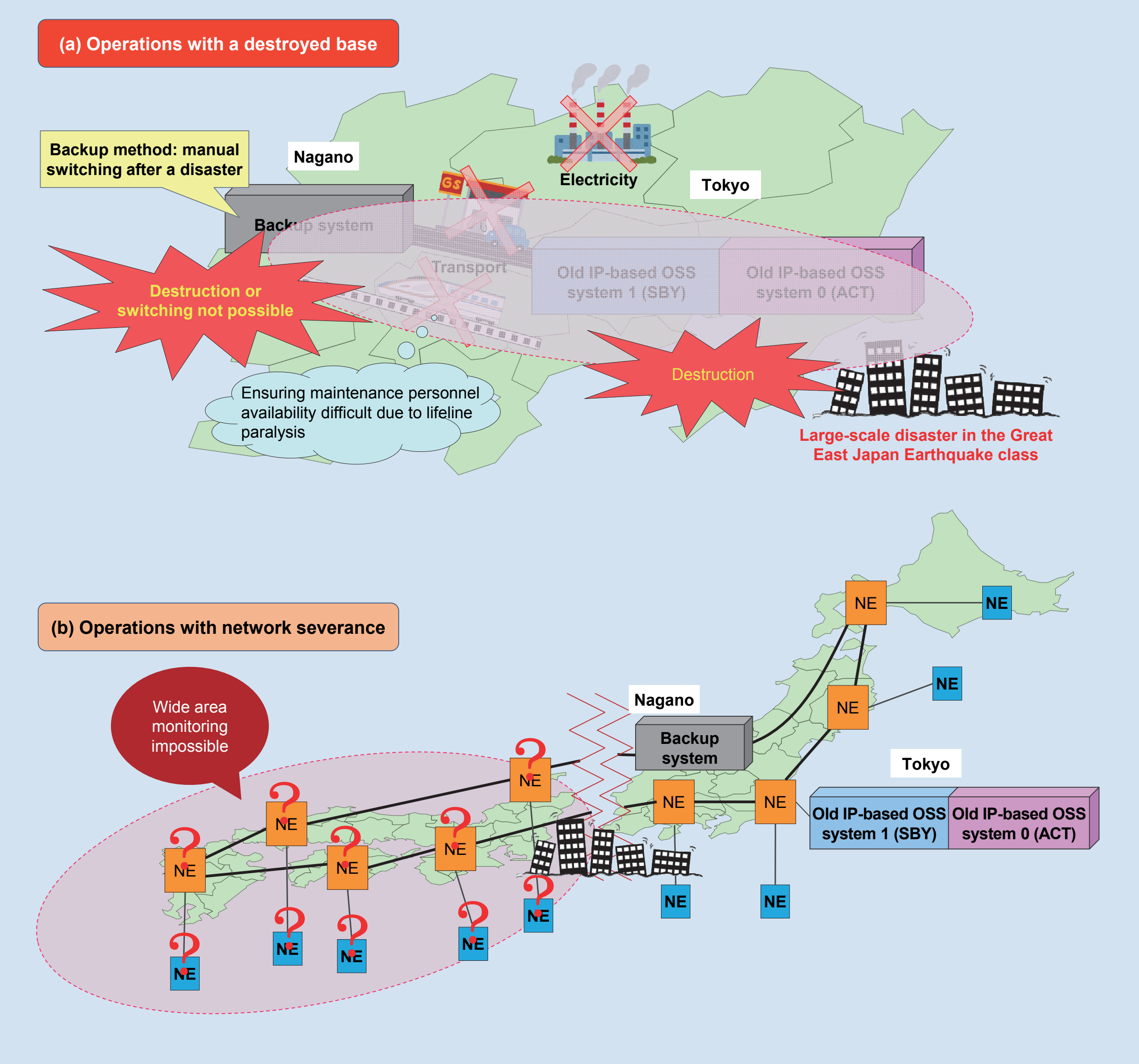

Figure 2　Overview of old IP-based OSS, and large-scale disaster issues

(2) In the second scenario, network transmission paths on networks accommodating NE nationwide could be severed. In this case, it would be impossible to monitor NE beyond the point of severance, and hence the affected areas would be extremely large (Fig. 2(b)).

Since these conventional backup systems are costly because they require the hardware resources of a whole extra system even though they are not operational during normal times, and since their operation cannot be satisfactorily guaranteed in times of large-scale disasters, NTT DOCOMO decided to shift to new IP-based OSS with advanced disaster resilience. The new IP-based OSS are designed to enable discontinuance of high-cost backup systems while enabling building of low-cost redundant systems in locations that are far apart so that they are not affected by the same disaster, without increasing the number systems. As shown in **Figure 3**, the StandBY (SBY) system has been moved to Osaka, where a 24-hour maintenance system can be established to enable remote redundancy between Tokyo and Osaka by adopting a 2-base, 1-system configuration where two systems can be operated simultaneously [1].

Figure 4 shows the structure and operation of the new IP-based OSS compared to the old system. With the new IP-based OSS, a remote cluster is formed from the two systems with a dedicated broadband network (several tens of Gbps) between the bases in Eastern and Western Japan. This enables messaging between the two systems including keep-alive*5, and database synchronization to achieve redundancy of the two systems (Fig. 4, top).

In normal times, the bases in Eastern and Western Japan operate as ACTive (ACT)/SBY*6 (strictly speaking, ACT/SBY is switched for individual functional servers, however, for brevity, this description assumes that all functional servers are switched over to one base). NE are set to always send monitoring messages to the systems in both bases, and consideration has been given so that in any condition, no monitoring messages are lost, even in the routing chaos right after damage has been caused by a disaster (**Figure 5**). These monitoring messages from NE are processed at the ACT side, and the results of processing are synchronized with the

*5 **Keep-alive:** Communications performed periodically to confirm the validity of connections between devices on a network.

*6 **ACT/SBY:** A system configuration in which two servers perform the same function with one server in active mode (ACT) and the other in standby mode (SBY). Service interruptions are prevented by immediately continuing operations on the SBY server whenever a fault occurs on the ACT server. The SBY server is always kept in the same state as the ACT server during normal operations in preparation for switching.

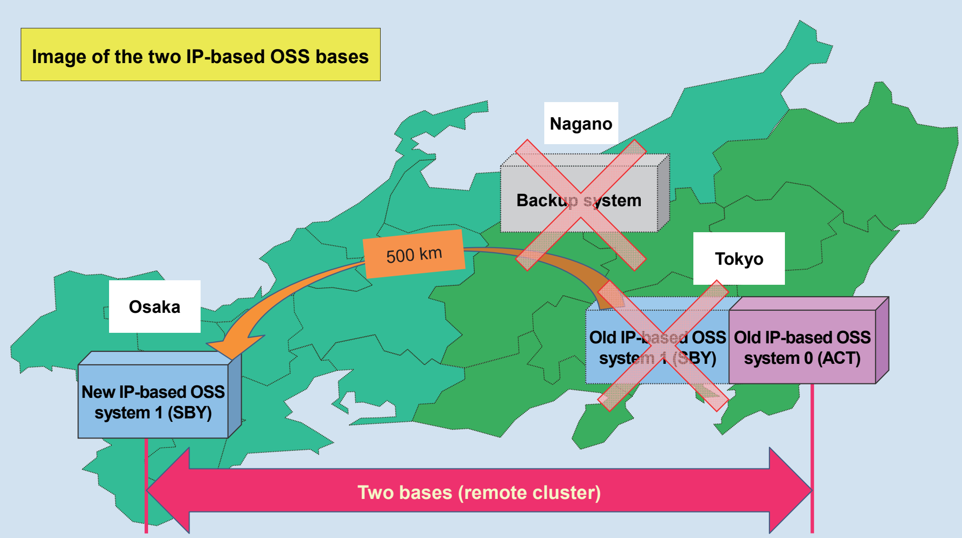

Figure 3 Image of the two IP-based OSS bases

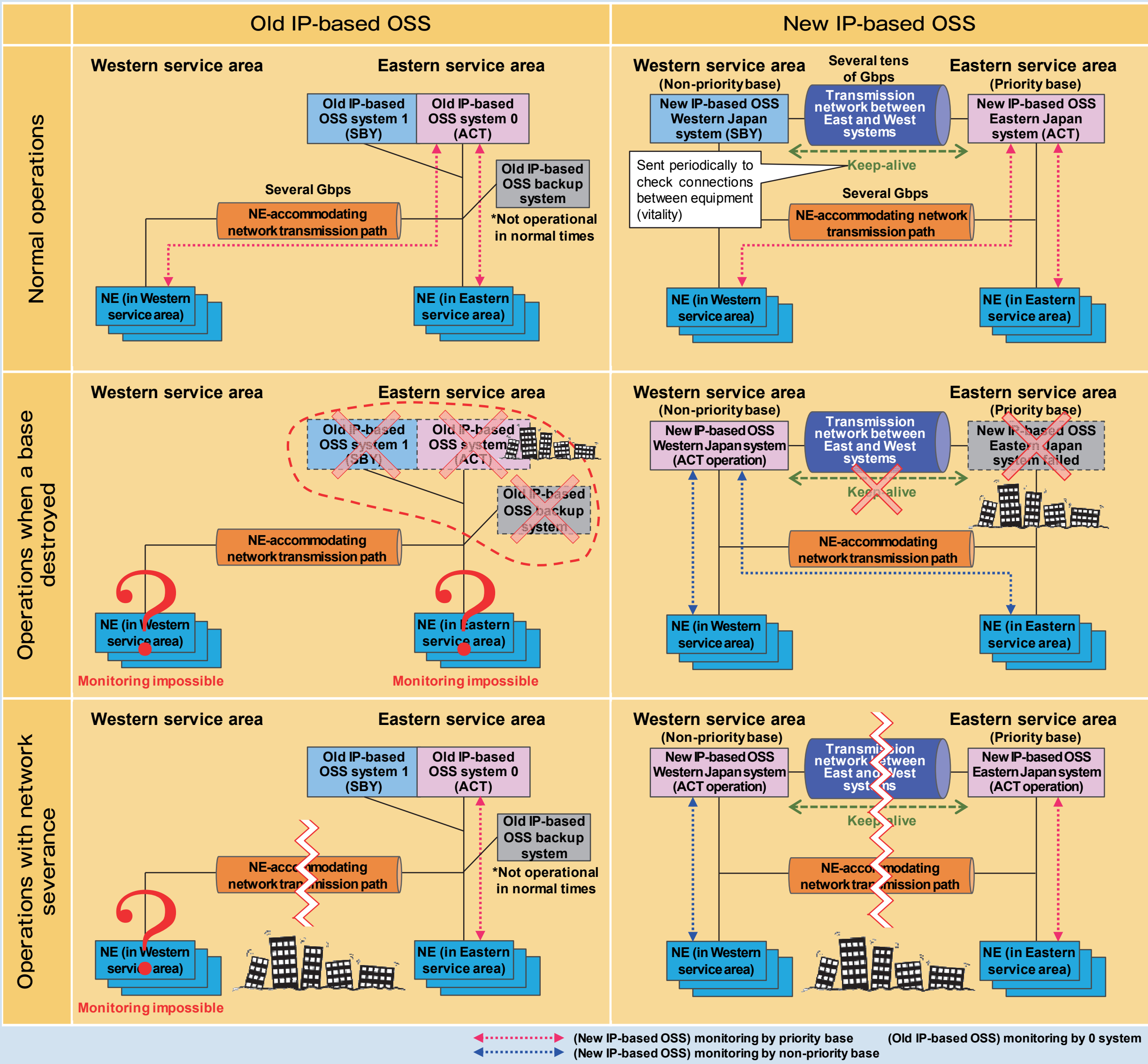

Figure 4　Configuration of old and new IP-based OSS systems and operations with disasters

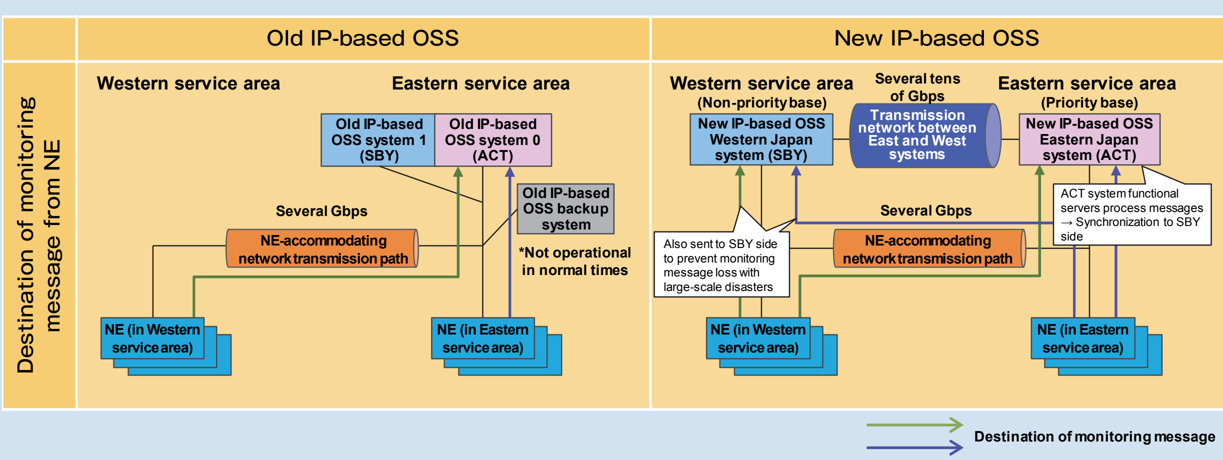

Figure 5　Sending monitoring messages from NE to the old and new IP-based OSS

SBY side.

(1) In the first scenario, if a base is destroyed due to a large-scale disaster, the old IP-based OSS is no longer able to monitor. However, with the new IP-based OSS, if keep-alive between ACT and SBY cannot be received, the SBY side immediately switches to ACT and continues monitoring (Fig. 4 center).

(2) In the second scenario, if the communications network between the bases in Eastern and Western Japan is severed, the old IP-based OSS will no longer be able to monitor NEs beyond the severance point. However, if the new IP-based OSS fails to confirm the vitality through keep-alive, the SBY system in Western Japan commences ACT operations, and since both systems are now operating in ACT, monitoring of nationwide NE can continue. Since the network between Eastern and Western Japan is completely severed, the systems in Eastern and Western Japan can only monitor NE under their respective service areas (Fig. 4, bottom).

Introducing simultaneous ACT operations in both bases has also brought about new issues. With operations in a network severance scenario with the new IP-based OSS, if some networks accommodating NE are lucky enough to survive the severance, that NE will be double monitored via both systems, which will increase monitoring processing load (**Figure 6** (a)). Here, although there were no significant impacts on most of the equipment, serious impacts were seen in ultra-large-scale routers with their vast number of monitoring points, preventing normal operations. Hence, attention is required as there is a tendency to think that ultra-large routers have spare processing capacity. In response to this issue, functions were added to the new IP-based OSS, so that when the system switches from SBY to ACT, vitality confirmation is performed via NE-accommodating networks just in case, and if ACT is detected at both bases simultaneously, then monitoring of double monitoring non-permissible NE is stopped at the non-priority base side (Fig. 6 (b)).

This article has described new IP-based OSS configuration and operations. The system was implemented and started commercial operations in

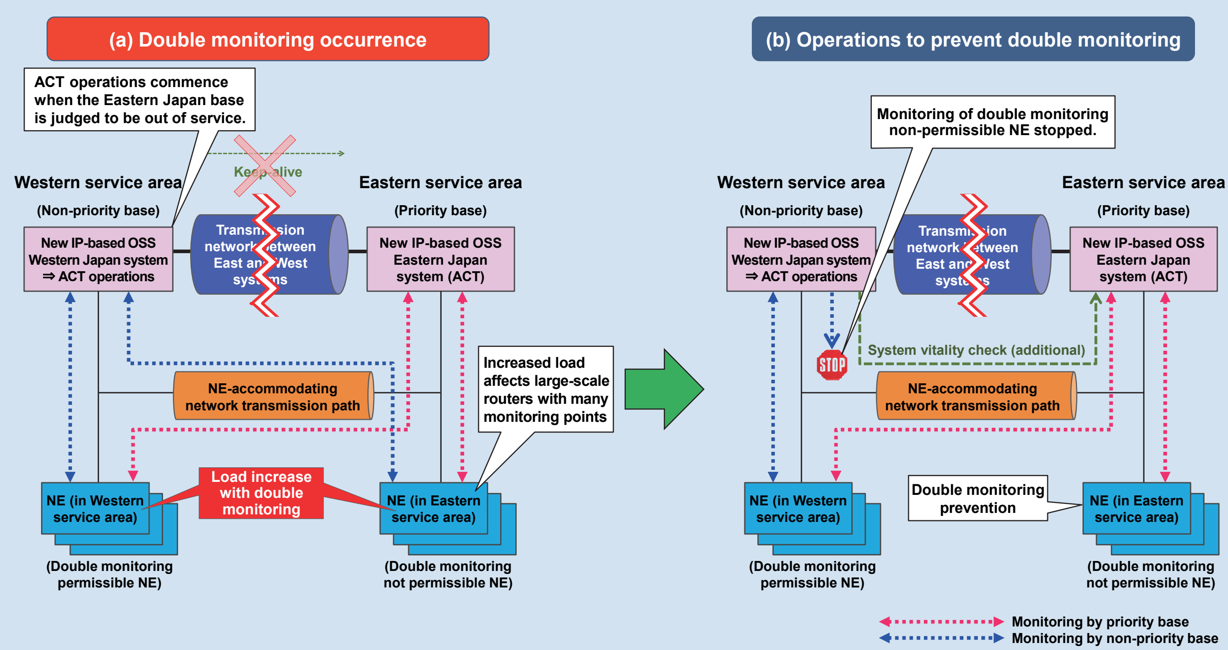

Figure 6 Operations to prevent double monitoring with new IP-based OSS

February 2016, and promises stable monitoring even at the time of large-scale disasters. As a future issue, we would like to automate some aspects of the database merge processing following elimination of simultaneous ACT operations in the two bases, which currently have to be done manually.

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2015 Wireless Innovation Forum Technology of the Year Award

NTT DOCOMO Research Laboratories and DOCOMO Communications Laboratories Europe GmbH received the Wireless Innovation Forum's "2015 Wireless Innovation Forum Technology of the Year Award" for two-year long endeavor beginning in 2013 to develop "METIS channel models" for the Mobile and wireless communications Enablers Twenty-twenty Information Society (METIS), an European research project on 5th generation mobile communications (5G) systems. Selected by members, this award is given to individuals or organizations for innovative products and technologies in the software radio and cognitive radio fields, and in this case, was awarded for contribution made to the development of the next-generation mobile communications (5G) by developing a new channel model to suit realistic scenarios and requirements. This model earned this award for its usefulness in promoting the development of next-generation radio technologies, as it enables next-generation radio device testing and optimization by targeting a wide range of frequency bands from those currently used for mobile communications through to those in the millimeter wavelengths. Development members other than the award winning channel model include Anite, Ericsson, Fraunhofer HHI, Nokia, Aalto University, University of Oulu and Elektrobit.

Channel model is made by modeling radio wave propagation characteristics required for designing mobile communications systems. In recent years, characteristics such as propagation delay, arrival direction and polarization in addition to propagation loss are modeled. Fourth generation (4G) models include the IMT Advanced Model standardized by the International Telecommunication Union-Radiocommunication Sector (ITU-R) and the 3D Channel Model standardized by the 3rd Generation Partnership Project (3GPP), while new considerations for 5G include:

- Application of higher frequencies: Targeting frequencies from 6 GHz to 100 GHz in addition to existing frequencies
- Array antenna technology advancements: Support for Massive MIMO technologies etc.
- Diversification of system construction scenarios: Scenarios in which large numbers of people gather in one place such as open-air festivals or stadiums are added to existing scenarios.

These are also new requirements added in channel model. METIS channel models is developed in consideration of these aspects.

In METIS, two models with different approaches have been proposed. One is a "stochastic model" similar to the conventional statistical analysis of measurement data, while the other is a "map-based model" made by analyzing propagation characteristics by using structure data like ray tracing.

The stochastic model is constructed by newly making measurement and analyzing data to suit 5G requirements. Since the basic approach to modeling is the same, this model is characterized by its high affinity with 4G channel modeling. However, because this model uses statistical analysis of measurement data, it can only model the average characteristics of various scenarios. For example, it does not reflect spacial and temporal distributions of flows of people.

For this reason, the map-based model was developed. This model analyzes propagation characteristics by seeking paths between the transmitting and receiving stations using structure data. Although the use of structure data make this model more difficult to use than the stochastic model, by further defining obstacles such as people and vehicles in addition to structures such as buildings, this model has the advantage of enabling analysis of propagation characteristics that reflect spacial and temporal distribution of these obstacles. In addition, the map-based model offers a way to keep the amount of computation as small as possible despite the fact that seeking paths between transmitting and receiving stations by using ray tracing generally involves a lot of computation.

As discussed above, this channel model was developed in METIS and meets the requirements assumed for 5G, and its achievements have been evaluated and awarded by the Wireless Innovation Forum. Please refer to the METIS home page for more details about this channel model [1].

Reference

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