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NTT docomo

Toward the Core Network in the 5G Era

The core network, while not as conspicuous as smartphones or base-station antennas in daily life, plays an extremely important role in ensuring communications for customers using mobile phones and providing added value to voice and data communications. I personally have been involved in the development of the core network since entering NTT and have witnessed the change in communications protocol and equipment architecture from generation to generation. In particular, I feel that the conversion to Internet Protocol (IP) and adoption of virtualization were major turning points in the evolution of the core network, so I will focus on these two developments here.

Let me begin with the conversion of communications protocol to IP. In the past, communications control within the core network was performed by the No. 7 Common Channel Signaling System (No. 7 CCS) making it necessary to use No. 7 CCS dedicated network equipment. Today, however, GPRS Tunneling Protocol (GTP) and Diameter are used as LTE IP-based protocols, and in the Voice over LTE (VoLTE) system, encoded voice data are controlled by IP-network communications control protocols, namely, Session Initiation Protocol (SIP). In addition, No. 7 CCS functions can now be used on an IP network in the form of SIGnaling TRANsport (SIGTRAN). As a result, a network that exchanges voice, data, and communications control signals can today be configured with general-purpose equipment such as routers and switches that are widely used in the IT world. The use of IP technology, meanwhile, enables the construction of highly flexible and reliable networks.

Turning now to virtualization, the equipment making up the core network prior to the adoption of virtualization ran dedicated software on high-performance, high-reliability dedicated hardware. This made it difficult to select hardware as freely as one might desire. In the IT world, however, the operation of applications on the cloud has become common practice and the prompt and efficient provision of services in a form blind to hardware has become possible. Against this background, international discussions on enabling communication systems too to enjoy the advantages of IT technology got under way at European Telecommunications Standards Institute Industry Specification Group Network Functions Virtualisation (ETSI ISG NFV), and in March 2016, NTT DOCOMO began operation of a network virtualization platform conforming to ETSI ISG NFV architecture. This approach is enabling the use of low-cost, general-purpose hardware while speeding up the provision of services and improving network reliability at the time of a natural disaster or system fault. At present, we are moving forward on virtualizing various types of existing equipment consisting of dedicated hardware.

General Manager of Core Network Development Department
Hiroyuki Oto

Finally, I would like to touch upon future directions. NTT DOCOMO plans to launch 5G pre-services in September 2019 and 5G full-scale commercial services in spring 2020. The initial configuration of the network will be of a form that extends existing Evolved Packet Core (EPC) LTE switches, but to promote new business creation, which is a key objective of 5G, we have undertaken the research and development of new technologies for the core network. One of these is “slicing technology” that aims to provide optimal communications tailored to the increasingly diversified needs of industry by dividing up the network in a virtual manner. Another is Multi-access Edge Computing (MEC), which attempts to shorten the delay in the wired interval by exploiting the low-delay characteristics of the 5G wireless interval. The idea here is to locate servers and switches that perform processing closer to customer devices. Using these technologies in even more advanced ways requires that the core network be virtualized and flexible, and to this end, discussions on 5G Core (5GC) next-generation packet switches based on the “cloud-native” concept are taking place within the 3rd Generation Partnership Project (3GPP), a 5G international standards organization. At NTT DOCOMO, we are committed to becoming a world leader in the development of a core network for the 5G era by engaging in international collaborative activities and taking the lead in solving issues that arise when applying IT to the world of communications.

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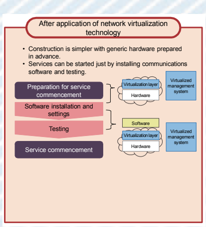

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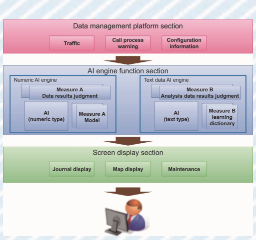

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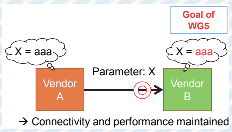

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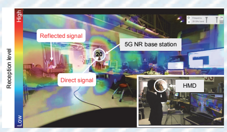

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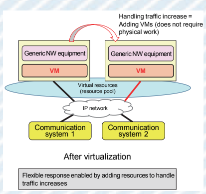

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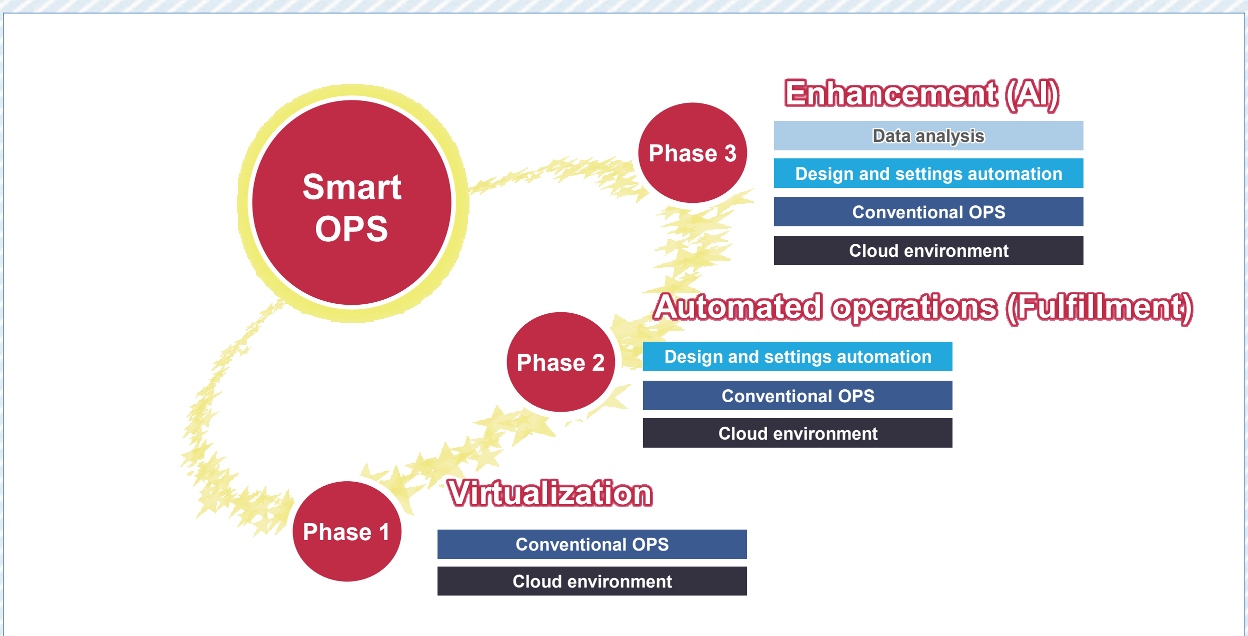

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5G AI IoT

DOCOMO Open House 2018 —5G Innovation and Collaboration—

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5G Laboratories Service Innovation Department Research Laboratories Innovation Management Department
Communication Device Development Department Corporate Marketing Strategy Department

NTT DOCOMO held "DOCOMO Open House 2018—5G Innovation and Collaboration—" at Tokyo Big Sight®*1 over two days on December 6 and 7, 2018. This article presents an overview of this event and provides a detailed look at major exhibits.

1. Introduction

"DOCOMO Open House 2018—5G Innovation and Collaboration—" (hereinafter referred to as "this event") was held at Tokyo Big Sight (Tokyo's premier convention and exhibition center) over two days on December 6 and 7, 2018.

Looking to 2020 and beyond, NTT DOCOMO seeks to "amaze" and "inspire" our customers with services exceeding their expectations through co-creation with our business partners of "new value" in many areas. With this in mind, and building upon the past role of "DOCOMO R&D Open House" of conveying to the world the progressiveness and technical power of NTT DOCOMO, this DOCOMO Open House was held as a unified effort by the entire company introducing not only R&D technical achievements but business solutions from its corporate departments and initiatives from its network departments as well. Together with NTT DOCOMO's co-creation business partners, this event introduced new technologies in 5G, AI, and IoT and business solutions applying those technologies while holding a variety of presentations and programs. With about 14,000 visitors in total, DOCOMO Open House 2018 was deemed a great success (**Photo 1**).

This article describes major exhibits and presentations at this event.

† Currently Human Resources Management Department

*1 Tokyo Big Sight®: A registered trademark of the Tokyo Metropolitan Government.

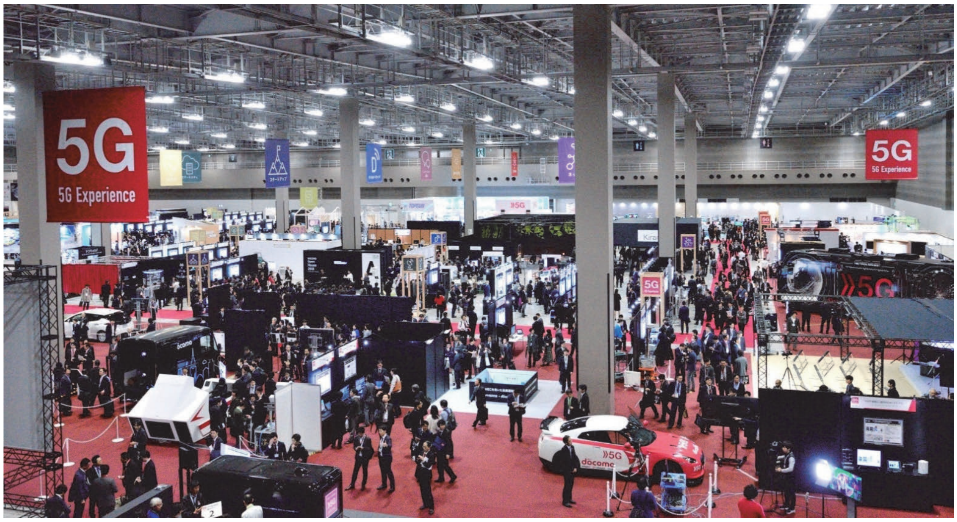

Photo 1 View of DOCOMO Open House 2018

2. Event Overview

This event included 239 exhibits including 9 from NTT divided into the 15 categories of Device-UI/UX, AI, IoT, Smart City, Creation of Innovation, New Exciting, Healthcare, Startup, Digital Marketing, Disaster Preparedness, Network, 5G Solution, 5G Experience, CSR, and 2020. Each exhibit conveyed NTT DOCOMO's worldview to visitors through hands-on experiences and demonstrations using actual equipment.

Kazuhiro Yoshizawa, NTT DOCOMO President and CEO, delivered the keynote presentation on the first day (**Photo 2**). Titled "For a Richer Future with 5G," this presentation introduced NTT DOCOMO's vision of the future in the 5G era and its medium-term strategy. Then, on the second day, Hiroyasu Asami, NTT DOCOMO Senior Executive Vice President, delivered a keynote presentation titled "DOCOMO's Vision for Digital Transformation" (**Photo 3**). This presentation described changes in NTT DOCOMO's marketing environment and associated reforms.

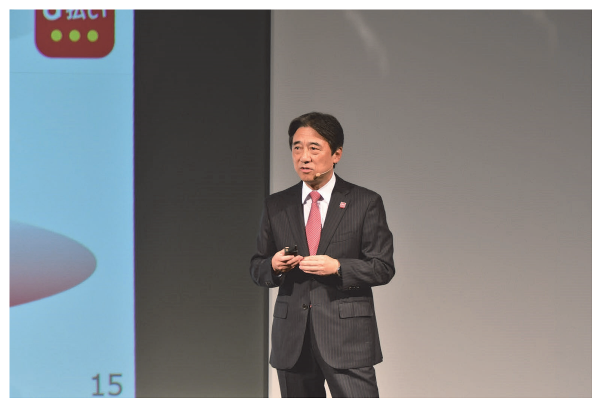

Photo 2 Keynote presentation by Kazuhiro Yoshizawa

Photo 3 Keynote presentation by Hiroyasu Asami

Furthermore, in addition to other presentations delivered by NTT DOCOMO executives, a variety of presentations on diverse themes were made by a number of NTT DOCOMO business partners. These included presentations delivered by Sunwoo Lee (Korean Telecom), Philippe Lucas (Orange), Masanobu Fujioka (Ericsson Japan), Akira Fukabori (ANA), Kevin Kajitani (ANA), Jungo Kanayama (Shibuya City Tourism Association), and Kenro Suto (Future Design Shibuya).

3. 5G Experience

Exhibits in the 5G Experience area featured trials and demonstrations based on co-creation with partners in a wide range of industries toward the development of new 5G services with a view to commercialization in 2020 (**Photo 4**). They introduced, in particular, near-future services making maximum use of 5G features through hands-on demonstrations via actual 5G communications. These services ranged from remote operation of industrial robots and construction equipment, remote medical care, and a high-presence musical session by remotely located musicians to next-generation mobility initiatives such as connected cars. Also presented were the status and results of research and development toward 5G evolution and 6G.

3.1 Remote Control of Humanoid Robot

This exhibit demonstrated remote control of a humanoid robot (T-HR3®*2) over 5G in collaboration with Toyota Motor Corporation. It connected an operator at a remote location (TOKYO Solamachi®*3) and T-HR3 at Tokyo Big Sight using 5G over a portion of the link. The demonstration showed how 5G could be used to send remote operation and control signals to T-HR3 from the operator and receive feedback from T-HR3 in the form of power (torque) with low latency. In this way, the operator

Photo 4 5G Experience booths

*2 T-HR3®: A registered trademark of Toyota Motor Corporation.
*3 TOKYO Solamachi: A trademark or registered trademark of the Tobu Railway Co., Ltd.

is made to feel at one with T-HR3 enabling free and safe control of the robot by a human. The T-HR3 robot performed a variety of complicated tasks for visitors such as stacking and arranging blocks, guiding a chess piece through a maze while blindfolded using only the sense of touch, and shaking hands with someone, all at a level of control comparable to that of a wired connection. Visitors were quite impressed and offered many comments. Remote control of a humanoid robot in this way is expected to have use in a wide variety of fields, from everyday activities such as housework and caregiving to on-site construction work and medical care.

3.2 "Mobile SCOT" Remote Smart Medical Care

This exhibit demonstrated "Mobile SCOT (Smart Cyber Operating Theater)[*4]" using 5G in collaboration with Tokyo Women's Medical University. It showed visitors how advanced surgery could be performed by enabling surgeons to share surgery-related video and information with a doctor at a remote "mobile strategy desk" over a 5G connection so that a consensus on how to proceed can be reached. It demonstrated, in particular, that the status of a surgical procedure could be understood in real time by high-quality video even from a remote location through a high-speed/low-latency 5G connection and that a high standard of medical care could be received "at anytime from anywhere." For example, Mobile SCOT could provide surgical support regardless of where a specialist with extensive experience may currently be located, or it could enable the best diagnosis to be given and advanced treatment to be performed at the time of an emergency when transport to a hospital is difficult. In short, it can provide a high-standard medical care environment even in sparsely populated areas where doctors are scarce or at the scene of a disaster.

3.3 Reflector Applying Metamaterial Technology

With a view to setting up 5G areas using radio waves in high-frequency bands, this exhibit conducted a 5G demonstration in which a reflector applying metamaterial[*5] technology developed by Metawave Corporation was actually installed at this event's venue. The exhibit also introduced the circumstances behind the world's first successful field trial of a 5G transmission incorporating the metamaterial reflector. This reflector, whose design depends on its installation location, can guide reflected waves in a specific direction so that a high-quality 5G coverage can be expanded to even locations in the shadow of buildings or outside the line-of-sight of the base station. In more detail, this exhibit introduced the results of a 5G field trial using this reflector conducted in November 2018 at this venue. It also held a demonstration of forming a 5G area within the venue by actually installing a metamaterial reflector so that visitors could see with their own eyes the arrival of 5G radio waves in the 28 GHz band with a real-time radio wave visualizer. In this way, it was shown that a 5G area could be efficiently and flexibly set up and expanded even for radio waves in high-frequency bands having highly directional propagation.

Together with progress in the development of a 5G system toward the launch of commercial services in 2020, the design and commercialization of new services that can be achieved through 5G is accelerating reflecting a shift toward the next stage

*4 SCOT®: A remote smart healthcare support system and a registered trademark of Tokyo Women's Medical University.

*5 Metamaterial: An artificial material that behaves with respect to electromagnetic waves in ways not found in natural materials.

of development. Through hands-on demonstrations using 5G communications co-created with partners in diverse industries, the 5G Experience area enabled visitors to experience for themselves the benefits of 5G in a variety of industries and to be surprised and inspired many times over. In addition, this exhibit showed how NTT DOCOMO R&D is progressing rapidly toward NTT DOCOMO's vision of 5G and beyond while fostering innovation in the creation of new value.

4. AI

NTT DOCOMO is moving forward on the development of AI technology and AI solutions with the aim of "achieving the ultimate personal agent" and "solving social issues and enhancing industrial efficiency."

In the AI area of this event, the latest AI technologies and actual applications were put on display such as technology supporting the NTT DOCOMO "my daiz" AI agent, NTT DOCOMO's Natural-language Dialogue Platform, and image recognition. Visitors were encouraged to experience these exhibits for themselves.

4.1 AI Agent × AI Geeks

The AI Agent × AI Geeks booths introduced 27 solutions using AI agents all within a single area in the form of a shopping mall **(Photo 5)**. These were presented in collaboration with 21 partner companies that had taken the lead in using NTT DOCOMO's AI Agent Application Program Interface (API)[*6]. On viewing many solutions and application examples, visitors commented that they could imagine using them in all sorts of ways in their companies. They also asked the partner companies that had collaborated with NTT DOCOMO many questions, which showed how this exhibit had become a good opportunity for visitors and partners to connect.

4.2 Natural-language Dialogue Platform

The AI area presented many dialogue systems using NTT DOCOMO's Natural-language Dialogue Platform. For example, the "Chatbot[*7] for Sport Spectators" can engage in conversation reflecting

Photo 5 AI Agent × AI Geeks

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*6 API: General-purpose interfaces for using functions and data.

*7 Chatbot: A program that automatically conducts dialog with people with speech or text chat.

real-time changes in the state of a match and provide in-depth information on teams and athletes using a knowledge database. The "chat-oriented dialogue service katarai™*8," meanwhile, enables the provision of a dialogue service in a short period of time without the need for creating scenarios thanks to its scenario database on a scale of 40-million utterances. The "xAIML SUNABA™" development environment that simplifies the task of developing a natural-language platform for developers was also introduced and the development of multi-language capabilities to support dialogue services in languages other than Japanese was also described. Also on display were services that had already been commercialized such as "Natural Dialog Engine FAQ Chatbot" and "my daiz" as examples of NTT DOCOMO's efforts in introducing voice-interactive technologies for a wide variety of usage scenarios.

4.3 Image Recognition

The "Image Recognition for 5G Security Camera" exhibit showed how image recognition technologies such as individual detection, tracking, and attribute estimation on a cloud platform connected directly to NTT DOCOMO's 5G network could be applied to security cameras. This scheme enables advanced image recognition technology to be applied without transmitting security camera video over the Internet, which should enable the provision of security camera solutions that take into account security and privacy. In addition, the "Field Weeding Robot using AI" exhibit introduced a robot that can distinguish crops from weeds in a field and remove those weeds while moving about autonomously using onboard image recognition technology.

In this way, visitors to this event were able to understand how NTT DOCOMO is striving to enhance added value through total solutions that include the 5G network and edge devices in addition to image recognition technologies.

NTT DOCOMO seeks to develop services and solutions using AI and big data with the aim of expanding the user experience and opening up new markets through co-creation with partners in diverse industries.

5. IoT

The IoT area introduced NTT DOCOMO IoT technologies for solving a wide range of problems that currently affect modern society under the theme of "changing the way people live and work through new value" (**Photo 6**). Visitors expressed much interest in these technologies and asked many interesting questions revealing deep expectations of NTT DOCOMO IoT.

5.1 docomo IoT Smart Maintenance Package

The "docomo IoT Smart Maintenance Package™*9" is a package service that uses vibration data collected from sensors that can be retroactively fitted in industrial facilities to (1) monitor the operation of facilities, (2) detect abnormal vibrations, and (3) detect signs of failures in vibrations.

Launched in December 2018, this service features a variety of key technologies. In addition to storing vibration data on the cloud and enabling its visualization, it can perform quantitative diagnosis conforming to diagnostic criteria of rotating facilities*10 stipulated by ISO 10816*11 and predict the

*8 katarai™: "katarai" and "SUNABA" are trademarks of NTT DOCOMO.

*9 docomo IoT Smart Maintenance Package™: "docomo IoT Smart Maintenance Package" and "AI Infotainment Service" are trademarks of registered trademarks of NTT DOCOMO.

*10 Rotating facilities: Facilities having a mechanism that rotates about an axis such as a motor, pump, or compressor.

*11 ISO10816: A widely used standard for comprehensively judging the condition of rotating machinery.

Photo 6 IoT area

transition of vibration features using machine learning.

With this service, customers can monitor their facilities, detect abnormalities, predict failures, and perform appropriate maintenance. It supports the operation of a manufacturing line without facility breakdowns and stoppages.

5.2 AI Infotainment Service

The "AI Infotainment Service®" is a cloud-based service that changes the automobile from simply a means of mobility to a convenient and enjoyable "mobility space." It features the following technologies.

- "Natural-language dialogue technology" featuring noisy speech recognition with world-class accuracy that enables necessary car-related tasks such as destination searching to be performed through natural dialogue.
- "Behavior anticipation technology" that learns the daily behavior of a person and recommends optimal behavior that reflects an understanding of that person's interests and preferences.
- "Advanced information searching and delivery technology" that can perform a variety of tasks such as searching for popular facilities, delivering information at just the right time such as on much-talked-about events, and predicting traffic jams.
- "Emotion recognition technology" for analyzing user sentiment from the user's voice pitch, tone, intonation, etc.

NTT DOCOMO uses these AI technologies to understand the user and provide him or her with a safe, convenient, and enjoyable infotainment service.

5.3 Remote Monitoring Service

The "Remote Monitoring Service" provides a privacy-oriented means of monitoring people who are living alone but need support by analyzing ambient sounds such as coughing, snoring, and television noise with Fujitsu's original algorithm making use of sound analysis technology cultivated by Fujitsu

Limited in mobile phone development (**Photo 7**). Its main features are twofold. First, it can sense sounds or human movement through IoT devices installed in rooms and can determine an abnormal situation by detecting noise above a previously established threshold or no human movement for longer that a certain period of time. At that time, the service notifies a call center that dispatches an on-call nurse to check on that person's state of health. Second, the sensing data collected by the service can be used to support health consultations or health-related advice offered during periodic contact.

6. Device-UI/UX

The Device-UI/UX area presented 23 exhibits surveying device technologies for driving the evolution of mobile services and technologies for achieving new UI/UX (**Photo 8**). For example, visitors were asked to experience for themselves a "device cluster" service that enables new ways of using devices, an AR/MR platform that provides a consistent Augmented Reality (AR)*12/Mixed Reality (MR)*13 experience regardless of device or OS, and applications that use an avatar communication platform enabling communication while sharing materials and video (XR telepresence meeting and "dSPS" avatar communication). Visitors offered a variety of reactions to these exhibits.

6.1 Device Cluster

This exhibit presented new formats for using devices appropriate for the 5G era such as the sharing of smartphones, tablets, and peripheral devices and information linking with public devices. This technology constitutes a platform equipped with diverse functions such as user authentication, device management and control, and billing. It would enable, for example, a user who normally uses a smartphone to rent a tablet during a trip while continuing to use one's own applications and data. Additionally, for a user wondering which way to proceed when exiting a train station gate, it would enable navigation information specifically for that user to be displayed on that gate.

Going forward, NTT DOCOMO plans to open

Photo 7 Remote Monitoring Service

*12 AR: Technology for superposing digital information on video taken of the real world and presenting the result to the user.

*13 MR: Technology for superposing digital information on video taken of the real world and presenting the result to the user. In contrast to AR, MR makes information appear as if it's actually there in the real world from any viewpoint.

Photo 8 Device-UI/UX area

up this technology and to expand tie-ups and co-creation with business partners providing supported devices and services.

6.2 AR/MR Platform

Recognizing that AR/MR is slated to become a new experiential service in the 5G era, this exhibit introduced technology for providing a uniform AR/MR experience independent of device or OS. It featured a demo experience corner where visitors could enjoy AR/MR content interactively among multiple terminals running Android™[*14], iOS[*15], and Windows®[*16]. This corner included a screen for controlling position, slant, and field of vision in real time within the AR/MR space of such multiple devices.

Visitors could sense the advanced nature of this technology through an "AR/MR experience of Christmas living" on an AR large-screen display that included decorating a Christmas tree with virtual ornaments and coloring of a 3D Santa Claus or snowman.

6.3 XR Telepresence Meeting and "dSPS" Avatar Communication

This exhibit presented an avatar communication platform as a new form of communication enabling people within a VR space to become avatars while sharing materials, video, etc. It introduced, in particular, the application of this technology platform to (1) a telepresence meeting application using a 3D full-body scanner enabling immediate avatar generation and (2) an application that enables conversation and video to be enjoyed while viewing video on a large screen.

Many visitors commented that they look forward to the commercialization of this technology as they could sense great potential in communicating and viewing video within a VR space.

NTT DOCOMO plans to continue its R&D efforts in devices and UI/UX with the aim of providing

*14 Android™: A trademark or registered trademark of Google LLC., United States.

*15 iOS: A trademark or registered trademark of Cisco in the United States and other countries and is used under license.

*16 Windows®: A trademark of Microsoft Corp. in the United States and other countries.

new value to customers and achieving compelling services through co-creation with business partners.

7. TOPGUN

The TOPGUN area introduced solution-creation activities promoted by NTT DOCOMO since October 2017 based on three-party collaboration among corporate customers, NTT DOCOMO R&D departments, and NTT DOCOMO corporate sales departments (**Photo 9**). Consisting of 13 exhibits in all, one provided an overview of these TOPGUN activities, 11 introduced 11 projects in progress, and one previewed a project scheduled for launch in the near future.

7.1 Location Net

Location Net is a solution that enables human and object positioning using Bluetooth® Low Energy (BLE)[*17] technology. To give visitors to this exhibit an idea of how this solution can be used to detect the positions of employees or perform flow management, detectors were installed at 22 locations with the event venue and a heat map of the positions of BLE tags given out to event visitors was displayed on a large liquid-crystal display in real time. This heat map is shown in **Photo 10**.

7.2 Robot for Programming Education: embot

This is a programming kit geared to elementary school students that enables a robot assembled from cardboard and a printed circuit board to be programmed and controlled on a tablet device. A giant embot was placed at the entrance to the TOPGUN area in a welcoming pose (**Photo 11**) and exhibition and sale of the kit was also conducted.

7.3 Information Board with Touch and Voice

The "Information Board with Touch and Voice" is an interactive AI-based information and reception service that responds to user touch on a screen and human voices. This board was displayed as

Photo 9 TOPGUN area

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

shown in **Photo 12** so that visitors could experience interaction with Saya*18 for themselves.

This event on the whole was enthusiastically received, and many visitors dropped by the TOPGUN area showing much interest in TOPGUN activities, that is, in the co-creation of solutions, the problems that can be solved by each project, and associated usage scenarios. This included consultations on specific customer issues that led in some cases to specific solution proposals and negotiations at a later date. TOPGUN was an extremely significant exhibit as it helped visitors understand the value that NTT DOCOMO can provide to customers while providing a forum that could lead to specific business opportunities.

8. 5G Solution

The 5G Solution area exhibited 5G solutions co-created with a variety of partners participating in the DOCOMO 5G Open Partner Program. It was also the scene of a number of programs including 5G open seminars and workshops (**Photo 13**). The number of business partners and organizations participating in the 5G Open Partner Program launched in February 2018 continues to increase having exceeded 2,000 companies and organizations as of April 2019 spanning all sorts of industries and business areas (**Photo 14**).

This area included a panel looking back at the content of workshops held three times in the past in collaboration with various regions in Japan that have been a part of this program from the start. In this way, visitors could see for themselves how NTT DOCOMO is advancing steadily toward achieving a 5G future.

Photo 10 Real-time heat map within venue by Location Net

Photo 11 Giant embot

Photo 12 Information board with touch and voice

*18 Saya: An original virtual human created by a husband and wife duo known professionally as TELYUKA. Using advanced computer graphics as an expressive medium, Saya was announced in 2015 becoming a worldwide sensation practically overnight. Born as a handmaid, Saya is an ongoing project showing evolution and growth as she searches out a new role (guide) with a unique organic existence different from humans.

Photo 13 Introduction to 5G Open Partner Program

Photo 14 Nationally expanding Open Partner Program

The exhibit area presented 31 solutions leveraging the high-speed, low-latency, and large-capacity features of 5G in the fields of AR/VR, AI, image recognition, 8K video, drones, IoT, digital signage*19, and more.

8.1 Wireless IoT Technology Demonstration Contest for Colleges of Technology

This exhibit presented two technologies adopted by the 5G division of this contest held with an eye to solving regional problems and creating new services. The first technology developed by the National Institute of Technology, Okinawa College applies "5G + AR" technology to diving goggles to provide a diver with various types of information. The second technology developed by the National Institute of Technology, Toyota College enables users to experience high sense of presence in 3D by VR in sports.

*19 Digital signage: Advertising media using digital technology. Using displays or projectors to change advertising content in response to time or location, this technology is gaining attention as an alternative to conventional advertising media such as posters etc.

8.2 AVATAR MUSEUM

As an initiative promoted by ANA Holdings Inc., Toppan Printing Co., Ltd., and Rekimoto Lab of the University of Tokyo, the "AVATAR MUSEUM" presented a solution for experiencing sightseeing from a remote location with a high sense of presence. This is accomplished by viewing real-time, omnidirectional video captured by an "avatar robot" equipped with a 4K 360-degree camera and installed at a tourist site such as an art gallery, aquarium, or museum (**Photo 15**).

Photo 15 AVATAR MUSEUM

8.3 DOCOMO 5G Open Lab

NTT DOCOMO has set up DOCOMO 5G Open Lab in Yotsuya (Tokyo), Osaka, Okinawa, and Guam as a site for experiencing 5G. It has come to be used by many business partners. This exhibit featured a reproduction of a verification experiment actually performed by a business partner at such a site (**Photo 16**).

Photo 16 Reproduction of DOCOMO 5G Open Lab verification experiment

8.4 Open Partner Events

DOCOMO Open House 2018 held many practical events such as presentations by business partners and brainstorming workshops for a relatively small number of participants (**Photo 17**).

A workshop titled "Putting Open Innovation into Practice using SDGs × 5G" was held on the morning of both the first and second day of the event. This workshop divided several dozen participants into groups of several individuals at different tables to train them on thinking about business problems and their solutions from the viewpoint of Sustainable Development Goals (SDGs)*20 using a worksheet.

In addition, a workshop titled "5G Exhibits x Workshop" was held on both days. This workshop likewise divided participants into small groups for a "5G Exhibit Tour" guided by an NTT DOCOMO employee who took them around the venue while explaining the 5G exhibits. This tour was followed by a participatory-type brainstorming workshop conducted for each group.

In terms of presentations by business partners, "IoT x 5G Special Session" was held in the afternoon of the first day. This session, presented by ELIIY Power, Fujitsu, and UNIADEX, introduced IoT solutions development activities for solving social problems from the viewpoint of SDGs.

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


Open innovation in practice using SDGs x 5G


Brainstorming workshop

IoT solution development activity

5G Co-Creation Session

Photo 17 Open Partner events

Next, partners participating in DOCOMO 5G Open Cloud™*21 held "5G Co-Creation Session" in the afternoon of the second day. In this session, Wacon, Trend Micro, RICOH, and NTT TechnoCross each ascended the stage to introduce solutions from various viewpoints such as VR, security, IoT, and AI.

9. Conclusion

This article introduced "DOCOMO Open House 2018—5G Innovation and Collaboration—" held by NTT DOCOMO on December 6 and 7, 2018 and described the exhibits presented. With the launch of 5G services scheduled for 2019, NTT DOCOMO seeks to create services that bring joy and amazement to its customers and to foster innovation in customer experience, lifestyle, and work style. NTT DOCOMO is committed to finding solutions to social problems with the aim of promoting growth in Japan and achieving a prosperous society.

*21 DOCOMO 5G Open Cloud™: A trademark of NTT DOCOMO.

Technology Reports

Network Operation Automation AI

Special Articles on Smart OPS for Further Efficiency and Advancement of Network Operations

Overview of Smart OPS

DOCOMO Technology, Inc. Solution Service Division

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Toward 5G and diverse IoT services, a revolution in high speed, high capacity and diversification of communications systems is happening on mobile networks as they become social infrastructure for everything from methods people use to communicate with each other through to wide-ranging industries and social lifestyles. Additionally, OPS, which are responsible for stable network operations, are also becoming increasingly important. Hence, NTT DOCOMO has made dramatic steps to advance the efficiency and enhancement of OPS with its "Smart OPS." This article describes Smart OPS.

1. Introduction

Operation systems (OPS)*1 are critical systems used to collectively monitor operating states of the equipment that comprises the network and situations in which warnings have occurred, and make settings for such equipment to maintain stable operation of mobile networks.

As the mobile network advances to become a social infrastructure supporting diverse industries and social lifestyles, superior OPS are required to achieve efficient operations for individual services with different Service Level Agreements (SLA)*2 on increasingly expansive and complex networks.

Hence, NTT DOCOMO has taken dramatic steps to advance the efficiency and enhancement of OPS with its proposal of the Smart OPS concept. The Smart OPS concept includes three general phases

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

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

of technical innovation to advance OPS. This article describes an overview of these technical innovations.

2. The Smart OPS Structure

With the aim of providing a stable and uninterrupted mobile service, NTT DOCOMO has developed and introduced commercially the OPS used in its network operations. Circumstances surrounding the increasingly complex and diversified mobile networks of recent years have led to increasing demands on network operations for even greater efficiency, agility and enhancement. To satisfy these demands on the network and enable provision of high quality mobile services, NTT DOCOMO has been revolutionizing OPS with the so-called "Smart OPS." Smart OPS implementation consists of three phases (**Figure 1**).

1) Phase 1: Virtualization

As well as shifting the OPS operating environments from physical environments to OpenStack*3 virtualized cloud environments*4, Phase 1 includes improved continuity of operations in disasters by distributing OPS facilities across geographically separated locations. This has given OPS facilities greater efficiency, agility and flexibility in their operations, and has achieved a high level of reliability.

Please refer to past articles introducing Phase 1 in this journal for more details [1].

2) Phase 2: Automated Operations (Fulfillment*5)

In Phase 2, the Fulfillment Operation Support System (OSS)*6 was introduced to further automate

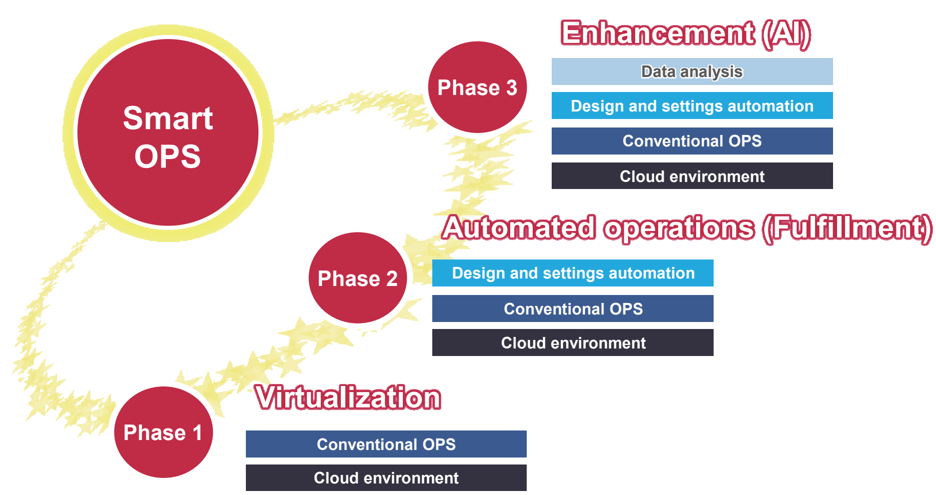

Figure 1　Smart OPS overview

*3 **OpenStack**: Cloud-infrastructure software that uses server virtualization technology to run multiple virtual servers on a single physical server. It can allocate virtual servers to different cloud services in use. OpenStack is open source software.

*4 **Cloud environment**: A virtualization platform such as VMware and OpenStack for achieving virtualization.

*5 **Fulfillment**: Construction (design and setting) of network facilities to provide communication services.

operations. The expansion and diversification of 5G and the Internet of Things (IoT) services will put even greater demands on network facilities for rapid construction and settings changes. In addition, high quality networks in both construction and operations must be maintained as the network becomes more complex.

To address these issues, NTT DOCOMO introduced a new OPS called "Fulfillment OSS" to combine speed and high quality with operational automation. Fulfillment OSS realizes automated design and settings by centrally managing resource information such as network facility IP addresses*7 and equipment numbers, etc. as well as design rules and policies. Phase 2 is described in detail in another special article in this journal [2].

3) Phase 3: Enhancement (AI)

Phase 3 achieves enhancement of network operations using AI and big data to maintain provision of high-quality services even as the network becomes more complex.

This includes real-time analysis using AI of information required for monitoring, analysis and countermeasures from big data such as alerts, equipment statuses, and traffic data gathered from the network. This enables more detailed and proactive network operations than conventional systems, based on prediction and forecasting. Phase 3 is also described in detail in another special article in this journal [3].

3. Conclusion

This article has described "Smart OPS," which is supporting the advance of DOCOMO's network. Phase 1: Virtualization achieved improvement of economy and reliability of OSS, Phase 2: Automated operations (Fulfillment) achieved automation of operations that were conventionally performed by people, and Phase 3: Enhancement (AI) achieved enhanced and detailed network analysis that is impossible for people to perform.

As described above, Smart OPS enables uninterrupted network operations that are more efficient and enhanced than the conventional OPS. In combination with further expansion and variation of networks and the services provided on them, improved expanded areas of application and accuracy of OPS functionality will continue to contribute to the maintenance of DOCOMO's high-quality network.

REFERENCES

[1] Y. Kishikawa et al.: "Large-scale OSS Migration Using Private Cloud and Virtualization Technologies," NTT DOCOMO Technical Journal, Vol.19, No.2, pp.31-40, Oct. 2017.

[2] K. Ishii et al.: "Automated Facility Construction Work Achieved through the Implementation of Fulfillment OSS," NTT DOCOMO Technical Journal, Vol.21, No.1, pp.21-28, Jul. 2019.

[3] A. Shiozu et al.: "Achieving Advanced Maintenance Works with AI," NTT DOCOMO Technical Journal, Vol.21, No.1, pp.29-37, Jul. 2019.

*6 OSS: Enterprise operational support systems. For communications operators, this can include some or all of the fault management, configuration management, charging management, performance management and security management for the networks and systems used to provide services.

*7 IP address: A unique identification number allocated to each computer or communications device connected to an IP network such as an intranet or the Internet.

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Special Articles on Smart OPS for Further Efficiency and Advancement of Network Operations

Automated Facility Construction Work Achieved through the Implementation of Fulfillment OSS

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Network facility construction works need to be fast and flexible for the commencement of 5G services and the ongoing expansion and diversification of IoT services. To address these issues, NTT DOCOMO has been implementing virtualization technologies in its core network facilities, and has introduced the Fulfillment OSS to achieve automation and efficiency with the design and settings input, which are crucial elements of the lifecycle of core network facilities, to significantly reduce the complexity of design and settings operations and operate the network with even higher quality.

The Fulfillment OSS incorporates equipment design rules and parameters as input data required for constructing and changing the network facilities needed for services, and improves quality and efficiency of facility construction works by enabling automatic management and design of parameters and schematics required for various equipment.

1. Introduction

Network facility construction works need to be fast and flexible for the commencement of 5G services and the ongoing expansion and diversification of IoT services.

NTT DOCOMO developed its core network[*1] virtualization platform system based on Network

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

Functions Virtualisation (NFV)*2, which uses common requirements and reference architectures defined by the European Telecommunications Standards Institute (ETSI)*3 [1] [2]. Since commencement of its commercial services in March 2016, this system has achieved improved reliability, rapid service provision, easy connection during times of congestion and improved economies with network facilities and operations.

NTT DOCOMO introduced NFV to enable on-demand responses with planned hardware construction to match demand for facilities and software building as required. To broadly visualize virtualized facility construction processes, gain a thorough understanding of them, bring even more reliability, speed and efficiency to virtualized facility construction, and reduce OPerating EXpenses (OPEX)*4, NTT DOCOMO implemented the Fulfillment Operation Support System (OSS)*5 for automation and efficiency of the design and settings works in the lifecycle of NFV related equipment.

This article describes an overview of the Fulfillment OSS.

2. Targets of Fulfillment OSS Automation and Requirements

The Fulfillment OSS is a system that automates facility construction work after the application of network virtualization technologies as shown in **Figure 1**, by incorporating input information such as design rules and parameters for equipment requiring construction and update.

Currently, separate hardware and software

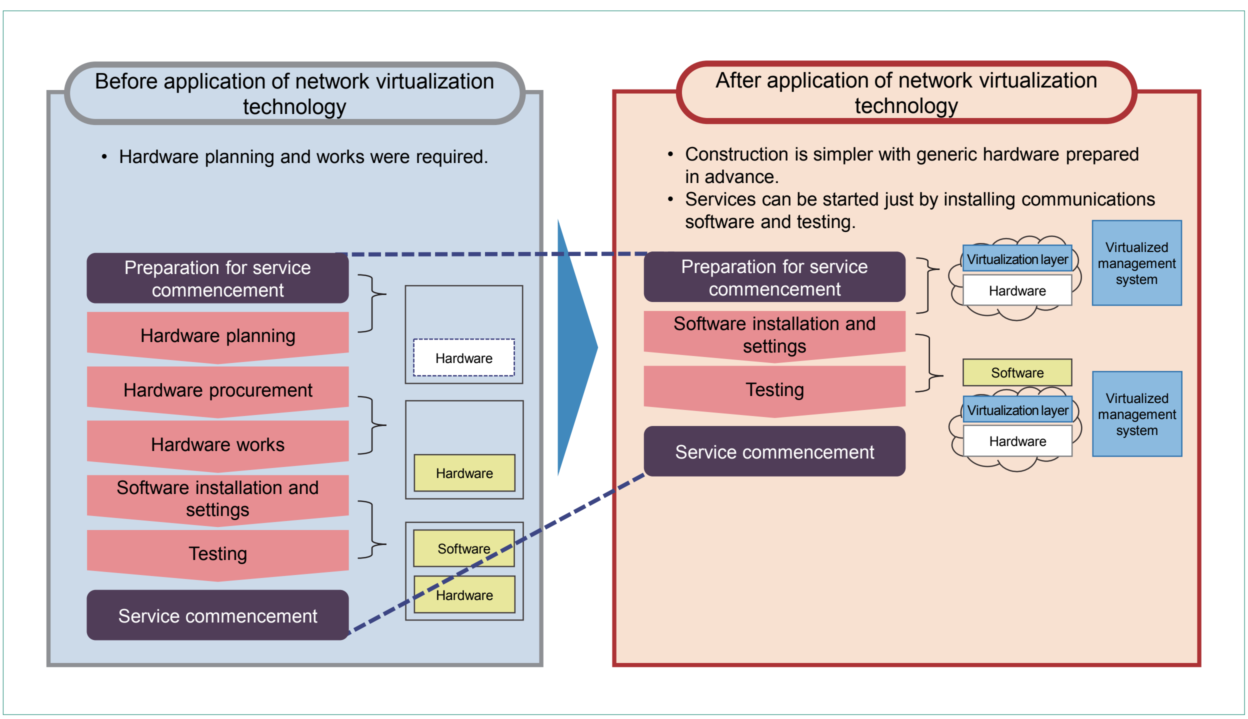

Figure 1 Changes to facility construction processes up to service commencement through the application of network virtualization technologies

*2 NFV: Achieving a telecommunications carrier network on generic hardware using virtualization technologies.

*3 ETSI: A European non-profit organization that formulates standard specifications for the telecommunications field.

*4 OPEX: The amount of money expended for designing, setting, maintaining and managing facilities.

*5 OSS: A system for discovering, controlling, and dealing with faults and congestion on a mobile communications network, or an operations support system for network operators. For a network operator, this means a system for full or partial network or system fault management, configuration management, charging management, performance management, and security management.

design and construction work and on-demand responses are enabled with virtualized facility construction work. While this has made work more efficient, we faced the challenges of optimizing the sophisticated and complex work processes that handle massive amounts of design rules and parameters associated with facility construction, and thoroughly visualizing the progress of facility construction works to enable a broad view and complete understanding so that such works can proceed steadily and efficiently in situations where a number of constructions are performed in parallel. To solve these issues and maximize the effectiveness of network virtualization by the implementation of the Fulfillment OSS, the following requirements must be satisfied.

- Review and improvement of the work processes so that they suit virtualized facility construction
- Efficient management and automated design of schematics and parameters required for facility construction
- Comprehensive progress management of entire processes from design through to completion

3. Optimizing Facility Construction Works Based on Standard Specifications

In reviewing work processes for virtualized facility construction, as a reference model, we used the enhanced Telecom Operation Map (eTOM)*6 framework*7 advocated in the Tele Management Forum (TM Forum)*8 for standardization of operations work [3]. **Figure 2** shows the eTOM framework.

This framework divides operational targets into

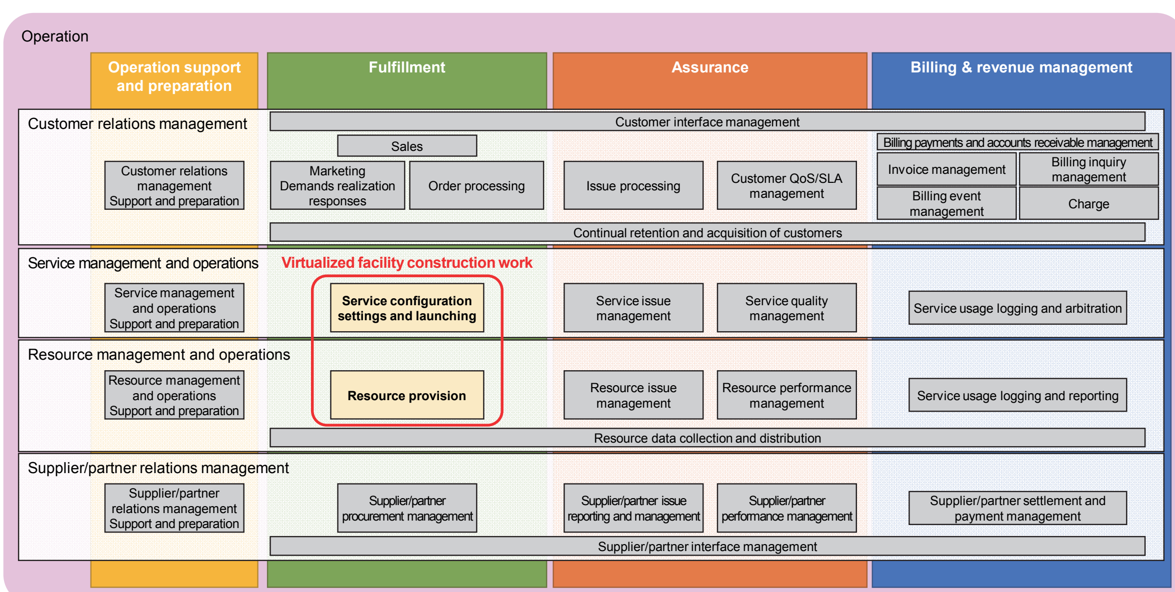

Figure 2　The eTOM framework

*6　eTOM: A collection of frameworks formulated by TM Forum summarizing work processes and information distribution in operations in the telecommunications field.

*7　Framework: Software that encompasses functionality and control structures generally required for software in a given domain. In contract to a library in which the developer calls individual functions, code in the framework handles overall control and calls individual functions added by the developer.

*8　TM Forum: A European non-profit organization that formulates standard specifications for the telecommunications field.

four layers - customers who use services, services provided, resources that comprise services, and suppliers and partners that provide resources. Work to manage customer information and information related to service structures and prepare support, work in the fulfillment area required to build and achieve services, work in the assurance area for maintenance and management of service operations, and work required for billing for service usage are systematically sorted for each of these separate operational layers.

Virtualized facility construction work entails "service configuration settings and launching" and "resource provision," which fall into the fulfillment area of the framework. In this work, workflows for understanding current usage conditions of the facility required for services, facility planning, physical and logical parameter design for building, and setting and testing equipment have been standardized.

In our review of work processes, we studied the aspects below to apply this framework.

(1) Clarification of current work processes and tasks
(2) Task optimization and sorting of work processes
(3) Separating the facility construction work of virtualized facility construction and settings into (1) design work using common design parameters as "common design" and "physical works," and (2) design work using different design parameters for each construction as "network settings," "virtualization platform settings" and "communication software settings," and then assigning tasks to their related work modules after defining these five work modules
(4) In addition to the five work modules, we defined "progress management" for managing the progress of overall works

Table 1 shows the defined work modules and the details of work of each module. Also, **Figure 3** shows work modules for design and construction

Table 1　Works entailed in each work module

Work module	Details of work
Process progress management	Overall work process progress management
Common design	Processes of unified management of network design rules and parameters, and facility design work
Physical works	Processes of on-site settings work required for physical equipment installation and wiring, and initial equipment startup
Network settings	Processes of physical network equipment settings to implement SDN and testing work
Virtualization platform settings	Processes of NFVI and VIM settings and testing work
Communications software settings	Processes of VNF settings and testing work

NFV Infrastructure (NFVI): Virtualization functions including physical resources consist of generic hardware and storage to run communications software, and hypervisors.
Software Defined Network (SDN): A generic term for technology that enables centralized control of communications equipment with software.
Virtualized Infrastructure Manager (VIM): Functions for controlling NFVI.

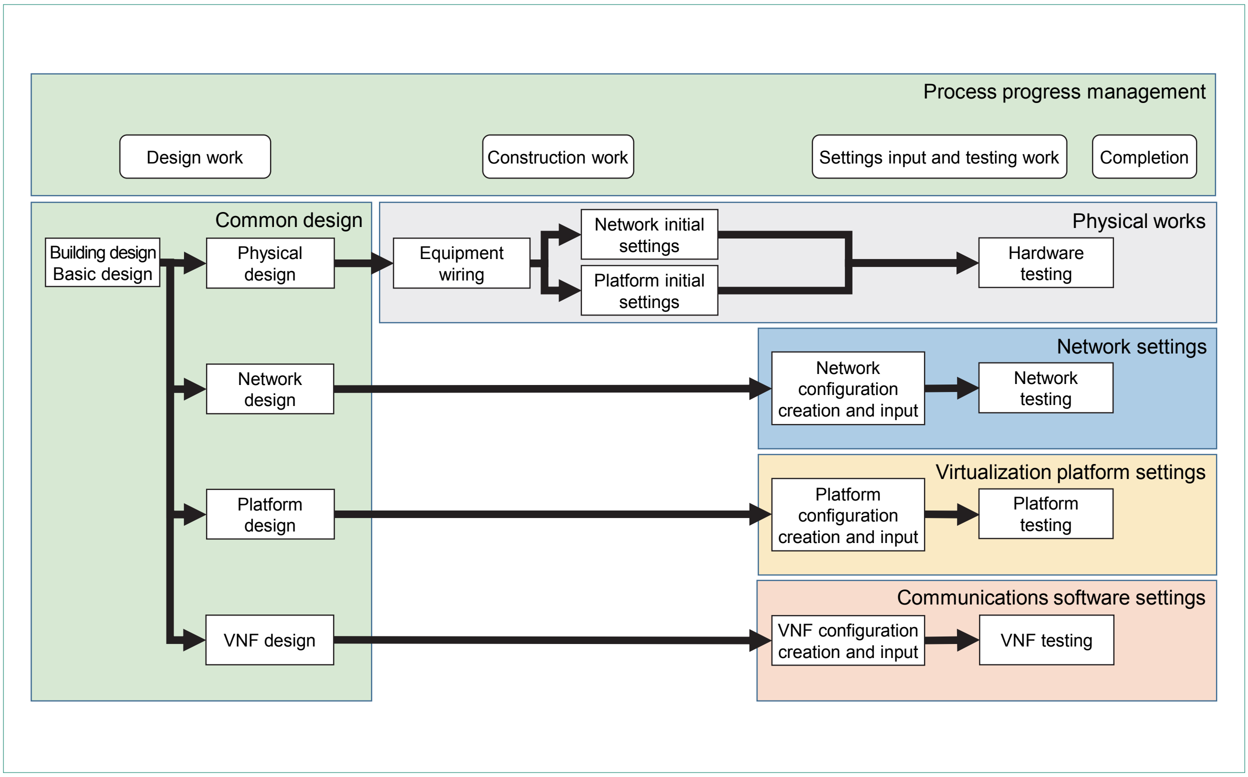

Figure 3　Work modularization for design and construction of virtualized facilities

of virtualized facilities.

4. System Structure of the Fulfillment OSS

When we systemized the work modules defined in the previous section with the Fulfillment OSS, we studied the Fulfillment OSS system structure in terms of the eTOM framework.

When considering system configuration, the following requirements must be satisfied to make application scope expansion easy and enable flexible response to network specifications changes in future.

- A loosely coupled system configuration based on functional segments
- Localized scope of influence when responding to network specifications changes

In terms of system configuration, when defining work modules, we adopted a policy of constructing a system based on work modules with optimized and loosely coupled design and construction work segments sorted for each target construction. Systematization entails defining the work modules as Function Blocks (FB)*9 and then systemizing in FB units. Also, with FB, to respond to network specification changes, we adopted a policy of localizing the scope of influence as a mechanism to avoid affecting FBs other than those for managing facilities with changing specifications, by managing only network information and design parameters for

*9　FB: Functional sections in which services offered by the system are divided into functions or target devices, etc. and implemented. Single FB or linked multiple FBs achieve the services.

facilities targeted for management.

When defining FB, we aimed for efficient implementation while accounting for the characteristics of the information managed with work modules. The information managed with work modules can be generally divided into the two categories of "information that spans processes and equipment under construction" and "information only related to the class of equipment under construction." **Table 2** shows information managed with work modules.

For process progress management and common settings, information is systemized and managed uniformly with the same FB to manage information spanning overall processes and target equipment. For other work modules, we implemented independent FB because only the information for each device under construction is retained.

Table 3 shows the defined work modules and their corresponding FBs. Also, **Figure 4** shows the defined FB and their corresponding function segments in the eTOM Fulfillment area.

As shown in Table 3 and Fig. 4, the Fulfillment OSS consists of design and inventory FBs, network provisioning[*10] FBs, virtual platform provisioning FBs, and Virtual Network Function (VNF)[*11] provisioning FBs. The roles of the four FBs that make up the Fulfillment OSS used to construct

Table 2 The information managed with the work modules

Work module	Managed information
Process progress management	Process progress information spanning processes and equipment targeted for construction
Common design	Design information spanning processes and equipment targeted for construction
Physical works	Management of details of physical work for construction and on-site settings information only
Network settings	Management of settings information for network devices for construction only
Virtualization platform settings	Management of settings information for virtualization platforms for construction only
Communications software settings	Management of settings information for VNF for construction only

Table 3 Defined work modules and their corresponding FBs

Work module	FB
Process progress management	Design, inventory FB
Common design	Design, inventory FB
Physical works	Actual physical works cannot be systemized, and are thus exempt from FB definitions
Network settings	Network provisioning FB
Virtualization platform settings	Virtual platform provisioning FB
Communications software settings	VNF provisioning FB

*10 Provisioning: Hardware and software settings and testing work required to operate resources such as the networks necessary for providing services.

*11 VNF: Communications functions implemented with software running on virtual machines.

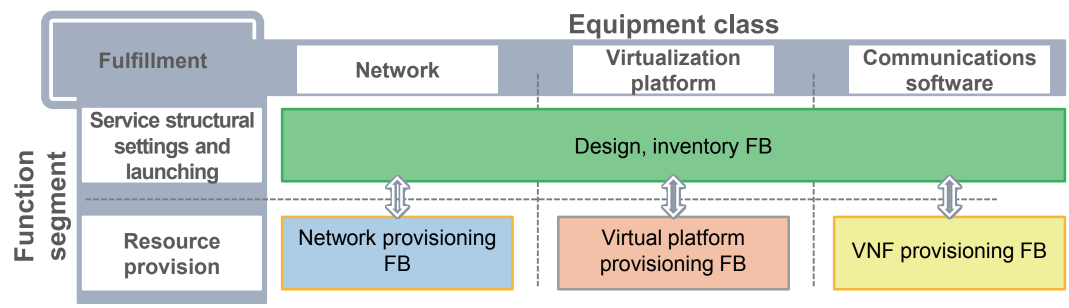

Figure 4 Defined FBs and their corresponding function segments in the fulfillment area

virtualized facilities and change their settings are shown below.

1) Design, Inventory FB

This FB is responsible for uniform management of network design rules and parameters required for overall construction and settings changes of virtualized facilities, automation of facility design works, and overall work process progress management.

Design information is created as schematics with this FB and is passed to provisioning FBs for the class of equipment under construction to achieve efficient task execution.

Simply updating the internal data of this FB enables response to changes to design rules and parameters specifications that come with diversifying and ever-more complicated networks, and thus achieves the flexibility and agility required to keep up with network changes accompanying the implementation of new networks such as 5G and IoT.

In future, as the range of equipment classes applicable to the Fulfillment OSS expands, simply adding functions to this FB and introducing new FBs will enable application of the Fulfillment OSS to such equipment without influencing other provisioning FBs.

2) Network/Virtualization Platform/VNF Provisioning FBs

This FB is responsible for automated generation and input of configuration files*12 as well as commands for facilities under construction, and automatic testing to confirm normalcy based on the schematics received from the design and inventory FB.

This FB manages rules for generating commands and configuration files for settings and inputs to facilities under construction, and enables simple response to changes to configuration file and command specifications due to version updates, etc.

Also, by defining provisioning FBs separately and structuring them so that there are no links

*12 Configuration file: A file containing the information for the settings required to operate a network facility such as IP addresses and equipment numbers. Settings values in configuration files are loaded into network facilities, which behave according to the details of those settings.

between the provisioning FBs, FBs are configured so that they don't influence other provisioning FBs due to specification changes for facilities under construction, since network equipment, virtualization platforms and VNFs have different equipment characteristics.

5. Conclusion

This article has described a review of work processes of construction and settings changes of core network virtualization facilities, and automation of works through the implementation of the Fulfillment OSS to achieve efficient and automated design and settings input for facilities construction on complexing and diversifying mobile networks.

The implementation of the Fulfillment OSS has resulted in dramatically greater efficiency with a 77% reduction in work targeted for automation in construction of virtualized facilities (**Figure 5**).

Currently, we are proceeding with developments to achieve automated design and settings not only for network equipment in virtualized facilities, but also for the physical network equipment that comprises and provides closed networks by expanding the scope of application of network provisioning FB, by the first half of FY 2019.

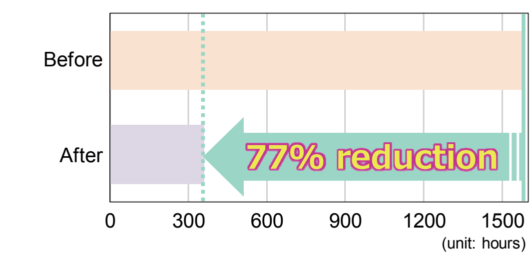

Figure 5　Effects of Fulfillment OSS implementation

As well as core networks, we aim to expand the scope of application to other networks, achieve automated design and settings in terms of units of service rather than units of equipment, and provide quick and efficient end-to-end services as soon as user demand arises.

REFERENCES

[1] ETSI: "Network Functions Virtualisation (NFV)." http://www.etsi.org/technologies-clusters/technologies/nfv

[2] H. Oto et al.: "Application of Virtualization Technology to Communications Networks," NTT DOCOMO Technical Journal, Vol.18, No.1, pp.4-10, Jul. 2016.

[3] TM Forum: "Business Process Framework (eTOM)." https://www.tmforum.org/business-process-framework/

[4] OpenStack Web site https://www.openstack.org/

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Special Articles on Smart OPS for Further Efficiency and Advancement of Network Operations

Achieving Advanced Maintenance Works with AI

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Mobile networks are becoming increasingly sophisticated with the implementation of new technologies such as network virtualization and 5G. The accompanying amount of mobile network maintenance work has burgeoned dramatically, leading to demands to reform conventional reactive maintenance (follow-up measures). Thus, as Phase 3 of the Smart OPS concept, we have taken initiatives to develop systems with AI technology that will enable advanced analysis to achieve proactive maintenance (advance preventive measures) based on predictions that would be difficult for humans to make.

1. Introduction

With the implementation of network virtualization[*1] and 5G, mobile networks are expected to become more complicated and mobile services more diverse in future. Hence, maintenance operations (hereinafter referred to as "operations") to identify and rectify network failures would clearly entail increased amounts of work and time taken for work since rapid and accurate analysis using only conventional human-centered methods to identify and analyze impacts on user services would be problematic.

Thus, to shift away from conventional follow-up

*1 Network virtualization: A method of implementing network control functions as software running on virtualized operating systems on servers.

maintenance measures enacted after an alarm is detected (hereinafter referred to as "reactive"), NTT DOCOMO is implementing Artificial Intelligence (AI) in operations which is anticipated to bring efficiency to a range of fields.

This article describes usage of AI in operations, and initiatives to shift from reactive maintenance to advance preventive maintenance (hereinafter referred to as "proactive").

2. Circumstances Surrounding Mobile Networks and Work Issues

2.1 Mobile Network Circumstances

Going forward, accompanying network virtualization, 5G implementation and the rapid spread of devices on the Internet of Things (IoT), mobile networks will require update to accommodate communications for various services with different traffic characteristics and network specifications than conventional communications, such as the low latency and multiple simultaneous connections. Thus, new technologies such as virtualization and network slicing*2 have been introduced into the systems providing these services. The logical network structures that provide these services are complex structures with multiple virtualized logical resources that require an enormous workload in their operation compared to the conventional maintenance work done by humans.

2.2 The Current State of Operations

To provide a comfortable and easy to use network to users 24 hours a day, 365 days a year, network operations must maintain high network communications quality and are thus predicted to become even more complicated as services diversify into the future. In addition, so that network quality is maintained, and users are able to enjoy comfort and cutting-edge innovations, operations need to be reformed for proactive maintenance based on predictions and warning signs in place of reactive maintenance only enacted as recovery measures after a problem has occurred.

Achieving such proactive maintenance requires advanced operations such as detecting "silent failures*3" in which alarms are not received from Network Elements (NE)*4 despite affecting users, visualizing network quality based on user Quality of Experience (QoE), detecting signs of failure, swift identification of locations of failures when they occur, and fast service recovery methods [2].

Operations are generally classified as work for monitoring, analysis, and countermeasures. These works are described in general as follows.

1) Monitoring Work

This entails monitoring services and network operating conditions to detect anomalies. Mainly, monitoring is based on warning information, equipment status and traffic information, etc. collected and notified from NE.

2) Analysis Work

This entails determining causes and locations of malfunctioning NEs or sections when errors are detected with a service or on the network.

3) Countermeasures Work

This entails enacting countermeasures in response to the determined cause of the failure to recover normal status. This work can include remote control or on-site replacement work, etc. according to NE recovery procedures.

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*2 Network slicing: Technology for providing services according to their application by virtualizing the network and splitting network resources.

*3 Silent failure: Failures caused by breakdowns of the fault detection package or main processor, etc. that the equipment itself cannot recognize and hence maintenance personnel cannot detect.

*4 NE: A generic term for a base station, switching station, or relay device that makes up the system.

2.3 Work Efficiency with AI Usage

AI technologies are currently experiencing their "third boom." AI with "machine learning" to automatically learn from patterns and rules based on certain standards from a large amount of data called "big data" has been commercialized, and "deep learning" to accumulate knowledge data so that the AI can learn patterns and rules itself without any particular standards has appeared.

According to the "Information and Communications in Japan" White Paper of 2016, functions that AI actually brings to services are generally classified as "identification," "prediction" and "execution" [1]. NTT DOCOMO has applied AI's identification and prediction functions to the monitoring and analysis work involved in its operations, and has applied execution functions to countermeasures work. There are hence also great expectations on AI to bring efficiency to operations.

3. Study on Sophistication of Operations with AI

We also studied the general areas of the respective monitoring, analysis and countermeasure work to advance these enormous operations through the use of AI. **Figure 1** shows an image of these advances.

1) Monitoring Work

Through the use of AI technologies such as machine and deep learning with vast amounts of data collectible from the network such as warning information, equipment status and traffic, operation systems can detect signs of equipment failures and predict impacts on services that would be impossible for a human to accomplish. When events are detected, any resulting service quality*5 deteriorations are displayed on a map screen for each area and service alerts are displayed as a

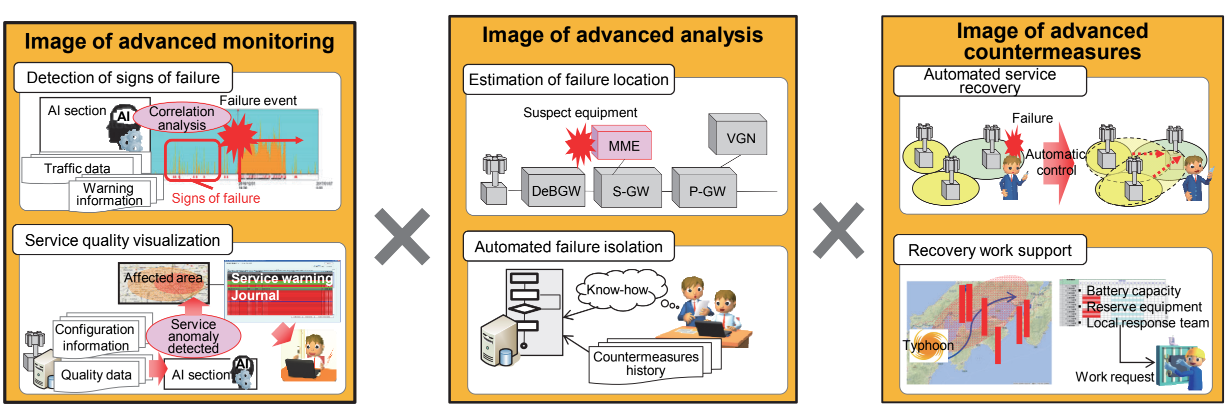

Figure 1 Image of advanced operations with AI

*5 **Service quality:** A level of quality on the network that can be set for each service. The amount of delay or packet loss is controlled by controlling the bandwidth that the service can use.

journal.

The following describes cases of these advanced measures.

(1) Connection quality anomaly detection in radio base stations

In this case, AI enables detection of signs of events impacting user services by learning trends in normal data in radio base stations and detecting data that is different from usual.

(2) Detection of user quality of experience deterioration

AI enables detection of deteriorated QoE by numeric quantification of user QoE from the time required to display a webpage.

2) Analysis Work

When service quality deterioration is predicted with monitoring work, the operations system estimates the cause of the failure or its suspect locations based on data analyzed from the complex logical network structure. Also, using past human know-how to isolate failures, the operations system supports work by recommending optimized analysis procedures triggered by equipment alarms.

3) Countermeasures Work

The operations system automatically enacts recovery countermeasures for failure causes identified with analysis work. For example, at a location and time where many people gather such as an event venue, adjustments to base station tilt*6 can be made to optimize for coverage of the area to prevent impacts on services before they occur. Not only with remote maintenance, for on-site maintenance works, the operations system also provides workers with support through guidance by suggesting parts that may be required for a project or optimized response procedures in cases where work is required on multiple base stations, etc.

4. The System Structure and Example Application of AI Technology

This section describes the system structure using AI technology to achieve advanced operations, using cases of connection quality anomaly detection in a radio base station and user QoE deterioration detection as examples.

4.1 A System Structure Enabling Multiple Simultaneous AI Usage

Essentially, operations consist of analysis of text data such as system log and numeric data such as traffic. This may include multiple data patterns depending on the work. There are also algorithms and products available with AI technologies that excel at analysis of text and numeric data, and hence there are demands for this kind of analysis depending on the work.

For this reason, a diverse range of AI technologies must be executed simultaneously in operations, and NTT DOCOMO has developed a system to enable this. **Figure 2** shows a schematic of system we developed.

In this system, the "data management platform section" that manages big data, the "AI engine function section" that analyzes big data and the "screen display section" that displays the results of AI analysis exist independently. Thus, as well as adopting multiple AI engines, future implementation of new AI products or replacement of existing AI products can be done easily.

*6 **Tilt:** The inclination of an antenna's main beam direction in the vertical plane.

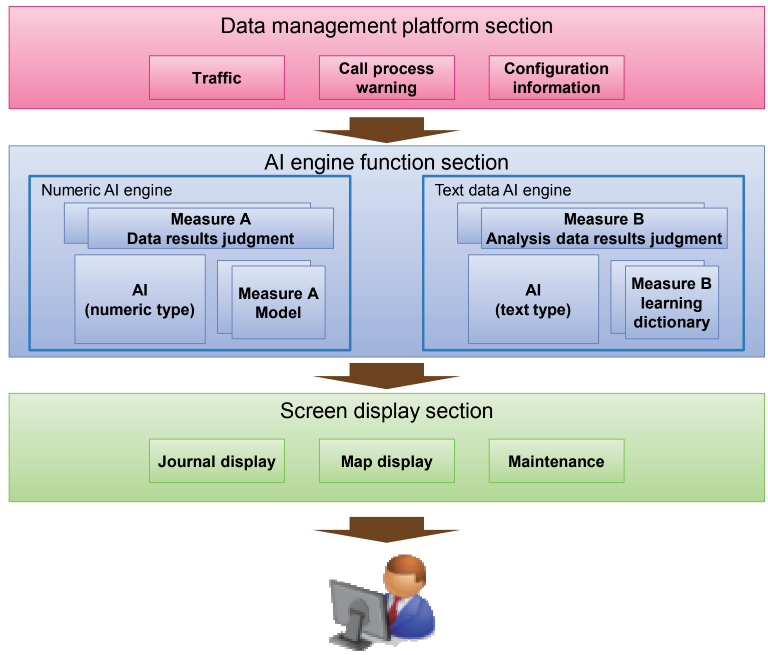

Figure 2 System structure

4.2 Connection Quality Anomaly Detection in Radio Base Stations

1) Detecting Connection Quality Anomalies through Equipment Alarm Monitoring

Conventional maintenance of radio base stations makes it possible to respond to equipment anomaly events through analysis and countermeasures work triggered by equipment alarms, without the need for detailed knowledge of the radio base station. However, by the time of the alarm event, equipment anomalies may have already significantly impacted users. Thus, to address this issue, anomalies must be detected before equipment alarm events occur and the necessary countermeasures taken.

2) Connection Quality Anomaly Detection with AI

We have developed technology (hereinafter referred to as "connection quality anomaly detection") that detects signs of anomaly events in radio base stations by looking for anomalous trends in the network data such as traffic, warnings and logs, etc. that NTT DOCOMO regularly accumulates (**Figure 3**).

This technology is divided into a learning phase in which normal statuses are learned from network data (**Figure 4** STEP (0)), and an analysis phase in which anomalies are detected based on the learning model (Fig. 4 STEP (1) to (3)). In network data

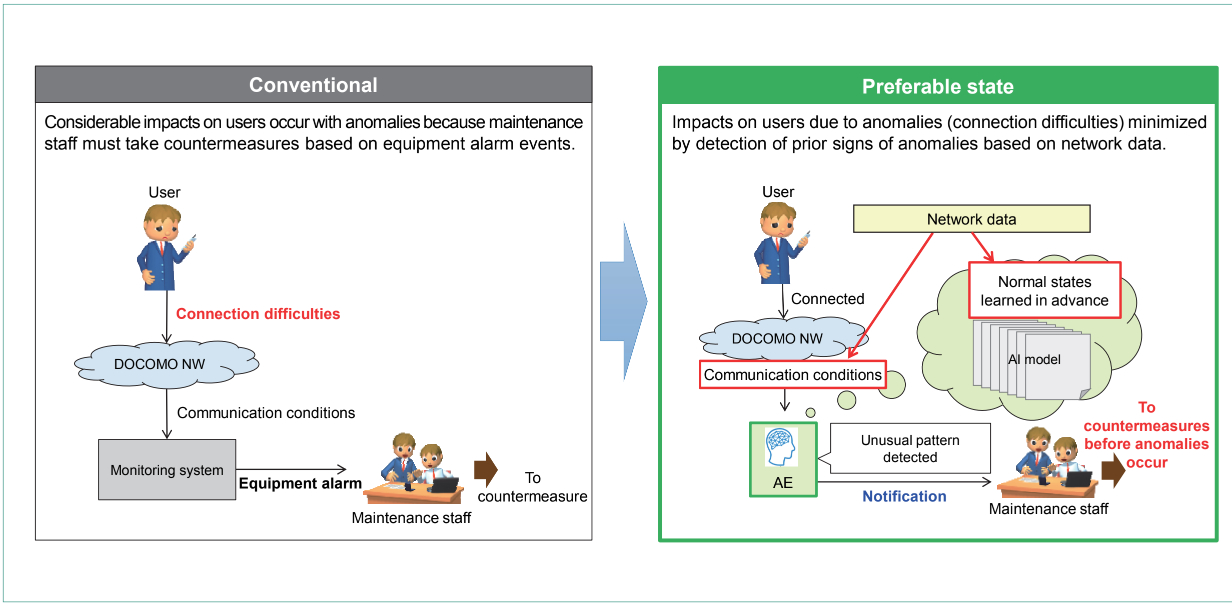

Figure 3 Connection quality anomaly detection with AI technologies

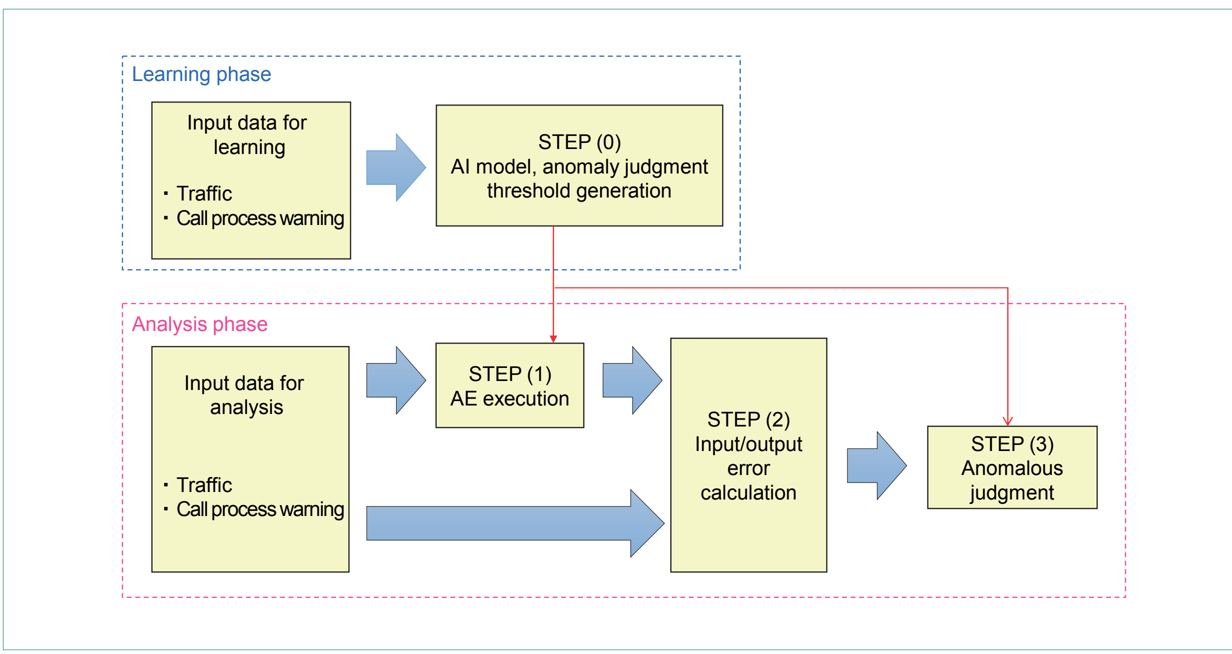

Figure 4 Process overview of connection quality anomaly detection with AI technology

used for model learning and analysis, the amount of time for anomalous events is only a small amount of the overall working time of the radio base station, and data for anomalous events is tiny compared to normal times. Thus, we adopted Auto Encoders (AE)*7 often used for anomaly detection in recent

*7 AE: A type of algorithm designed for dimensional compression using neural networks in machine learning. Conventionally used for prior learning with deep learning.

years, because they can learn from data from normal times. Learning is done by reproducing normal time input data with the AE. Then, when input data appears that cannot be reproduced with the learning model, it is judged as anomalous to enable detection.

(a) Learning phase

In the learning phase, normal time network data is input to generate the AE model. This technology makes use of call processing alarm data, a type of warning information in mobile communications connection processing, and traffic data collected from mobile base stations. We used the call processing alarm data and traffic data excluding data for equipment failures, etc. judged beforehand as periods of anomaly as normal learning data, so that learning data can be faithfully reproduced when learning the model.

(b) Analysis phase

Newly acquired network data is given as input data to the model generated in the learning phase, and the model output result and input data are compared. If the input data is acquired during normal times, the input and output will not be that different. However, if data that does not appear normal is input, there will be a significant difference between the input and output. Then, the Residual Sum of Squares (RSS)*8 is calculated for the input and output, and an anomaly is judged if the RSS exceeds the threshold calculated in the learning phase.

Figure 5 shows an example of application of this technology to a radio base station in which an equipment alarm event has occurred.

The plotted red points in Fig. 5 represent degrees

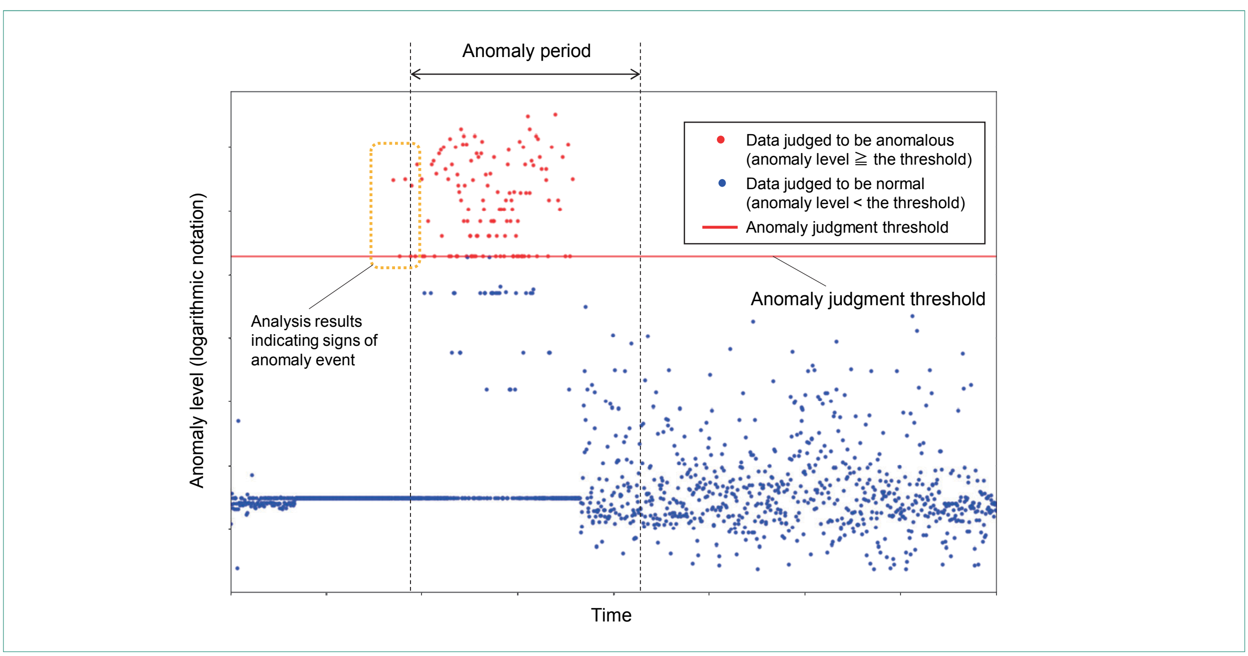

Figure 5 Connection quality anomaly detection application example

*8 RSS: The squared and summed value of the residual error (the difference between the input value and our value in this case). A scale for evaluating mismatches between input values and model output values.

of anomaly that are RSS calculated in a single analysis phase. If the level of anomaly exceeds the threshold, an anomaly is judged (the red points in Fig. 5). In Fig. 5, signs of anomalous events were detected with this technology because a number of analysis results judged as anomaly were detected in the stage prior to the anomalous period the equipment alarm events occurred.

We also confirmed consistent results of anomaly detection because anomalies were judged by the system in the stages prior to 60% of equipment alarms events in the results of similar testing done on randomly selected base stations.

4.3 Detection of User QoE Deterioration

1) Current Issues with Network Monitoring

Current network monitoring entails analysis and countermeasures triggered by equipment alarms to prevent large-scale impacts on networks. However, it is not possible to detect situations in which users cannot comfortably enjoy Web browsing or video streaming services at locations that become crowded such as events where large numbers of people gather or major terminal stations.

2) Approaches to Solving These Issues

A solution to the aforementioned issue of not being able to detect situations in which users cannot comfortably use network services, can be achieved by quantification of QoE and visualization of quality conditions to quickly detect and rectify QoE deterioration.

3) QoE Visualization Method

DOCOMO has developed a visualization method that entails estimation of the Mean Opinion Score (MOS)*9 of QoE on a scale of 1 to 5 of feature values*10 for traffic data collected from NE, as shown below (**Figure 6**).

(1) The traffic data collected by NE for each area is input into a preestablished QoE estimation model to estimate the average QoE for the area.

(2) The predicted QoE is quantified for each time and area so that the operator can confirm conditions of deteriorated QoE.

4) QoE Estimation Model

To build a QoE estimation model to reproduce

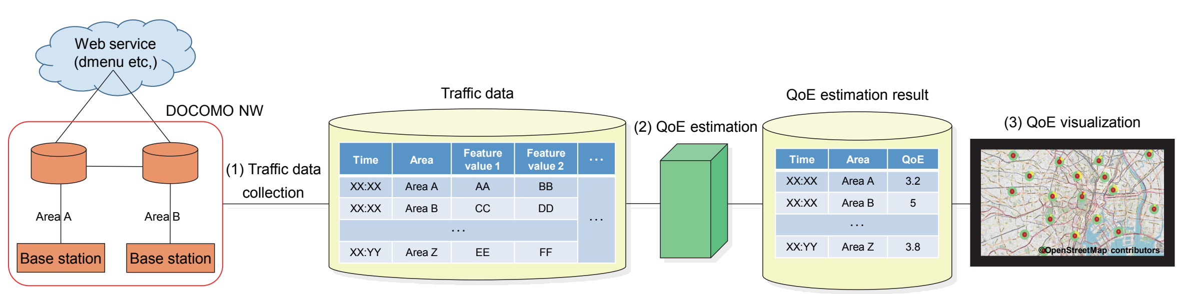

Figure 6 QoE visualization method overview

*9 MOS: A widely used measure of subjective quality representing the average value of subjective evaluations given by multiple subjects.

*10 Feature value: An amount (a numeric value) extracted from data to characterize the data. In this article, feature values represent the average throughput acquired from nodes, etc.

actual usage conditions, we took field measurements in a wide range of areas and analyzed the relationship between the QoE measured with mobile devices and the traffic data in the areas. As a result of analyzing the correlation*11 between the feature values of various traffic data collected by NE and QoE, we found the two feature values of average throughput*12 and number of users have particularly large impacts on QoE. Therefore, we built our QoE estimation model based on these two parameters.

Next, to confirm the effectiveness of the estimation model, we tested its accuracy using the data measured in the field. We defined deteriorated QoE as lower than 2.5 for the average value of QoE measured with a number of test mobile devices, and then assessed the percentage of actually estimated QoE deterioration with this technology. We found it to be 82.5% accurate in detecting deteriorated conditions, which we confirmed to be sufficient to enable QoE deterioration detection.

5. Conclusion

NTT DOCOMO implemented systems that use AI technologies in its operations at the end of March 2019. Going forward, we will continue to increase monitoring targets and advance operations in stages for analysis and countermeasures to achieve proactive maintenance work.

REFERENCES

[1] Ministry of Internal Affairs and Communications: "Present and Future of Artificial Intelligence (AI)," Information and Communications in Japan 2016, White Paper, Part 1, Chapter 4, Section 2.

[2] T. Kimura, S. Shibata, K. Yamamoto, T. Moroishi, M. Furutani and T. Otani: "A Study on AI Application to Network Operation," IEICE Tech., Vol.117, No.491, ICM2017-70, pp.85-90, Mar. 2018 (In Japanese).

*11 Correlation: An indication of the relationship between two feature values. If one feature value increases, and another feature value increases or decreases with a similar trend, they are said to be in a correlative relationship. If the trends of increase and decrease are dissimilar, there is no correlation.

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

Standardization

RAN Open O-RAN

Special Articles on Standardization Trends toward Open and Intelligent Radio Access Networks

O-RAN Alliance Standardization Trends

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NTT DOCOMO and other major global operators founded the O-RAN Alliance in February 2018 with the aim of promoting open and intelligent radio access networks in the 5G era. Since then, O-RAN Alliance membership has grown to include many operators and vendors. This article explains the background to the founding of the O-RAN Alliance and describes its vision, reference architecture, and the focus areas of its workgroups.

1. Introduction

The volume of data traffic in mobile communications is spiraling upward with no signs of slowing down as mobile services such as social networking, video streaming, and online gaming continue to expand. At the same time, there is an increasing desire to achieve the Internet of Things (IoT) connecting just about everything to the Internet, create new industries through collaborative ventures between mobile communications and other industries, and contribute to the solving of social issues. However, these initiatives cannot be achieved solely from the viewpoint of increasing the speed and capacity of the mobile network. It will also be important to reduce power consumption, expand coverage, lower prices, reduce latency, and improve reliability while being able to connect many devices simultaneously (massive connectivity).

The fifth-generation mobile communications system (5G) [1] formulated by the 3rd Generation Partnership Project (3GPP), an international standards development organization for mobile communications, meets the above requirements, and there are many interested parties that are looking forward to its early commercialization.

NTT DOCOMO is no exception, and it plans to launch 5G pre-services in September 2019 and full-scale 5G commercial services in spring 2020. However, to provide not only services geared to existing mobile terminals and smartphones but to also create new industries through collaborations with other industries and achieve new value-added services, it will be necessary to construct an open Radio Access Network (RAN)*1 that can combine and utilize various types of equipment and modules. It is also important that the network be made intelligent to efficiently provide a wide variety of services. In response to these needs, NTT DOCOMO joined up with other operators to found the Open RAN (O-RAN) Alliance in February 2018 with the aim of promoting open and intelligent RAN.

This article provides some background to the founding of the O-RAN Alliance and describes its vision, reference architecture, and the focus areas of its technical workgroups.

2. Background to Founding of O-RAN Alliance

The O-RAN Alliance was founded in February 2018 by five operators—AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO, and Orange—with a view to integrating the xRAN Forum*2 and C-RAN Alliance*3 (**Figure 1**). The xRAN Forum mainly consisted of American enterprises but also included among its members NTT DOCOMO and Japanese, Korean, and European enterprises. Its counterpart, the C-RAN Alliance, mainly consisted of Chinese enterprises. Both organizations were involved in interoperable open interfaces, intelligent control using big data, and virtualization in RAN. In this way, it was thought that the integration of these two organizations would have many benefits.

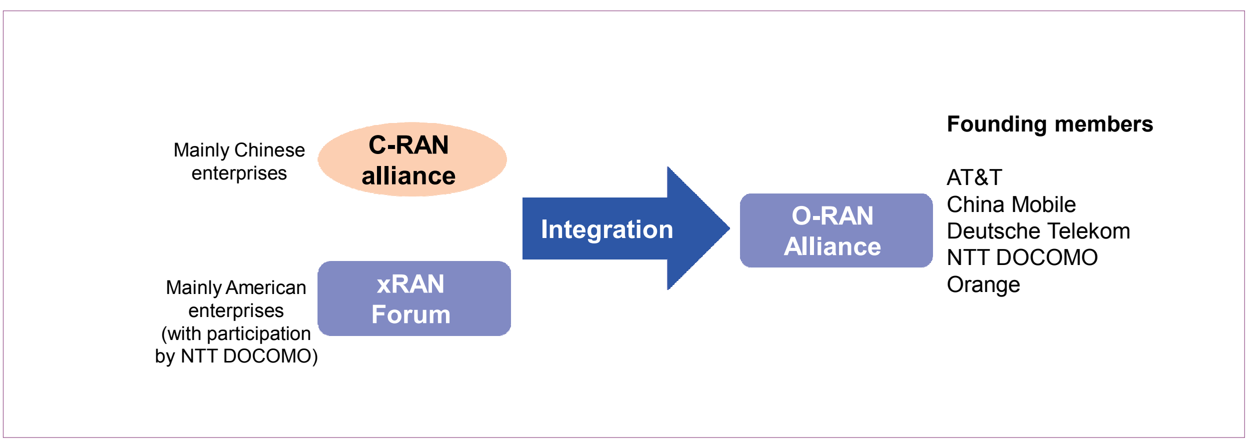


Figure 1　Founding of O-RAN Alliance

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

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

*3　C-RAN Alliance: An industry organization that had been active in promoting C-RAN. It is presently integrated with the O-RAN Alliance.

Following its founding, the first O-RAN board meeting was held in June 2018 and the first workgroup meetings in September 2019. As of March 2019, the O-RAN Alliance has come to consist of 19 operator members and 55 contributor members including major vendors and venture firms (**Figure 2**). Activities have begun in earnest.

3. O-RAN Alliance Vision and Reference Architecture

In the face of increasing volumes of mobile traffic, the mobile network and its constituent equipment are required to be more software-based, virtualized, flexible, intelligent and energy efficient. The O-RAN Alliance seeks to achieve these goals by evolving RAN to a higher level of openness and intelligence. Specifically, the O-RAN Alliance specifies reference designs consisting of virtualized network elements using open and standardized interfaces. It also calls for a more intelligent network through real-time information collection at those network elements and the use of machine learning*4 and AI technology. The following describes the O-RAN Alliance vision and reference architecture.

3.1 Vision

1) Open

The O-RAN Alliance sees the need for building open RAN that can combine and use various types of equipment and modules to achieve more cost-effective and flexible function extensibility. By specifying open interfaces, the O-RAN Alliance aims to build a more vibrant ecosystem*5 in which original services can be constructed in a short period of time through component-based function extensions, networks can be customized to meet specific needs and requirements, and networks using multi-vendor equipment can be achieved. The O-RAN Alliance also considers that Open Source Software (OSS) and hardware reference designs can be effective in stimulating and accelerating innovation.

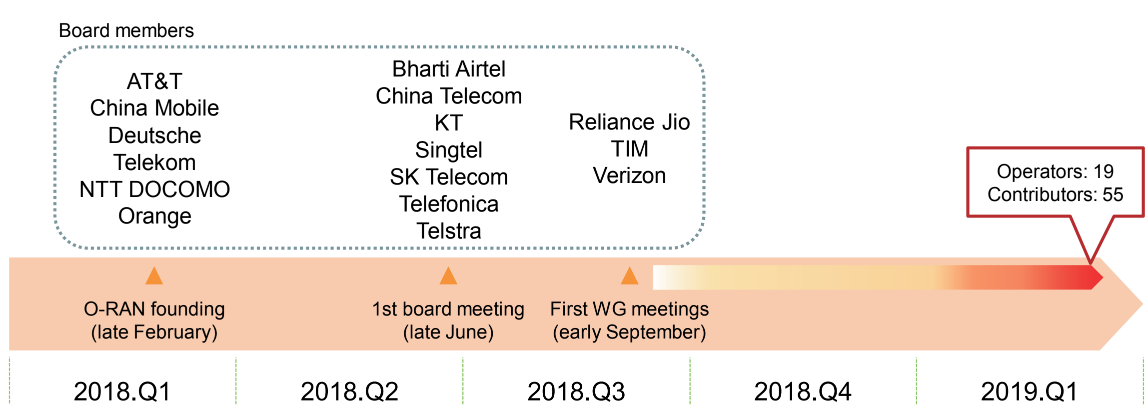


Figure 2　O-RAN Alliance development after founding

*4 **Machine learning:** A framework that enables a computer to learn useful judgment standards through statistical processing from sample data.

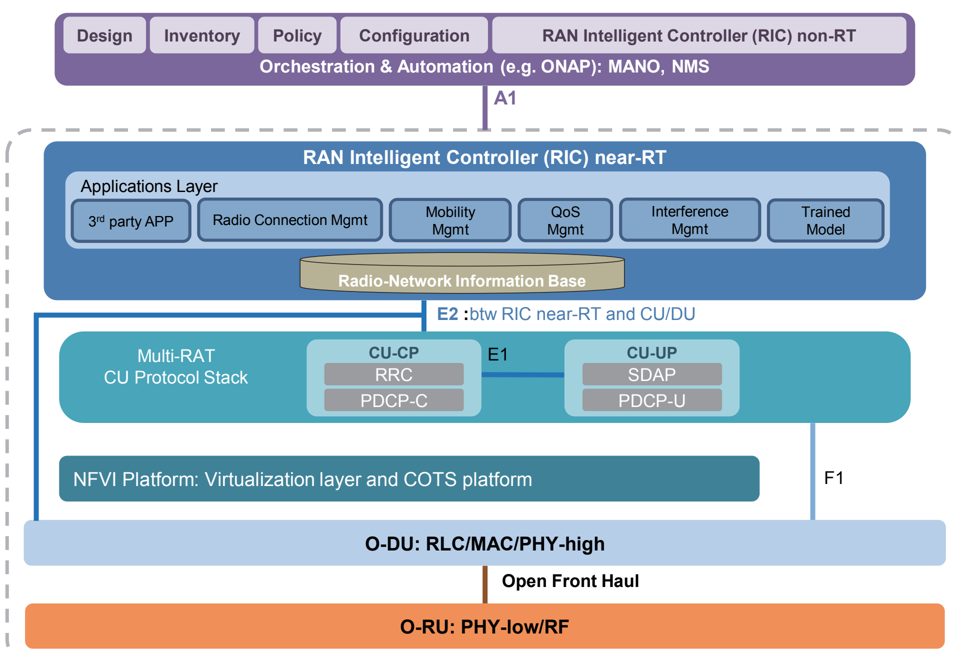
*5 **Ecosystem:** A symbiotic mechanism in which multiple enterprises collaborate in business activities making the most of each other's technologies and assets as part of a flow ranging from research and development to sales, advertising, and consumption encompassing even consumers and society.

2) Intelligent

The O-RAN Alliance expects that the network of the 5G era will become increasingly complex in order to support all kinds of applications, which should make it increasingly difficult to manage operations and achieve network optimization by traditional labor-intensive means. To solve this problem, autonomous and automatic network operations using machine learning are essential, and to this end, the O-RAN Alliance aims to leverage rapidly evolving deep learning*6 to make RAN intelligent and optimize the entire network. In addition, AI-optimized automation in combination with O-RAN open interfaces is expected to open up a new era in network operations.

3.2 Reference Architecture

On commencing activities, the O-RAN Alliance created reference architecture as a foundation for all future activities. The O-RAN Reference Architecture is shown in **Figure 3**. The following summarizes the components of this architecture.



Source: O-RAN Alliance

CP: Control Plane
MAC: Media Access Control
MANO: Management and Orchestration
NFVI: Network Functions Virtualisation Infrastructure
ONAP: Open Network Automation Platform
PDCP: Packet Data Convergence Protocol
PHY: PHYsical layer
RAT: Radio Access Technology
RF: Radio Frequency
RLC: Radio Link Control
RRC: Radio Resource Control
SDAP: Service Data Adaptation Protocol
UP: User Data Plane

Figure 3　O-RAN Alliance reference architecture

*6　**Deep learning**: Machine learning using a neural network with a many-layer structure.

1) RAN Intelligent Controller (RIC)*7 non-Real Time (non-RT RIC)

The O-RAN Alliance defines the controller for the intelligent RAN as the RIC and divides it into non-RT (> 1s) and near-RT (< 1s) layers. The non-RT RIC performs policy management, RAN analytics, and AI-based function management. Here, the A1 interface is defined between the network management platform governing orchestration and automation including non-RT RIC and evolved NodeB (eNB)*8/gNB*9 including near-RT RIC.

2) RIC near-Real Time (near-RT RIC)

The near-RT RIC layer provides Radio Resource Management (RRM)*10 functions with embedded intelligence. In addition to legacy RRM functions such as load balancing*11 per unit of User Equipment (UE) and Resource Block (RB)*12 management, this layer will provide new functions such as Quality of Service (QoS)*13 management and seamless handover*14 control. As for interfaces, the A1 interface described above is defined between this layer and the non-RT RIC layer while the E2 interface is defined between this layer and the Central Unit (CU)*15/ O-RAN Distributed Unit (O-DU)*16.

3) Multi-RAT CU Protocol Stack

This function layer supports various protocol stacks including 4G and 5G multiple radio access. It supports virtualization and consists of functions that execute commands issued by the non-RT RIC. It also supports F1/W1/E1/X2/Xn interfaces specified by 3GPP.

4) O-DU and O-RAN Radio Unit (O-RU)*17

The O-DU and O-RU functions consist of real-time Layer 2 (L2)*18 functions and a function group performing baseband signal*19 processing and radio signal processing. Open fronthaul*20 interfaces are newly specified between O-DU and O-RU.

4. Focus Areas of O-RAN Alliance Workgroups

The O-RAN Alliance conducts technical studies to fulfill its vision in a total of eight Work Groups (WGs) each having a different focus area. The Technical Steering Committee (TSC) oversees the work of these WGs (**Table 1**).

These eight WGs can be broadly divided into WG1 for studying use cases and overall architecture, WG2 and WG3 for optimizing and automating (making intelligent) RAN RRM, WG4 and WG5 for achieving interoperability (open interfaces) between RAN equipment supplied by different vendors, and WG6, WG7, and WG8 for commoditizing (virtualizing and modularizing) the RAN software and hardware platform.

Each WG adopts a co-chair format consisting of three or four chairpersons selected from two operators and one or two vendors. NTT DOCOMO is serving as a co-chair of WG4 and WG5 focused on open interfaces. The following introduces the activities of these two WGs.

1) WG4 (Open Fronthaul Interfaces WG)

In C-RAN, a baseband processor is placed in an aggregating node and connected to multiple distributed nodes each with radio equipment*21 via fronthaul interfaces. Thanks to its performance and cost benefits, this configuration has been introduced in networks in many countries from the beginning of the LTE era and has similarly been adopted by NTT DOCOMO in its LTE network [2]. On the

*7 RIC: The controller that makes the RAN intelligent.
*8 eNB: A radio base station for LTE radio access.
*9 gNB: A radio base station for NR radio access.
*10 RRM: A generic term applied to control functions for appropriately managing limited radio resources, making smooth connections between terminals and base stations, etc.
*11 Load balancing: The process of distributing load between frequencies or cells.
*12 RB: A unit of frequency to be allocated when scheduling radio resources.
*13 QoS: A level of quality on the network that can be set for each service. Controlling the bandwidth available to a service controls the amount of delay or packet loss in that service.
*14 Handover: The technique of switching from one cell to another without interrupting communication when a terminal moves between base stations.

Table 1 O-RAN Alliance technical workgroups

Technical WG		Focus area
TSC		Overall management
WG1	Use Cases and Overall Architecture	Use cases and overall architecture
WG2	Non-real-time RIC and A1 Interface	Non-Real-Time RAN Intelligent Controller (non-RT RIC) that supports optimization of radio higher-layer procedures in RAN and RAN policies from a management platform consisting of MANO, NMS, etc. supporting orchestration and automation, and the A1 interface between non-RT RIC and RAN
WG3	Near-real-time RIC and E2 Interface	Near-Real-Time RAN Intelligent Controller (near-RT RIC) that supports optimization of radio connection management, mobility management, QoS management, interference management, etc. making use of big data and machine learning, and the E2 interface between near-RT RIC and various RAN components
WG4*	Open Fronthaul Interface	Open fronthaul interfaces achieving interoperability between the baseband processor and radio equipment supplied by different vendors
WG5*	Open F1/W1/E1/X2/Xn Interface	Open interfaces achieving interoperability between different vendors, targeting in particular 3GPP-specified interfaces (F1, W1, E1, X2, Xn) between network equipment
WG6	Cloudification and Orchestration	Reference designs that enable the decoupling of RAN software from hardware platforms (virtualization) and the use of commodity hardware platforms
WG7	White-box Hardware	Hardware platform that combines commodity components and a reference design that enables that platform
WG8	Open Source	Provision of RAN software in open source form

*NTT DOCOMO co-chair

other hand, the Common Public Radio Interface (CPRI)*22 specifications widely used by commercial C-RAN in LTE is seen as insufficient in terms of specifying standards for fronthaul interfaces. This has resulted in many parts having original specifications by different vendors so that, on a global basis, it has only been possible to connect between a baseband processor and radio equipment from the same vendor [3].

To solve this problem, WG4 is releasing O-RAN fronthaul specifications [4] to enable interoperability and promoting multivendor interoperability using that interface. In actuality, the O-RAN fronthaul specifications inherited the xRAN fronthaul specifications created and released by the xRAN Forum prior to its integration in the O-RAN Alliance. NTT DOCOMO has made major contributions to the formulation of these fronthaul specifications based on its own experience in achieving multivendor interoperability via the fronthaul in collaboration with vendor partners in the LTE network.

2) WG5 (Open 3GPP Interface WG)

WG5 promotes activities with the aim of achieving multivendor interoperability and improving

*15 CU: An aggregating node equipped with non-real-time L2 functions and RRC functions, etc. of the radio base station.

*16 O-DU: A functional section performing real-time L2 functions, etc. of the radio base station.

*17 O-RU: The radio equipment of a radio base station specified in O-RAN.

*18 L2: The second layer of the OSI reference model (data link layer).

*19 Baseband signal: The digital signal before conversion to radio frequencies.

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

*21 Radio equipment: The equipment that connects with the baseband processor via the fronthaul.

performance targeting network equipment interfaces specified by 3GPP (F1 and E1 equipment interfaces within base stations (see Fig. 3), X2 interface between eNB and gNB, Xn interface between gNBs, etc.). These interfaces have been designed with a relatively high degree of freedom to cover every conceivable operation scenario and equipment implementation to the degree possible. This has enabled operators and vendors to achieve their original operations and implementations while resulting in degradation of connectivity and other performance issues (for example, temporary data interruptions and degraded user throughput) in multivendor deployment.

An example of such a problem in multivendor operation is shown in **Figure 4**. First, Fig. 4 (a) shows the case in which vendor-A and vendor-B implement a 3GPP interface with different interpretations of parameter (X) of the interface. As a result, the equipment behaves differently between vendors A and B, which can raise concerns that a problem may occur causing degradation of connectivity and other performance issues. Fig. 4 (b), on the other hand, shows the case in which vendors A and B implement parameter X with the same interpretation. In this case, both units of equipment perform the same operation with respect to this parameter thereby enabling connectivity and performance to be maintained even in a multivendor scenario.

In this way, WG5 is working to clarify the interpretation of parameters specified by 3GPP and the expected behavior of equipment with the aim of achieving a multivendor environment with any combination of vendor equipment.

5. Conclusion

This article explained the background to the founding of the O-RAN Alliance, its vision and reference architecture, and the focus areas of each workgroup. The O-RAN Alliance is drawing much interest and expectation and currently includes

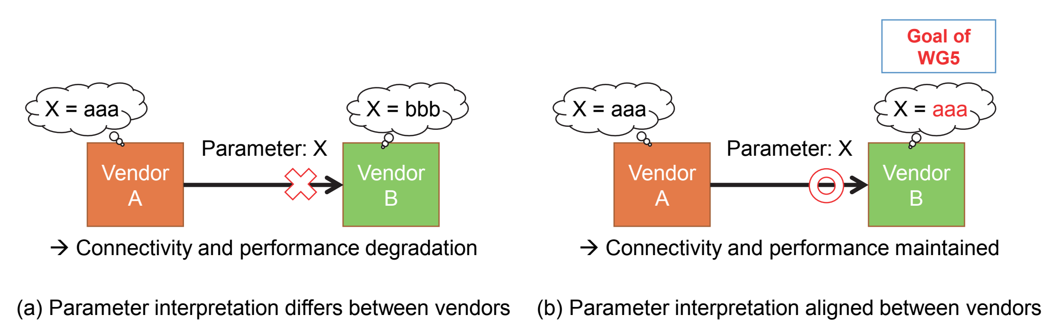


Figure 4 Problem in multivendor operation

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

many global operators and vendors as members. The O-RAN Alliance vision of "achieving open and intelligent RAN" reflects a commitment to developing radio access networks in the 5G era and expanding the ecosystem. Going forward, NTT DOCOMO will continue to promote and participate in O-RAN activities as part of this vision.

REFERENCES

[1] S. Nagata et al.: "Technical Overview of the 3GPP Release 15 Standard," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.37–48, Jan. 2019.

[2] S. Abeta et al.: "LTE-Advanced as Further Evolution of LTE for Smart Life," NTT DOCOMO Technical Journal, Vol.17, No.2, pp.4–9, Oct. 2015.

[3] A. Umesh et al.: "5G Radio Access Network Standardization Trends," NTT DOCOMO Technical Journal, Vol.19, No.3, pp.36–47, Jan. 2018.

[4] A. Umesh et al.: "Overview of O-RAN Fronthaul Specifications," NTT DOCOMO Technical Journal, Vol.21, No.1, pp.46–59, Jul. 2019.

Standardization

RAN Fronthaul Open

Special Articles on Standardization Trends toward Open and Intelligent Radio Access Networks

Overview of O-RAN Fronthaul Specifications

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Standard specifications for fronthaul interfaces with a view to the next-generation radio access network were released by the xRAN Forum in April 2018. Then, with the integration of the xRAN Forum into the O-RAN Alliance in March 2019, these specifications continued on as O-RAN fronthaul specifications. This article describes the O-RAN fronthaul specifications that are expected to be the first standard to enable interoperability between different vendors.

1. Introduction

As architecture already adopted by operators in many countries for their Radio Access Network (RAN)*1, Centralized RAN (C-RAN)*2 connects a baseband processing section in centralized base station equipment to multiple units of radio equipment via fronthaul*3 (**Figure 1**). In C-RAN, a centralized control section provides performance benefits through inter-cell and inter-frequency coordination while the centralized installation of equipment provides cost benefits through resource pooling and reduced installation space [1].

On the other hand, the Common Public Radio Interface (CPRI)*4 specifications that have come to be used in conventional C-RAN do not sufficiently

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

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

*3 Fronthaul: Circuit between the baseband processing section in base station equipment and radio equipment using optical fiber.

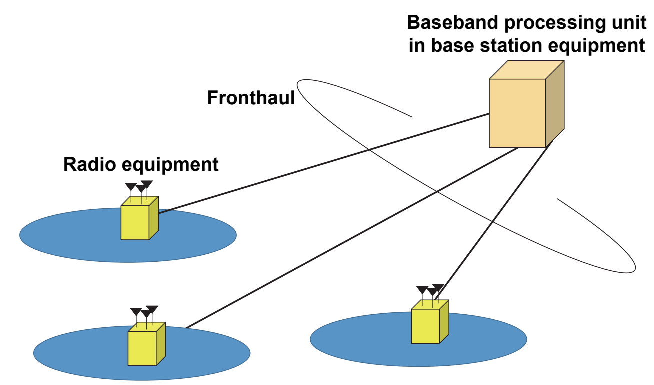


Figure 1 C-RAN overview

prescribe specifications for fronthaul interfaces, and as a result, there are now many regions having original specifications prescribed by different vendors. This state of affairs has made it difficult to achieve interoperability between baseband processing equipment and radio equipment from different vendors (hereinafter referred to as "multivendor RAN"). It has also been pointed out from many quarters that wider frequency bandwidths in the 5G era and higher antenna counts due to Massive Multiple Input Multiple Output (Massive MIMO)*5 schemes are increasing the required fronthaul transmission bandwidth and making it excessively large [2].

The Open RAN (O-RAN) fronthaul specifications were formulated against this background and are expected to help make multivendor RAN a reality in the 5G era.

Furthermore, in the face of this bandwidth problem, O-RAN fronthaul specifications include a new provision for functional splitting called Split Option 7-2x that places in radio equipment some Layer 1*6 functions traditionally located in the baseband processing section. They also prescribe Control, User and Synchronization Plane (C/U/S-Plane)*7 specifications that, while conforming to the eCPRI*8 framework, prescribe detailed signal formats and equipment operation required for multivendor RAN not prescribed in eCPRI specifications, and Management Plane (M-Plane)*9 specifications as well. These O-RAN fronthaul specifications support both New Radio (NR) and LTE as Radio Access Technology (RAT)*10. In this article, we first introduce Split Option 7-2x and then describe C/U/S-Plane and M-Plane specifications.

2. Split Option 7-2x

Split Option 7-2x is a specification for functional splitting between O-RAN Distributed Unit (O-DU) and O-RAN Radio Unit (O-RU) adopted by O-RAN

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

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

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

*7 **C/U/S-Plane:** The C-Plane and U-Plane are protocols for transferring control signals and user data, respectively. The S-Plane is protocol for achieving synchronization between multiple units of equipment.

*8 **eCPRI:** Internal interface specification for radio base stations prescribed by CPRI, an industry association.

*9 **M-Plane:** The management plane handling maintenance and monitoring signals.

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

fronthaul specifications. An overview of Split Option 7-2x is shown in **Figure 2**.

In the downlink (DL) process flow, the user bit sequence received from the Medium Access Control (MAC) layer*11 undergoes encoding and scrambling*12, modulation and layer mapping, and precoding*13 and resource element mapping*14 resulting in an IQ sampling sequence*15 of an Orthogonal Frequency Division Multiplexing (OFDM)*16 signal in the frequency domain*17. This sequence is then subjected to Inverse Fast Fourier Transform (IFFT)*18 processing, converted to an OFDM signal in the time domain*19, and finally converted to an analog signal. In this flow, Beam Forming (BF)*20 is performed before IFFT processing in the case of digital BF and after analog-signal conversion in the case of analog BF.

In the DL, Split Option 7-2x implements functions up to resource element mapping in the O-DU and supports both an O-RU that implements digital BF and later functions (Category A O-RU) and an O-RU that implements the above in combination with precoding (Category B O-RU). Here, Category A O-RU, which is easy to deploy, is expected to be the O-RU implementation of choice in 5G initial deployment. On the fronthaul an IQ sampling sequence of the OFDM signal in the frequency domain for each MIMO spatial stream (Category A O-RU) or each MIMO layer (Category B O-RU) will be transmitted. There is no need to transmit

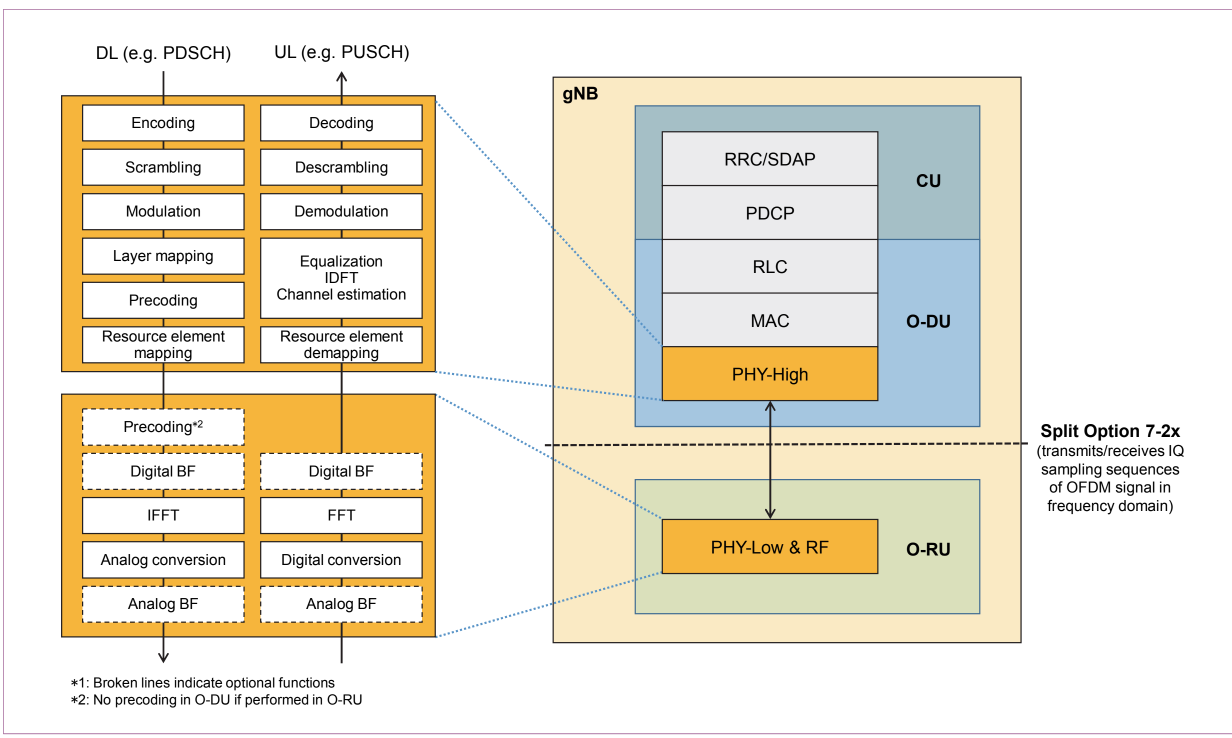


Figure 2 Split Option 7-2x adopted in O-RAN fronthaul specifications

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

*12 Scrambling: Masking of a data block to be transmitted using a specific bit sequence determined by the user or cell identifier.

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

*14 Resource element mapping: The mapping of an IQ sampling sequence to time/frequency resources in LTE, LTE-Advanced, and NR.

*15 IQ sampling sequence: A sampling sequence consisting of in-phase and quadrature components of a complex digital signal.

*16 OFDM: A digital modulation method where information is divided into multiple orthogonal carrier waves and sent in parallel making for high spectral efficiency in transmission.

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

on the fronthaul an IQ sampling sequence for a frequency resource transmitting no signals on the DL wireless interface.

Next, in the UpLink (UL) process flow, the OFDM signal in the time domain received at the O-RU and converted to a digital signal is subjected to FFT processing resulting in an IQ sampling sequence of the OFDM signal in the frequency domain. Then, after resource element demapping*21, the process flow continues with equalizing processing, Inverse Discrete Fourier Transform (IDFT)*22 processing, and channel estimation, and after demodulation, descrambling*23, and decoding, the process sends a user bit sequence*24 to the MAC layer. In this flow, BF is performed after FFT processing in the case of digital BF and before digital-signal conversion in the case of analog BF.

In the UL, Split Option 7-2x implements resource element mapping and higher functions in the O-DU and digital BF and lower functions in the O-RU. The fronthaul transmits an IQ sampling sequence of the OFDM signal in the frequency domain for each MIMO spatial stream. There is no need to transmit on the fronthaul an IQ sampling sequence for a frequency resource transmitting no signals on the UL wireless interface.

As shown in **Figure 3**, tradeoffs exist in the way that functional splitting is performed between the

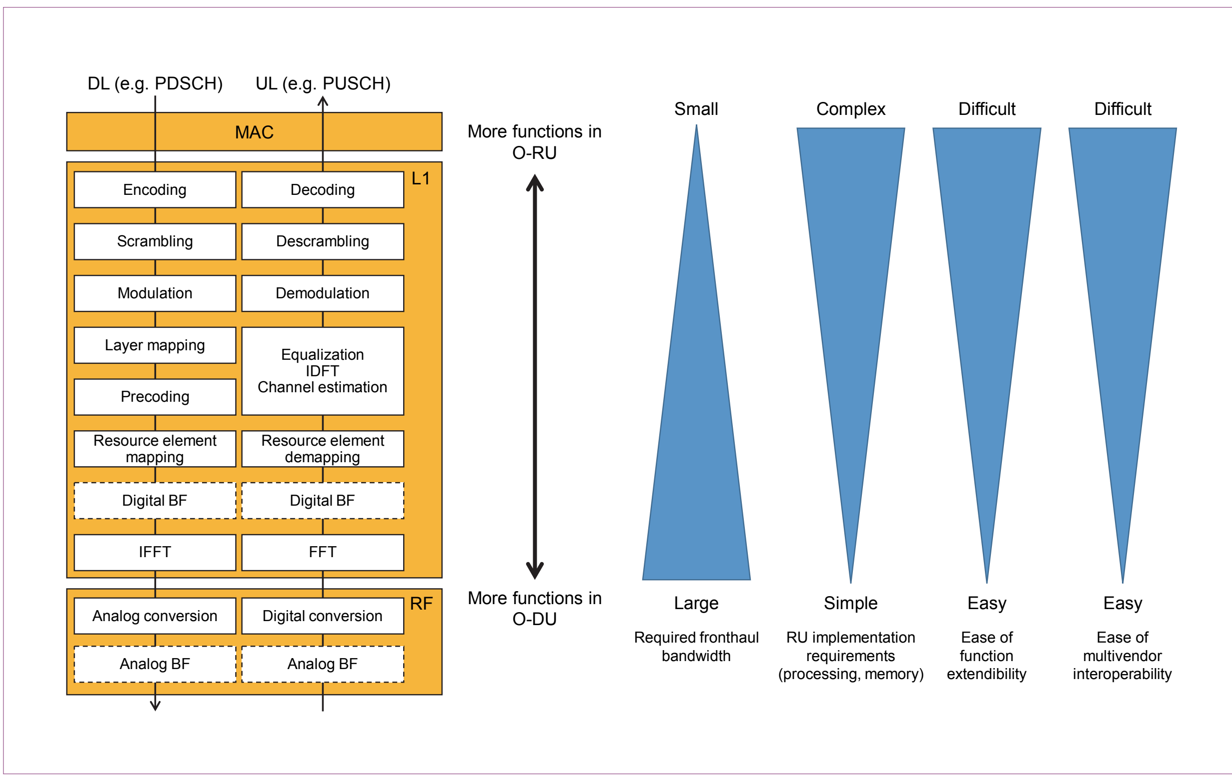


Figure 3 Tradeoffs in O-DU and O-RU functional splitting

*18 **IFFT:** A method for efficiently computing the time signal series corresponding to input frequency components (discrete data).

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

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

*21 **Resource element demapping:** A process for extracting an IQ signal sequence from an IQ signal mapped to time/frequency resources in LTE, LTE-Advanced, and NR.

*22 **IDFT:** An inverse discrete Fourier transform used to convert discrete data in the frequency domain to discrete data in the time domain.

*23 **Descrambling:** Unmasking of a received data block using a specific bit sequence determined by the user or cell identifier.

O-DU and O-RU. In general, the required fronthaul bandwidth becomes smaller as more functions become entrusted to the O-RU. For example, compared to CPRI in which the O-RU handles only the RF function section, placing IFFT/FFT processing in the O-RU can prevent an increase in the fronthaul required bandwidth caused by oversampling applied to the OFDM signal in the time domain. Similarly, placing DL precoding in the O-RU can prevent an increase in the required fronthaul bandwidth that occurs when the number of MIMO spatial streams is greater than the number of MIMO layers.

Furthermore, when the O-RU handles all Layer 1 functions, the required fronthaul bandwidth is essentially comparable to the baseband*25 bit rate. On the other hand, in that case, the amount of processing and memory required of dispersed O-RUs increases. Additionally, when making function modifications and extensions, it is often the case that not just the O-DU but the O-RU too must be upgraded.

Moreover, when performing resource element mapping/demapping on the O-DU side, data will be transmitted after user multiplexing thereby simplifying control signals on the fronthaul and making it easier to achieve multivendor RAN. Split Option 7-2x was adopted taking these tradeoffs into consideration.

3. Overview of Fronthaul Interfaces

3.1 Protocol Stacks

The protocol stack*26 of each plane in O-RAN fronthaul specifications are shown in **Figure 4**.

In the C/U-Plane, the O-RAN fronthaul specifications support a protocol stack that transmits signals used by eCPRI or Radio over Ethernet (RoE)*27 directly over Ethernet and an optional protocol stack that transmits the signals over User Datagram

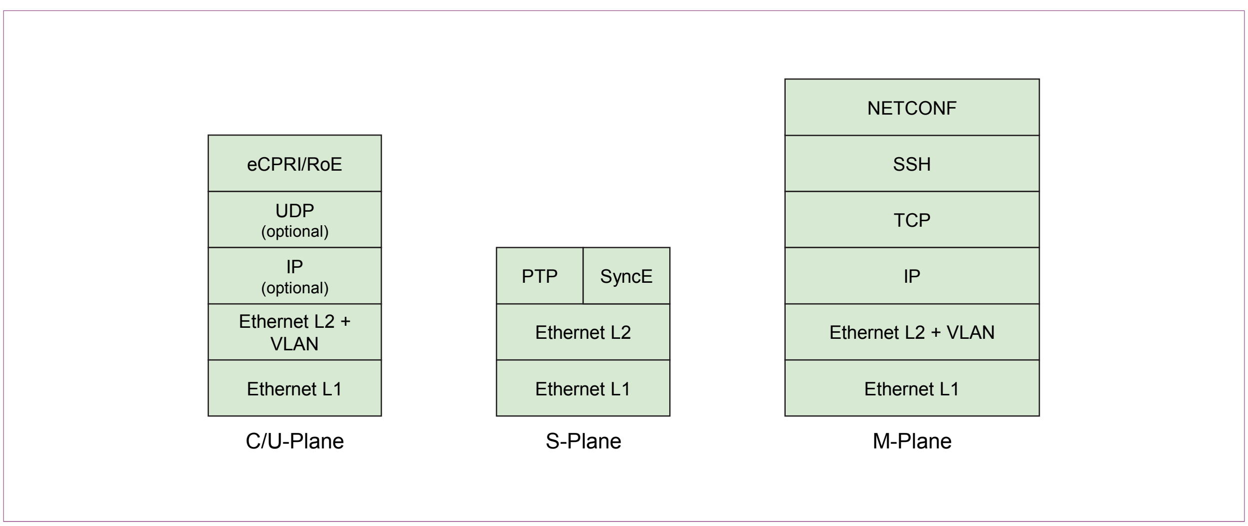


Figure 4 Protocol stack of each plane

*24 User bit sequence: The baseband bit sequence of user data.
*25 Baseband: The units or functional blocks that perform digital signal processing.
*26 Protocol stack: Protocol hierarchy.
*27 RoE: Internal interface specifications of a radio base station prescribed by IEEE.

Protocol (UDP)[*28]/IP.

In the S-Plane, meanwhile, the O-RAN fronthaul specifications support a protocol stack that transmits signals used in Precision Time Protocol (PTP)[*29] and SyncE[*30] over Ethernet.

Finally, in the M-Plane, the O-RAN fronthaul specifications support a protocol stack that transmits signals used in NETwork CONFiguration protocol (NETCONF) over Ethernet/IP/Transmission Control Protocol (TCP)[*31]/Secure SHell (SSH)[*32].

NETCONF, which was formulated as RFC6241 in the Internet Engineering Task Force (IETF)[*33], is a general-purpose protocol for managing network devices. The O-RAN fronthaul specifications are mainly concerned with the data model portion of NETCONF that is targeted by operations and treated as a matter of implementation.

3.2 C/U-Plane

1) U-Plane

The frame format for a U-Plane message is shown in **Figure 5**. The eCPRI header contains information such as message type (ecpriMessage), eCPRI payload[*34] size (ecpriPayload), message source and destination identifiers (ecpriPcid), and message sequence number (ecpriSeqid). The O-RAN fronthaul specifications prescribe an extended Antenna-Carrier (eAxC) as message source and destination identifiers.

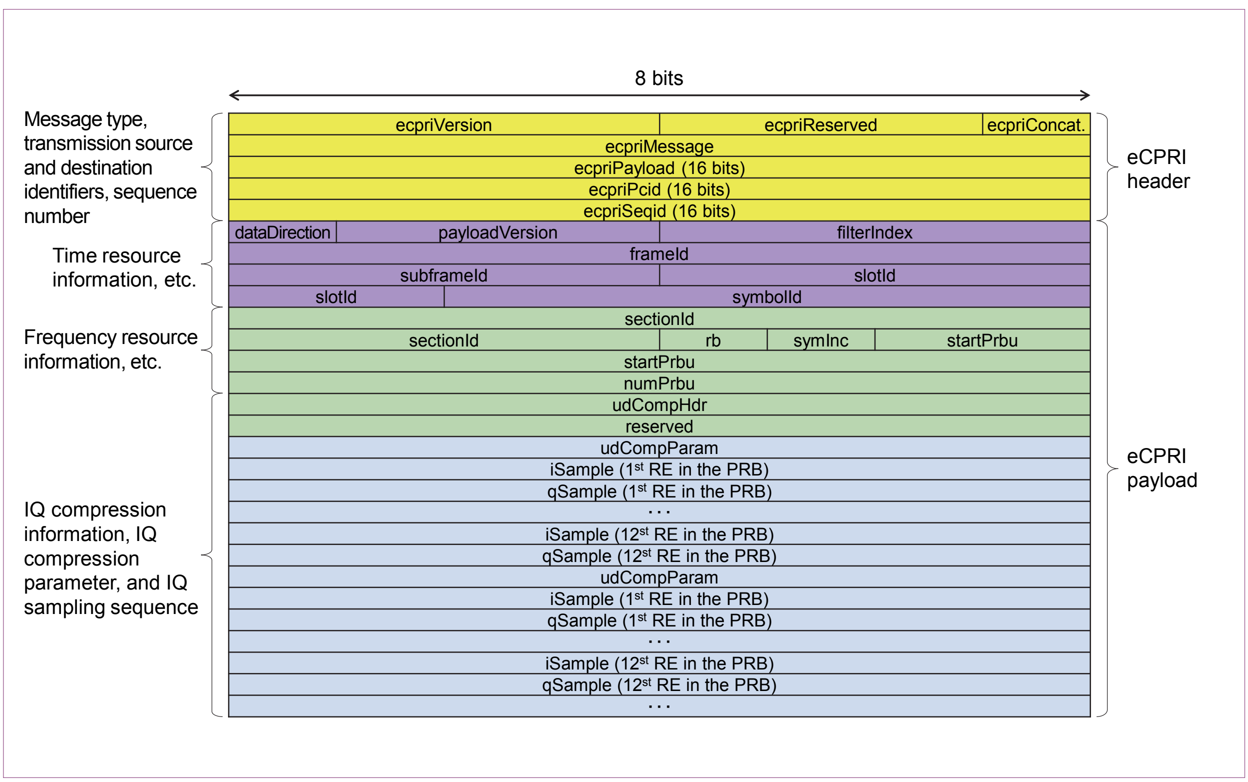


Figure 5 U-Plane message frame format

*28 UDP: A protocol on the transport layer featuring light processing by virtue of performing no delivery confirmation, congestion control, etc. It is used in communications for which a loss of data during transmission does not present a major problem.

*29 PTP: A protocol for achieving high-accuracy time synchronization among equipment connected to a network.

*30 SyncE: A system for transmitting clock signals on the Ethernet.

*31 TCP: A standard Internet upper-layer protocol above IP. It complements IP by providing functions for confirming the other party in the connection and data arrival, performing flow control, and detecting data duplication or loss to achieve highly reliable communication.

*32 SSH: A protocol for achieving secure remote login and providing network services.

*33 IETF: A standardization organization that develops and promotes standards for Internet technology. The technology specifications formulated here are published as Request For Comment documents (RFCs).

As shown in **Figure 6**, this eAxC consists of an O-DU port IDentifier (DU_Port_ID), Band Sector IDentifier (BandSector_ID), Component Carrier (CC)[*35] IDentifier (CC_ID), and O-RU port IDentifier (RU_Port_ID). A specific MIMO spatial stream or MIMO layer is identified on the basis of RU_Port_ID.

The eCPRI payload of the U-Plane message can be used to transmit an IQ sample (iSample/qSample) sequence of the OFDM signal in the frequency domain applying IQ compression and IQ compression information (udCompHdr). This information is transmitted together with time/frequency resource information that should be applied to the transmission and reception of the IQ sample sequence on the radio interface. Details of this eCPRI payload information are provided in O-RAN fronthaul specifications but not in eCPRI. Here, time resource information consists of identification information for radio frame[*36], subframe[*37], slot[*38], and OFDM symbol[*39] while frequency resource information consists of the Physical Resource Block (PRB)[*40] start position and number of PRBs (startPRBu, numPRBu). The IQ compression information consists of the applied compression scheme and the number of bits in the IQ sample after compression. Specifically, IQ compression is performed using a common IQ compression parameter (udCompParam) for each PRB (12 IQ samples). For example, when applying block floating point[*41] as the compression scheme, the IQ compression parameter and IQ sample sequence represent an exponent and mantissa, respectively, in floating point form.

In addition, the frame format of the U-Plane message is used in common in both directions, that is, for transmission from the O-DU to O-RU and transmission from the O-RU to O-DU.

2) C-Plane

The frame format for a C-Plane message is shown in **Figure 7**. The eCPRI header in a C-Plane message is the same as that of the U-Plane message. Here, the C-Plane message source and destination identifiers have become ecpriRtcid in contrast to ecpriPcid of the U-Plane message. In O-RAN fronthaul specifications, however, these identifiers are prescribed as an extended Antenna-Carrier (eAxC) the same as in the U-Plane message.

The eCPRI payload of the C-Plane message passed from the O-DU to O-RU consists of information specifying BF weights to be applied when transmitting and receiving IQ sample sequences included in the U-Plane message on the radio interface. It also consists of time resource information (the same

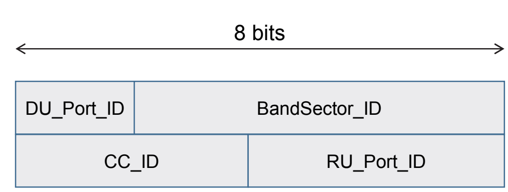


Figure 6　Example of eAxC

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

*35 CC: Term referring to one of several carriers bundled together to achieve CA (see *44).

*36 Radio frame: The smallest unit used for signal processing (encoding, decoding). A single radio frame is composed of multiple slots (or subframes) along the time axis, and each slot is composed of multiple symbols along the time axis.

*37 Subframe: A unit of radio resources in the time domain, consisting of multiple slots.

*38 Slot: A unit for scheduling data consisting of multiple OFDM symbols.

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

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

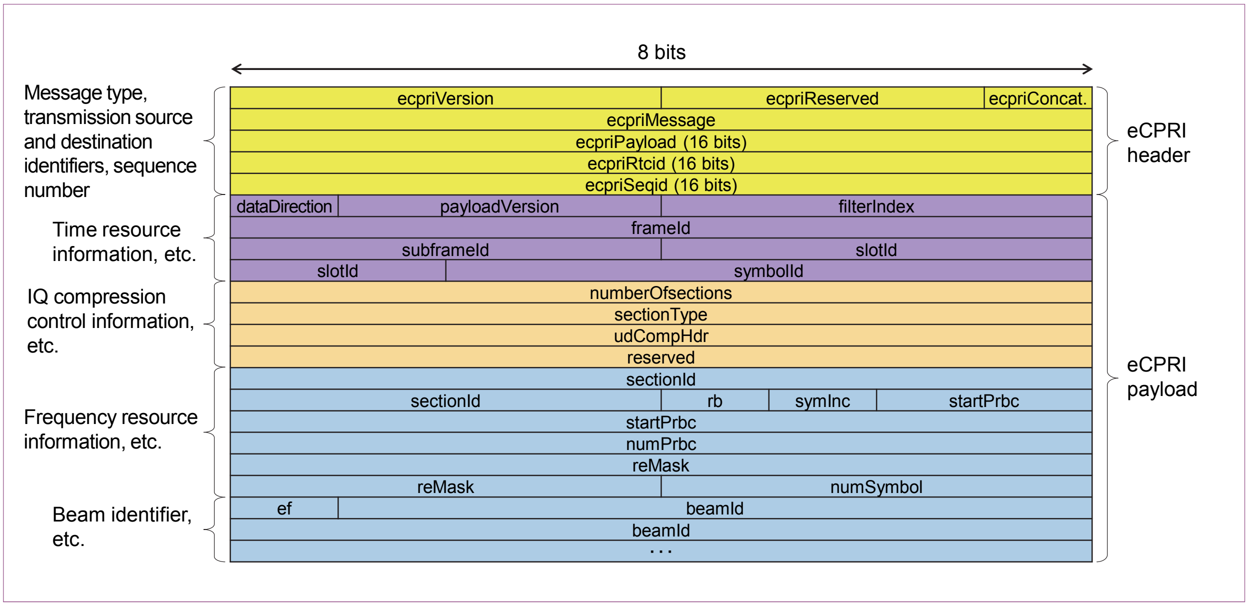


Figure 7　C-Plane message frame format (beam identifier)

as the U-Plane message) and frequency resource information (startPRBc, numPRBc) to which the above BF weights are to be applied. The O-RU uses this information to generate a beam for transmitting and receiving signals on the radio interface. A number of options have been prescribed as information for specifying BF weights, but in O-RAN fronthaul specifications, support for an interface using a beam identifier (beamId) as shown in Fig. 7 is mandated. In addition, this option using a beam identifier can be applied to digital BF, analog BF, or a combination of the two (hybrid BF).

3) Delay Management

Split Option 7-2x, which inserts a functional split between O-DU and O-RU within the physical layer of the radio interface, includes delay management given the need to transmit C/U-Plane messages on the fronthaul in accordance with transmit/receive timing of the radio interface and retransmission timing of the Hybrid Automatic Repeat reQuest (HARQ)[*42] technique. This form of delay management adopts the concept of a receive window and transmit window based on the eCPRI framework.

Delay management for transmission from the O-DU to O-RU is shown in **Figure 8**. On receiving the IQ sample sequence of the OFDM signal in the frequency domain from the fronthaul, the O-RU must complete certain processing (IFFT, analog conversion, BF, etc.) in time for transmitting the signal on the radio interface given specific time resources (radio frame, subframe, slot, OFDM symbol). For this reason, the position of the O-RU receive window is set before transmission timing on the radio interface at an offset corresponding to this O-RU processing delay. The O-DU, meanwhile, must transmit a C/U-Plane message to the fronthaul so

*41　Block floating point: A method used when expressing data in floating point form that calculates each data block with a common exponent instead of calculating each data item with a separate exponent.

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

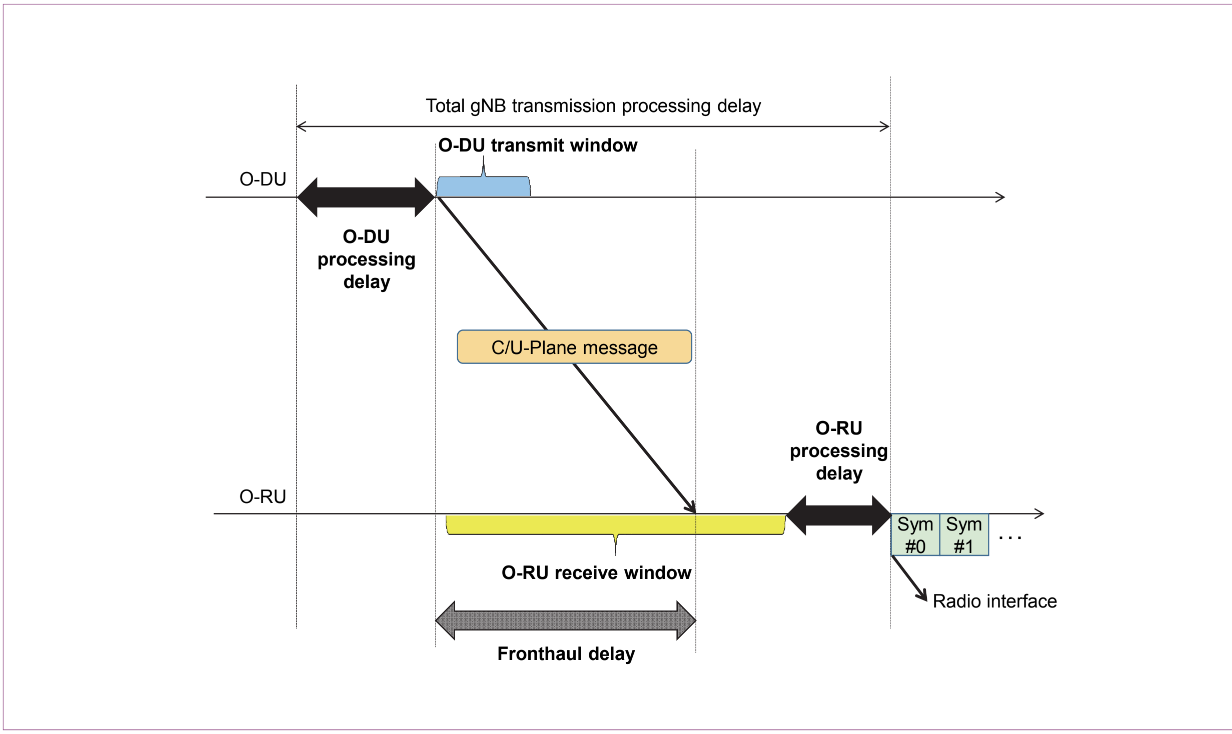


Figure 8 Delay management (transmission from O-DU to O-RU)

that it is delivered within the O-RU receive window. Accordingly, the position of the O-DU transmit window is set before transmission timing to the radio interface at an offset corresponding to O-RU processing delay and fronthaul delay. Here, fronthaul delay includes variable elements such as fronthaul distance and switch processing delay. The size of the O-RU receive window is set to a length that can cover this fluctuation in fronthaul delay and size of the O-DU transmit window. The size of the O-DU transmit window is set taking into account the processing time required for the O-DU to transmit the C/U-Plane message to the fronthaul.

Delay management using the same type of windows is also applied for transmission in the direction from O-RU to O-DU. Additionally, though omitted in Fig. 8, the fronthaul specifications define separate windows for the C-Plane and U-Plane.

3.3 S-Plane

In a C-RAN configuration, highly accurate synchronization between O-DU and O-RUs is required to achieve linking control that assumes inter-O-RU synchronization for Time Division Duplex (TDD)*43, Carrier Aggregation (CA)*44 using multiple O-RUs, MIMO, and other processes. As an S-Plane, O-RAN fronthaul specifications support protocols such as PTP and SyncE to achieve high-accuracy synchronization on the O-RU side by synchronizing with the clock on the high-performance O-DU side.

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

*44 CA: A technology that expands bandwidth and achieves high-speed transmission by performing simultaneous transmission and reception on multiple component carriers.

3.4 M-Plane

The M-Plane provides a variety of O-RU management functions to set parameters on the O-RU side as required by the C/U-Plane and S-Plane described above, to manage O-RU software (SW), perform fault management, etc. In this regard, O-RAN fronthaul specifications prescribe various parameters as data models to achieve the above. This eliminates dependence on each O-RU vendor's implementation and makes multivendor RAN possible.

The functions supported by the M-Plane are listed in **Table 1**.

1) M-Plane Architecture

In the M-Plane, the O-DU and Network Management System (NMS)*45 are specified as network devices managing O-RUs. In NETCONF, moreover, network devices managing O-RUs correspond to NETCONF clients while O-RUs targeted for management correspond to NETCONF servers.

The following two models are supported as M-Plane architecture (**Figure 9**).

(a) Hierarchical model: In this configuration, an O-RU is managed by one or more O-DUs. These O-DUs terminate the monitoring/control of a subordinate O-RU, which makes it unnecessary for NMS to handle the monitoring/control of all O-RUs and helps reduce the NMS processing load. Furthermore, in the event that the existing NMS does not yet support NETCONF, this model has the advantage of enabling network construction without affecting the existing system since O-DU supports NETCONF in this M-Plane.

(b) Hybrid model: In this configuration, an O-RU is managed by one or more NMSs in addition to O-DUs. An advantage of this model is that NMSs can monitor/control other network devices in addition to O-RUs enabling uniform maintenance, monitoring, and control of all equipment.

In either architectural model, management functions can be limited for each NETCONF client managing an O-RU making for flexible operation. For example, operations can be divided into a NETCONF client performing SW management and a NETCONF client performing fault management.

Table 1 Overview of M-Plane functions

Function name	Description
"Start up" installation	M-Plane startup procedure
SW management	O-RU SW management
Configuration management	O-RU parameter set/get
Performance management	Management of O-RU measurement items
Fault management	O-RU fault management
File management	Send/receive data files to/from O-RU

*45 NMS: Generic name for a system or function performing management tasks in a network.

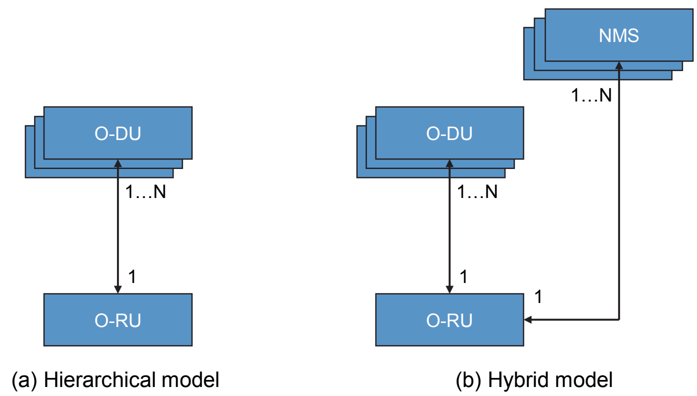


Figure 9 Architecture supporting M-Plane

2) M-Plane Functions

(a) "Start up" installation

"Start up" installation specifies the establishment of M-Plane connections between O-RU and NETCONF clients such as O-DU and NMS. Establishing these connections on the M-Plane requires mutual exchange of Transport Layer address*46 information.

For this function, O-RAN fronthaul specifications prescribe the following three options.

- Manual setting of Transport Layer addresses
- Allocation of Transport Layer addresses by a Dynamic Host Configuration Protocol (DHCP)*47 server
- Allocation of Transport Layer addresses by StateLess Address Auto-Configuration (SLAAC)*48 (when supporting IPv6)

In addition to the option of having maintenance personnel set Transport Layer addresses beforehand, support is also provided for a plug-and-play method of address resolution using a DHCP server, SLAAC, etc.

(b) SW management

An O-DU/NMS NETCONF client performs O-RU SW management via the M-Plane. In multivendor RAN, a NETCONF client of a certain vendor must manage the SW files of an O-RU heavily dependent on another vendor's implementation, so a mechanism of SW management that is independent of O-RU-implementation or vendor is important.

The main SW management procedure is as follows:

(1) SW inventory
(2) SW download
(3) SW installation
(4) SW activation

*46 Transport Layer address: Information such as an IP address required for establishing a connection on the Transport Layer.

*47 DHCP: A protocol used for automatically allocating information (e.g., IP addresses) to computers connected to networks.

*48 SLAAC: In IPv6, a protocol for automatically allocating information (e.g., IPv6 addresses) to computers connected to networks.

To begin with, the NETCONF client must get hold of the O-RU SW package provided by the O-RU vendor. In addition to the SW files needed for actual O-RU operation, this package should include a manifest file indicating which SW files should be installed in each O-RU. Such a manifest file is essential to achieving multivendor RAN.

The operation sequence is shown in **Figure 10**. First, in the SW inventory step, the NETCONF client gets information on what types of files are currently stored on the O-RU. This inventory information is compared with build-name/version and file-name/version information in the manifest file so that the NETCONF client can determine whether a download to the O-RU is necessary, and if so, which files should be designated for download. Depending on the manifest file formats specified in O-RAN fronthaul specifications, it is sufficient for the NETCONF client to compare only build-name/version and file-name/version information—there is no need to compare actual SW files dependent on the O-RU implementation. This enables SW management by NETCONF clients from different vendors. Continuing on, the management process instructs that the required SW files be downloaded to the O-RU and that those files be installed once the download completes. Finally, once installation completes, the process instructs that the SW files to be used at the next boot be activated.

(c) Configuration management

In this function, an O-DU/NMS NETCONF client sets O-RU parameters required on the

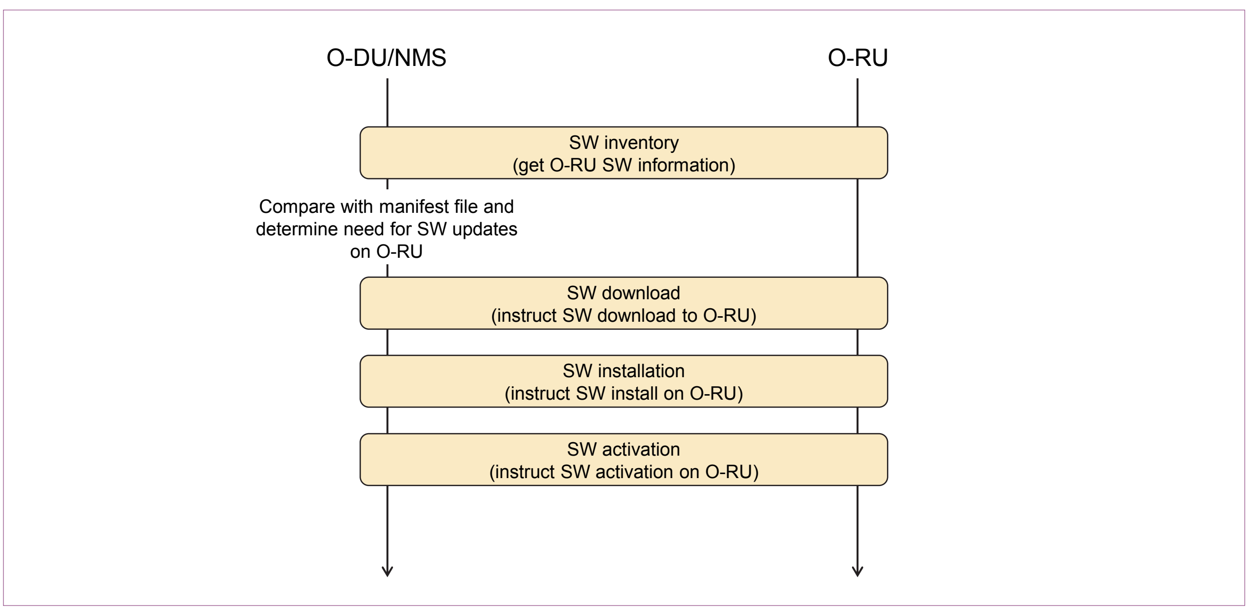


Figure 10　SW management

C/U-Plane and S-Plane and gets equipment status information via the M-Plane. This function is achieved using standard messages specified in NETCONF. The setting of required parameters is specified in the form of YANG modules and achieved in the following way.

In NETCONF, establishing a session*49 is accompanied by an exchange of <hello> messages. Each of these messages contains the NETCONF functions supported by that equipment and information on supported YANG modules. This enables the O-DU/NMS NETCONF client to determine what YANG modules are supported by the O-RU. NETCONF specifies <edit-config> and <get-config> as standard messages for setting parameters and getting parameter values, respectively. Sending these messages to an O-RU makes it possible to set various types of parameters and to get information on the parameters stored on the O-RU and the status of that equipment.

(d) Fault management

An NETCONF client manages O-RU faults via the M-Plane. In this function, the O-RU sends a notification to the O-DU/NMS NETCONF client using <notification> specified as a standard message in NETCONF. In the event of some sort of problem on the O-RU side such as an equipment fault, the O-RU notifies the NETCONF client of the fault together with the following detailed information.

- ID
- Location of fault occurrence
- Locations affected by fault
- Severity of fault
- New fault occurrence or a fault that has already been resolved

3.5 Fronthaul Network Topologies

Taking into account limitations on the number of physical lines between O-DU and O-RU, there may be cases when the fronthaul needs to take on network topologies other than point-to-point (**Figure 11** (a)) such as those using a Layer 2 switch*50. The C/U/S-Plane and M-Plane described above supports such network topologies as shown by the following examples (Fig. 11 (b)).

For example, case (1) in the figure depicts a topology in which the number of fronthaul lines can be different in each interval. This topology can be used to increase the fronthaul transmission capacity without having to increase the capacity per port of the O-DU and O-RU by simply increasing the number of ports each having the standard amount of capacity. In addition, this topology allows for only one line to be used between L2 switches, which can help keep line costs down.

Next, case (2) in the figure depicts a topology that gives redundancy to the fronthaul path between O-DU and O-RU. If either of the paths shown fails, this topology enables services to be continued via equipment using the other path.

Finally, case (3) in the figure depicts a topology that enables many O-RUs to be simultaneously connected by using the switch as a hub even if the number of physical ports on the O-DU should be limited.

*49 Session: A series of communications exchanged between a client and server.

*50 Layer 2 switch: A network device that assesses the MAC address included in a packet and relays that packet accordingly.

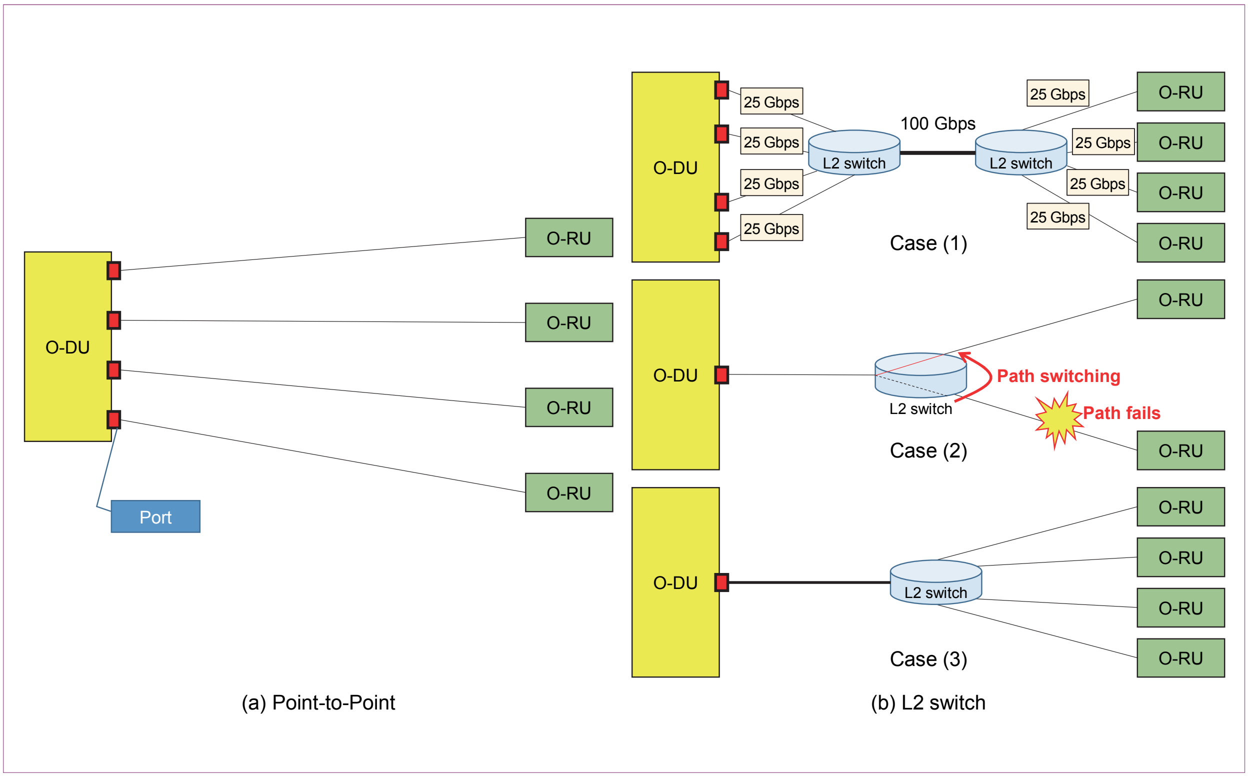


Figure 11　Examples of fronthaul topologies

4. Conclusion

This article introduced Split Option 7-2x adopted in O-RAN fronthaul specifications and described the C/U/S-Plane and M-Plane prescribed in the same specifications. Going forward, the O-RAN Alliance will continue to promote genuine multivendor RAN using O-RAN fronthaul specifications and to make useful extensions to those specifications. For its part, NTT DOCOMO will continue to support the activities of the O-RAN Alliance such as by drafting a multivendor RAN profile (compilation of fronthaul topologies, parameter settings, etc. for achieving interoperability in a multivendor environment).

REFERENCES

[1] S. Abeta et al.: "LTE-Advanced as Further Evolution of LTE for Smart Life," NTT DOCOMO Technical Journal, Vol.17, No.2, pp.4–9, Oct. 2015.
https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol17_2/vol17_2_000en.pdf#page=5

[2] A. Umesh et al.: "5G Radio Access Network Standardization Trends," NTT DOCOMO Technical Journal, Vol.19, No.3, pp.36–47, Jan. 2018.
https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol19_3/vol19_3_005en.pdf

Technology Reports

NR | Radio Wave Visualizer | Channel Sounding

Radio Wave Visualizer for 5G Area Optimization —Real-time Radio Wave Visualizer for 3GPP—

5G Laboratories Minoru Inomata Tetsuro Imai

The wavelengths of the high-frequency bands being considered for use with 5G are much shorter than those used previously, and these bands are much more affected by people, vehicles, and other objects in the vicinity of terminals such as mobile phones. NTT DOCOMO has developed equipment that uses a head-mounted display to provide a visualization of fluctuations in the state of arriving signals due to such effects. The equipment provides a 360° real-time visualization of signals from a 3GPP compliant base station, and can be used to facilitate efficient positioning of base stations, orientation of antennas, and optimization of cell areas.

1. Introduction

The 3rd Generation Partnership Project (3GPP)*1 has created the New Radio (NR) specification [1] that will enable the requirements for 5th Generation mobile communication systems (5G) to be realized, and mobile telephone operators around the world are now working hard to introduce 5G services.

With 5G, high-frequency bands of 6 GHz and higher are expected to be used to secure wider bandwidth and realize the high speed and capacity of enhanced Mobile BroadBand (eMBB) [2]–[4]. Other technologies are also being studied to implement Ultra-Reliable and Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC), which will accommodate large numbers of Internet of Things (IoT) terminals.

As part of this work, radio propagation characteristics*2 in various user environments need to be understood so that NR areas can be optimized, and the new high-frequency bands have extremely short

*1 3GPP: An organization that creates standards for mobile communications systems.

*2 Radio propagation characteristics: Refers to characteristics such as propagation losses, power and delay profiles, and angular profiles.

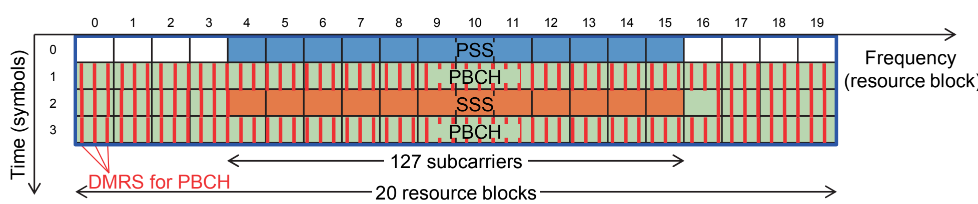
wavelengths and are affected by objects such as people and buildings surrounding mobile phones and other terminals. This can cause fading in the signals arriving from base stations. To make it easier to understand such fluctuations, NTT DOCOMO developed a real-time radio wave visualizer that could show the state of radio waves arriving from directions spanning 360°, which was partially completed in May 2018 [5]. Although this equipment was designed to support 360° visualization of signals, expanded from the initial range of 180°, it also needs to support the visualization of NR signals in order to receive signals from NR-conforming base stations. Therefore, the required visualization has not yet been achieved.

Then, in November of that year, NTT DOCOMO used a new NR-signal channel sounding*3 function to develop its 3GPP real-time radio wave visualizer, to visualize radio waves from NR conforming base stations in real time. By using Augmented Reality (AR)*4 technology, this equipment can visualize the arrival state of radio waves as they fluctuate from one minute to the next, and can be used to facilitate installation and configuration of base stations, and optimization of cell areas.

This article describes the system architecture of the equipment, along with an implementation example.

2. Channels for Radio Wave Visualization

This equipment uses the NR SS/PBCH Block (SSB)*5 to recognize signals from each base station and visualize them. The SSB structure is shown in **Figure 1**. NR uses Orthogonal Frequency Division Multiplexing (OFDM)*6, and this consists of Synchronization Signals (SS)*7: a Primary SS (PSS)*8



SSB subcarrier interval	SSB transmission bandwidth
15 kHz	3.6 MHz
30 kHz	7.2 MHz
120 kHz	28.8 MHz
240 kHz	57.6 MHz

Figure 1　SSB structure

*3　**Channel sounding:** Measurement of propagation channel characteristics such as path losses, delay profile, and angular profile.

*4　**AR:** A technology that superposes digital information on video of the real world such that it actually appears to be part of the scene to the user.

*5　**SSB:** Component including SS (see *7) and Physical Broadcast CHannel (PBCH), which is transmitted periodically. Terminals receive it for not only detecting cell ID and reception timing but also performing measurement of the cell quality.

*6　**OFDM:** A multi-carrier modulation format where information signals are modulated with orthogonal subcarriers.

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

and a Secondary SS (SSS)*9; a Physical Broadcast CHannel (PBCH), and the DeModulation Reference Signals for the PBCH (DMRS for PBCH)*10. Also, NR is composed of slots*11, subframes*12, and frames*13 made up of multiple OFDM symbols*14. Slots are composed of 14 OFDM symbols, regardless of the subcarrier*15 interval, frames are composed of 10 subframes, and the frame length is 10 ms. In this case, the timing of SSB transmission is in half of a frame, with length of 5 ms. **Figure 2** shows an example of SSB transmission structure when transmitting 64 SSBs with SSB transmission period of 20 ms and subcarrier interval of 120 kHz. As the figure shows, when transmitting SSBs, multiple SSBs are transmitted, each in different beams.

3. System Architecture for Visualizing Radio Waves

3.1 System Architecture

An example system architecture for this equipment is shown in **Figure 3**. The equipment uses a 360° camera, a multi-element array antenna*16, a channel sounder, and a PC to visualize signals arriving from base stations in real time. Signals emitted from base stations are received by the multi-element array antenna, channel estimation*17 is performed, and then the channel sounder analyzes the

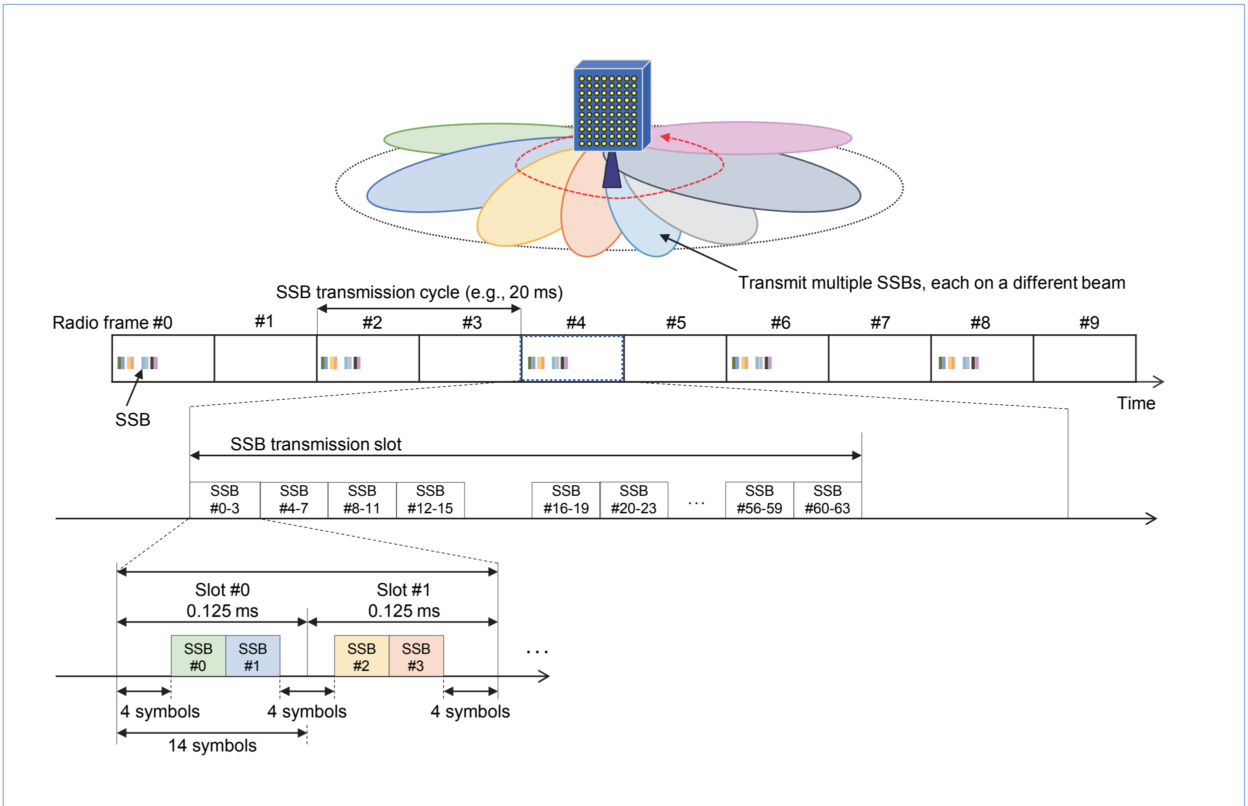


Figure 2 Example of an SSB transmission structure

*8 PSS: A known signal that the user equipment first searches for in the cell search procedure.

*9 SSS: A known signal transmitted to enable detection of the physical cell ID in the cell search procedure.

*10 DMRS for PBCH: A known signal transmitted to measure the state of a radio channel for PBCH demodulation.

*11 Slot: A unit for scheduling data consisting of multiple OFDM symbols.

*12 Subframe: A unit of radio resources in the time domain, consisting of multiple slots.

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

*14 Symbol: The unit of data transmission.

*15 Subcarrier: Each carrier in a multi-carrier modulation system that transmits bits of information in parallel over multiple carriers.

delay and angular profiles*18 of the arriving signals. The channel sounder function has a radio unit and a channel sounding unit. The PC performs image processing to integrate the results of this analysis with the video from the 360° camera and outputs it to the display.

3.2 Functional Architecture

The functional architecture is shown in **Figure 4**. To perform channel estimation, multiple SSBs emitted on different beams must be received and the SSB transmission timing detected. The radio unit*19 receives the signals from the multi-element array antenna, converts them to an Intermediate Frequency (IF)*20, and computes the correlation*21 with the SS to detect the timing that maximizes correlation. Based on the detected SSB transmission timing, the channel estimation result is computed, which is a matrix of 127 SS subcarriers by N array antenna elements. An Inverse Fast Fourier Transform (IFFT)*22 is then used to compute the delay profile. An anechoic chamber*23 is used to estimate channels for each arrival angle beforehand, and these are used to calibrate measurement

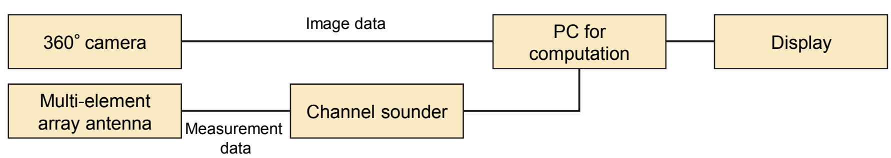


Figure 3 System architecture

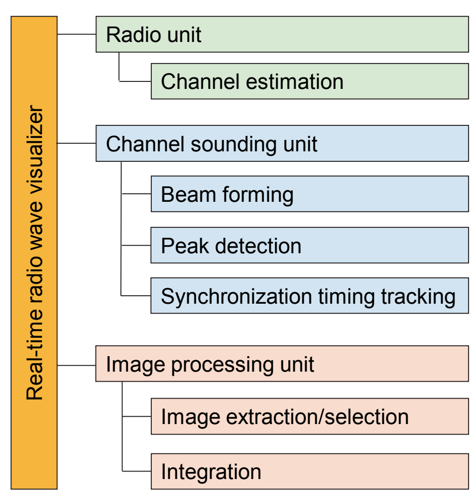


Figure 4 Functional architecture

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

*17 Channel estimation: Estimation of changes in parameters such as amplitude and phase as a signal traverses a radio channel.

*18 Delay and angular profiles: A waveform representing the relationships between propagation delay and received power for direct signals, reflected signals, and diffused signals arriving at the receiving station is called the delay profile, and that representing the relation between arrival angle and received power is called the angular profile.

*19 Radio Unit: Equipment that converts the received digital signal to an intermediate frequency, amplifies the received signal, receives the signals from antenna elements and other functions.

data for beam forming*24.

The channel sounding unit then performs synchronization timing tracking to enable stable angular-profile peak detection and channel sounding, which is used to define the beam forming and signal arrival angles. First, beam forming is done by computing the correlation between the analyzed delay profiles and correction data estimated beforehand, and then delay-angular profiles are computed for each arrival angle. Reception levels are then computed for each arrival angle from these results, peak detection is done to define the arrival angles, and this yields results indicating the angular profiles and arrival directions.

Finally, the image processing unit extracts image data for each of the arrival angles from the 360° camera video, and integrates it with the computed angular profiles obtained by the channel sounding unit to visualize the states of arriving signals.

4. Implementation

The equipment was implemented with a radio unit, a channel sounding unit, a PC, and a Head-Mounted Display (HMD)*25 (**Figure 5**). The radio unit consists of a 28 GHz cylindrical array antenna with 256 elements, arranged on 8 levels vertically, and in 32 directions around a circle, and a radio-frequency front-end. The PC is used to integrate image data with the channel sounding data, and the HMD provides a way to understand the 360° signal arrival state efficiently. A maximum of four channels can be received and the maximum number of antenna elements per channel is 64. The cylindrical array antenna was used so that signals

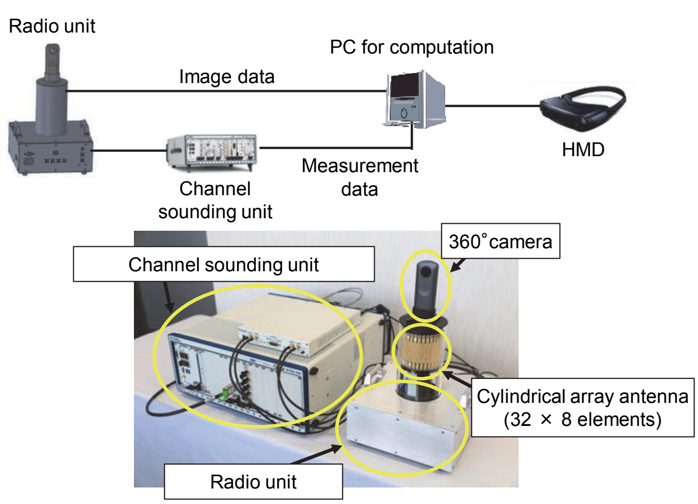


Figure 5 Example system implementation

*20 IF: A frequency that is lower than the carrier frequency. In most wireless communication systems, the baseband transmission signal is first converted to an intermediate frequency rather than being modulated directly to the carrier frequency (or the received signal is directly demodulated to the baseband signal).

*21 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.

*22 IFFT: A fast algorithm for converting discrete frequency domain data into discrete time domain data.

*23 Anechoic chamber: A test facility that is shielded from external radio waves and where the walls, floor and ceiling are covered with an electromagnetic absorbing material to suppress reflections.

arriving from a 360° range of angles can be visualized. For NR, SSB subcarrier intervals are specified to be 15 kHz, 30 kHz, 120 kHz, or 240 kHz and the number of subcarriers is fixed, so the transmission bandwidths for each subcarrier interval are different. As such, the equipment was made to support a maximum analysis bandwidth of 80 MHz, as shown in **Table 1**.

As shown in **Figure 6**, channel estimation is implemented in the radio unit using a Field Programmable Gate Array (FPGA)*26. Beam forming, peak detection and synchronization timing tracking are implemented in the channel sounding unit using FPGA and software. An FPGA was used to accelerate beam forming because it is computationally intensive, and peak detection and synchronization timing tracking are implemented in software. The image processing unit is implemented using the PC Graphics Processing Unit (GPU), and integrates the estimation data with image data, which is selected based on the orientation of the HMD being worn by the user.

Table 1 Equipment specifications

Item	Specification
Frequency band	28 GHz
Maximum bandwidth	80 MHz
Antenna	256 elements/32-sided cylindrical array antenna
Channels used	5G NR SSB

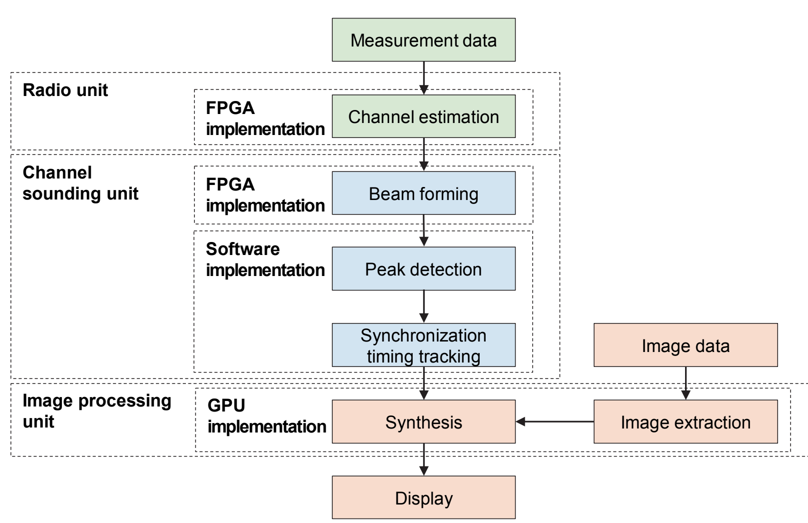


Figure 6 Implementation flow chart

*24 Beam forming: A technology that uses multiple antenna elements to give directionality to signals radiated or received by the antenna.

*25 HMD: Display equipment which is worn on the head, in the form of goggles or a helmet, with small display screens positioned directly in front of the eyes. There are monocular types, which display an image for only one eye, and binocular types, which display images for both eyes.

*26 FPGA: A large-scale integrated circuit capable of being rewritten, consisting of cells arranged in the shape of an array and wiring elements.

A timing chart for channel estimation, beam forming, and peak detection is shown in **Figure 7**. To receive signals from each of the directions properly, elements of the cylindrical array antenna in each direction are used, switching antenna elements while computing correlation with the SS to detect the timing of SSB transmission. The detected SSB transmission timing is used to estimate channels, computing results of beam forming for all antenna elements while switching every four elements in the cylindrical array antenna, so that the arrival state can be visualized over a 360° range. Thus, this implementation must have computation time of the SSB transmission cycle × antenna switching 64 times. In order to display the signal arrival states in a user friendly way on the HMD, data are displayed integrated with 4K video, including the angular profile with a color scheme according to reception level, the cell ID*27 indicating which base station the signal is from, and the peak position from the angular profile, which shows the arrival direction. When there are multiple base stations, measurements can be made for each base station, whether they are using the same frequency or not, and they are displayed with the cell ID for each base station.

Specialized control software makes it possible to perform channel sounding and to check the results

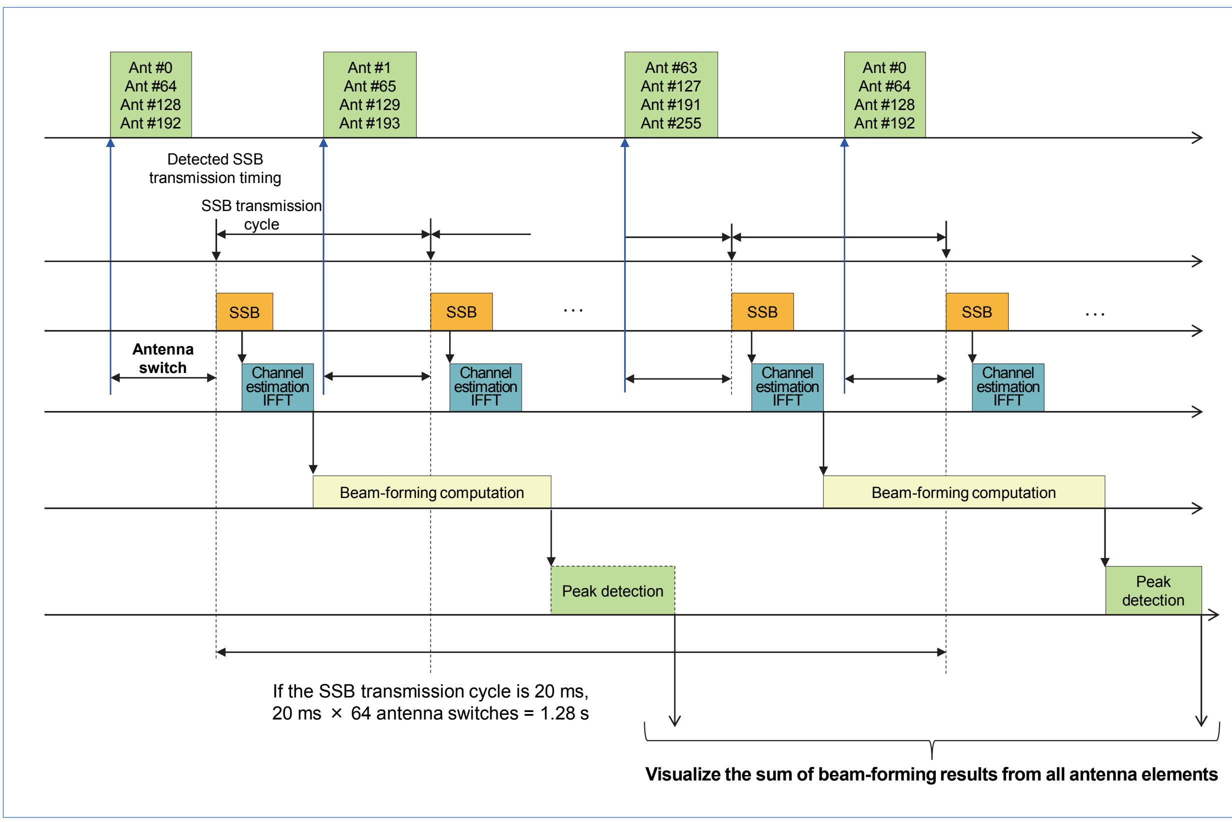


Figure 7　Timing chart for channel estimation, beam forming, and peak detection

*27 Cell ID: An identifier for the base station.

of the analysis easily with this equipment. Channel sounding is performed by just selecting the subcarrier interval and SSB transmission cycle and pressing the "Start Sounding" button. Intermediate data can be displayed including reception levels and the delay and angular profiles for each antenna element, as shown on the software control screen shot in **Figure 8**.

5. Visualizer Observations

Results of radio observations made using the equipment are shown in **Figure 9**. Fig. 9 (a) shows observation of signal arrival state made with two base stations operating at different frequencies within a radio anechoic chamber. Base station #0, with cell ID of 1, operated at 27.9 GHz, and base station #1 with cell ID of 2, operated at 28 GHz. In the image, color indicates the signal arrival distribution, with red indicating higher reception level, and blue indicating lower reception level. Peaks in the angular profile are shown as dots, and the number displayed above each dot is the cell ID. The image shows that peaks appear near the transmitters for each base station, indicating the signals arriving directly from the base stations. Fig. 9 (b) is the result when operating using the same frequency (27.9 GHz). Compared with Fig. 9 (a), there is more interference between the base stations, which appears as in an overall increase in reception levels. Fig. 9 (c) shows indoor observation of multipath signals*28. Signals arriving directly from the base station and also reflections from walls and other objects are apparent. This shows that the equipment can be used to visualize the effects of structures surrounding the equipment on the state of signals arriving from base stations in real time.

6. Conclusion

This article has described the system architecture and an implementation of a real-time 3GPP radio wave visualizer. The equipment provides a

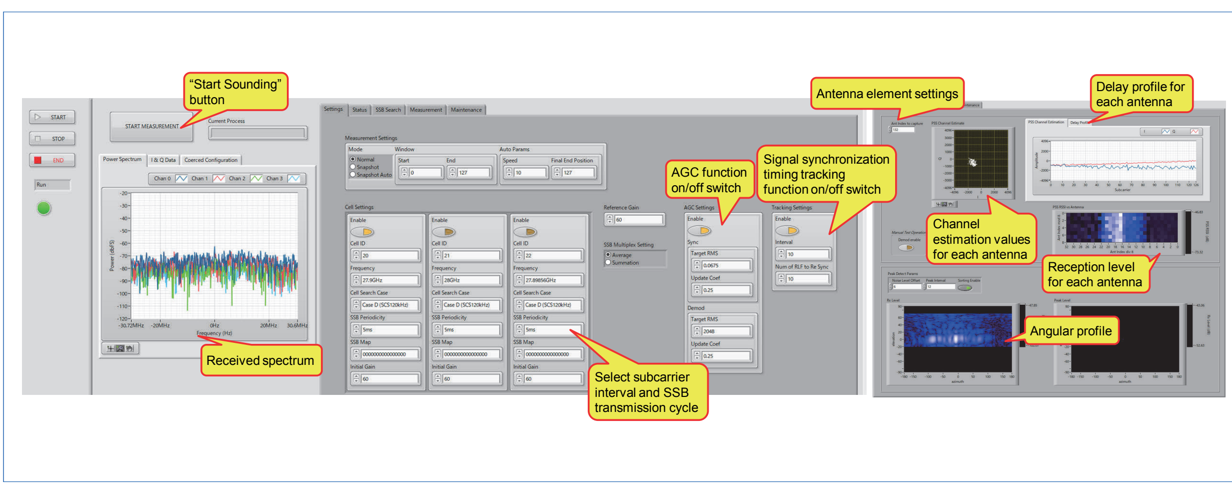
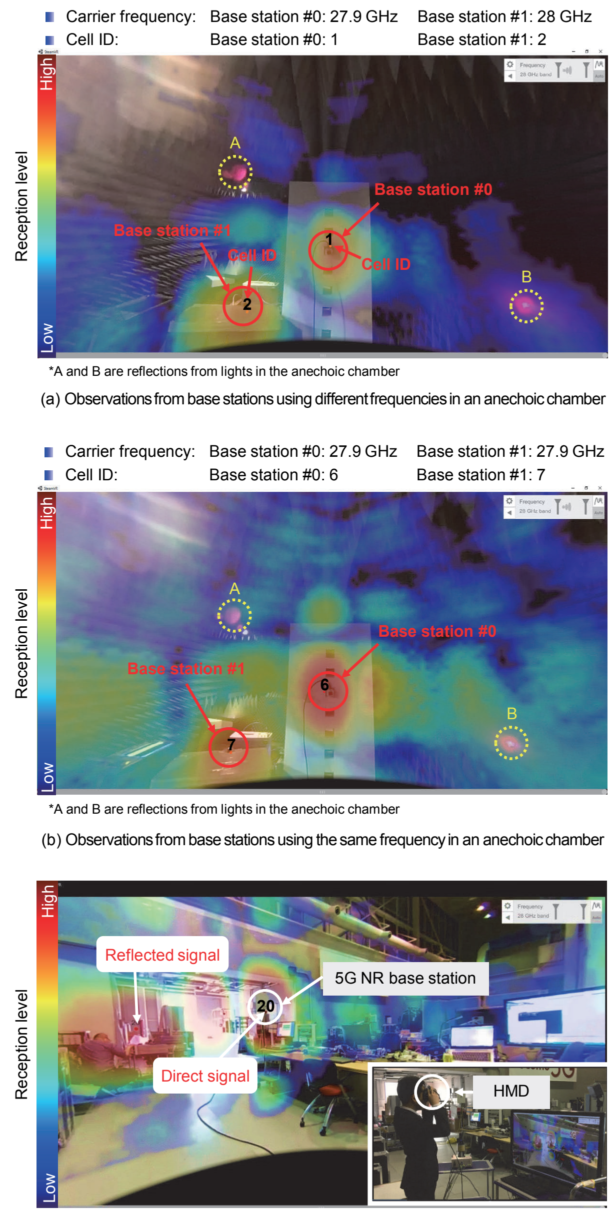


Figure 8　Screenshot of channel sounding control software

*28 **Multipath signal**: A signal that reaches the receiving station after traversing various propagation paths.



(a) Observations from base stations using different frequencies in an anechoic chamber

(b) Observations from base stations using the same frequency in an anechoic chamber

(c) Observations in the lab

Figure 9 Observation results

visualization of signal arrival state and can contribute to area optimization for NR-conforming base stations by using it to tune base station parameters such as antenna directionality. We intend to continue to contribute to development of 5G in the future by developing a smaller, general purpose device and promoting its use in various organizations and enterprises.

REFERENCES

[1] K. Takeda et al.: "Technical Overview of the 3GPP Release 15 Standard," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.49–61, Jan. 2019.

[2] NTT DOCOMO, INC.: "DOCOMO 5G White Paper—5G Radio Access: Requirements, Concept and Technologies," Jul. 2014.

[3] White paper on "5G channel model for bands up to 100 GHz," Global Communications Conference, 3rd Workshop on Mobile Communications in Higher Frequency Bands, Washington, D.C., U.S.A., May 2016. http://www.5gworkshops.com/5GCM.html

[4] ITU-R M.2412-0: "Guidelines for evaluation of radio interface technologies for IMT-2020," Oct. 2017.

[5] T. Imai, M. Inomata, K. Kitao and Y. Okumura: "Real-Time 5G Radio Wave Visualizer," ISAP 2018, Busan, Korea, Oct. 2018.

Initiatives for Generic NW Equipment Sharing on Virtualization Platforms

Core Network Development Department Nobuo Takeuchi Yoshiyuki Suzuki†

With the ongoing virtualization of mobile network communication systems at NTT DOCOMO, the company implemented for the first time the functions of generic network equipment (hereinafter referred to as generic NW equipment) such as Load Balancer (LB)*1, FireWall (FW)*2, Domain Name System (DNS)*3 on DOCOMO's virtualization platform systems [1], and begun its operation in April 2019. This enables DOCOMO to share generic NW equipment between multiple systems (hereinafter referred to as communication systems) on its mobile network, which holds promise for lower design and facility costs. This article describes the configuration design of generic NW equipment from the perspective of sharing between communication systems, and examples of application of generic NW equipment on the virtualization platform.

1) Approaches to Network Equipment Sharing

Sharing generic NW equipment between communication systems confers advantages in terms of facility costs. Generic NW equipment is also suited for sharing because the differences of individual communication systems requirements for generic functions such as LB, FW and DNS are essentially small. However, with on-premises*4 generic NW equipment running on dedicated hardware, increases in communications traffic also entail increases in hardware, which makes rapid handling problematic. To address this issue, virtualized generic NW equipment enables flexible response without the need to increase physical resources, by adding Virtual Machines (VM)*5 to virtual resources (the resource pool*6) shared on a virtualization platform (**Figure 1**).

2) Approaches to Application on Virtualization Platforms

In applying generic NW equipment to virtualization platforms, we aimed to:

(1) Create generic configurations (to lower design and testing costs)

(2) Make it easy to find out which function is in use (to improve maintenance operations)

(3) Define and commonize maintenance work (to improve maintenance operations)

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*1 LB: Equipment to distribute communications traffic load.

*2 FW: Equipment to prevent unauthorized access of an internal network from an external network such as the Internet.

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

*4 On-premises: Refers to an environment where HW that makes up a corporate system is possessed, operated and maintained by the company.

*5 VM: A computer (virtual machine) created in a virtual manner by software.

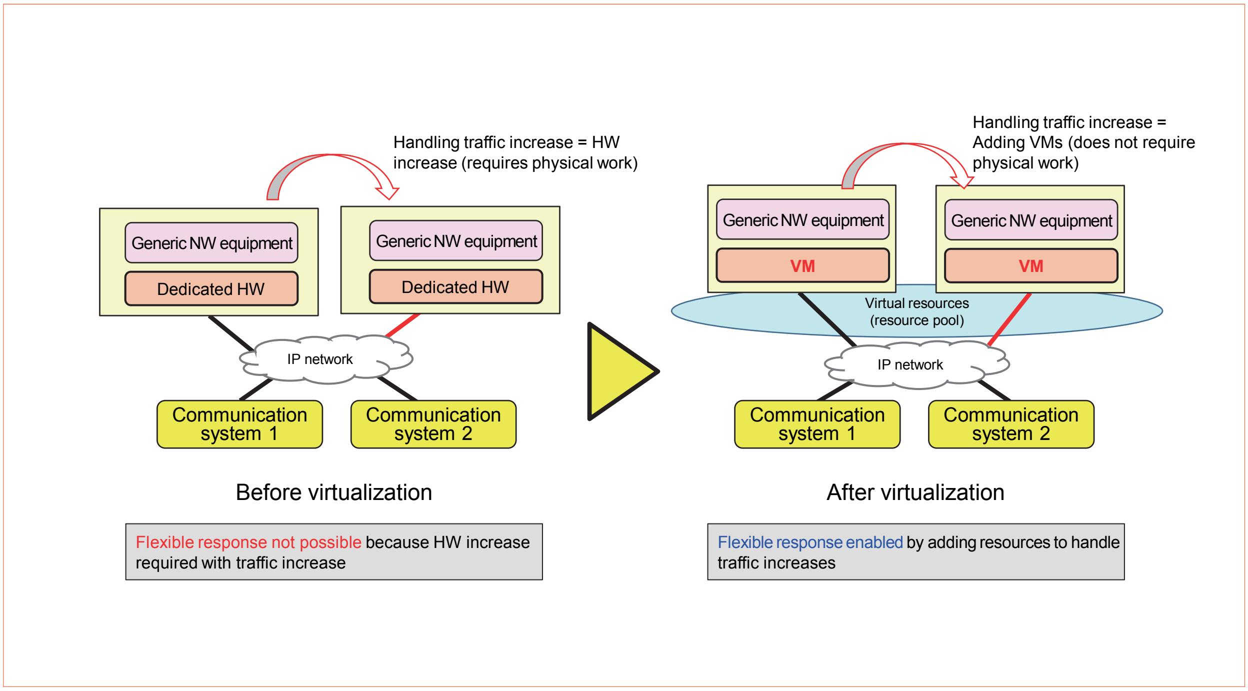

Figure 1　Image of shared generic network equipment

(4) Make the communications bandwidths on the mobile network more efficient (to lower facility costs)

Below, we describe the aspects we studied to satisfy the above goals.

(1) We defined a Virtual Network Function (VNF)*7 class called "generic NW equipment VNF" generalizing LB, FW and DNS functions, etc., and configured VNFs by adding VMs for each function. We also configure another VNF when adding each VM to cope with increases in communications traffic.

We commonized VNF functions and the VNF Descriptors (VNFD)*8 that define actions so that VNFDs are the same for all generic NW equipment. Below, the reasons for this are discussed in terms of design and testing costs.

- Defining individual VNFDs for each generic NW equipment function or addition of VM would require dedicated design and thus would contribute to increased costs.
- Changing VNFDs defined for VNF functions and operations on a virtualization platform would require testing of generalized operations to manage VMs, which would contribute to increased costs.

The same VNFD enables lower design and testing costs for LB, FW and DNS functions or when adding VMs to respond to increased traffic, and enables flexibility.

(2) In the definition of the VNF Records (VNFR)*9 that uniquely define each VNF, we newly defined LB, FW or DNS functions or added VMs and respectively distinguished these to make it possible to understand which VNFs

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*6　Resource pool: A set of resources achieved by bundling together many units of hardware each possessing certain types of resources (CPU, memory, HDD, etc.). Various types of virtual machines can be created from a resource pool.

*7　VNF: Communication functions that run on virtual machines achieved by software implementations.

*8　VNFD: A template that defines the behavior of a VNF function.

*9　VNFR: A variable in the same VNF class.

are operating with which functions. This approach achieves improvements in maintainability by enabling confirmation of the details of those definitions on monitoring systems using Operation Support Systems (OSS)*10, etc., and enabling understanding of which function is being monitored.

In light of (1) and (2) above, **Figures 2** and **3** show an example of generic NW equipment VNF configuration.

(3) In addition to general maintenance operations (instantiation*11, healing*12, etc.) for managing

*10 OSS: A system for discovering, controlling, and dealing with faults and congestion in a mobile communications network, or an operations support system for network operators. For a network operator, this means full or partial network or system fault management, configuration management, charging management, performance management, and security management for operating provided services.

*11 Instantiation: The process of launching communications software by preparing a virtual machine on generic hardware.

*12 Healing: A procedure for restoring communications software to a normal state in the event of a hardware or VM failure by moving the VM to (or recreating the VM on) hardware operating normally.

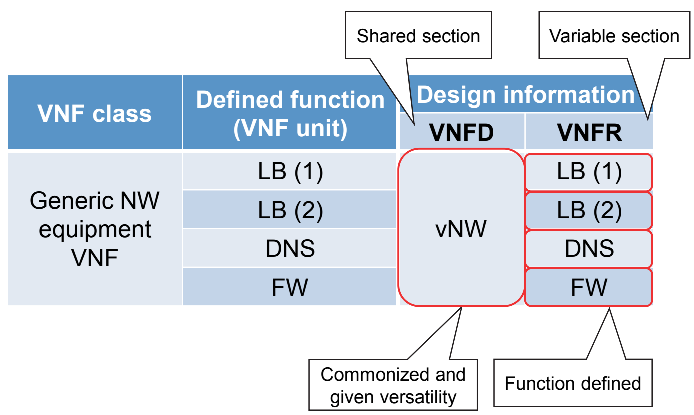

Figure 2 Generic NW equipment VNF configuration example (1)

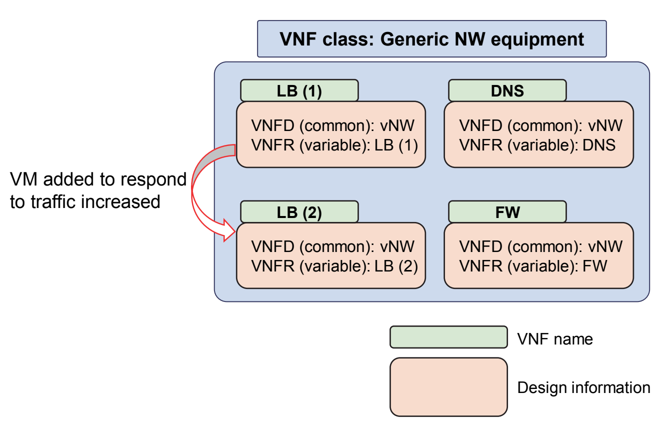

Figure 3 Generic NW equipment VNF configuration example (2)

VMs with Network Functions Virtualisation (NFV)*13, we commonized works specific for generic NW equipment such as OS and firmware update work and server firmware and hypervisor®*14 update work by newly defining them as maintenance operations linked to the virtualization platform, and commonizing the work as generic NW equipment VNF maintenance operations. This achieves better maintainability by providing commonized maintenance operations regardless of the generic NW equipment VNF function.

(4) Although communications between communication systems are done on an L3 connection via a switch (L3*15 switch) for connecting between different VNFs, more communications bandwidth efficiency is achieved by call back communications between communication systems and generic NW equipment with an L2 switch (L2*16 connection) connecting servers instead of an L3 switch.

Figure 4 shows an example of generic NW equipment VNF application in light of the above considerations.

This article has described points considered and the results of those considerations, and examples of application in the configuration design of generic NW equipment VNF from the perspective of sharing between communication systems in the application of generic NW equipment on a virtualization platform. With the success of this implementation case,

*13 NFV: Achieving a communications carrier network on generic hardware using virtualization technologies.

*14 Hypervisor®: A virtual server technology that assigns and manages physical resources for applications to mount on virtual machines, and runs multiple virtual machines on physical resources. A registered trademark of IBM Corp.

*15 L3: The third layer of the OSI reference model (the network layer).

*16 L2: The second layer of the OSI reference model (the datalink layer).

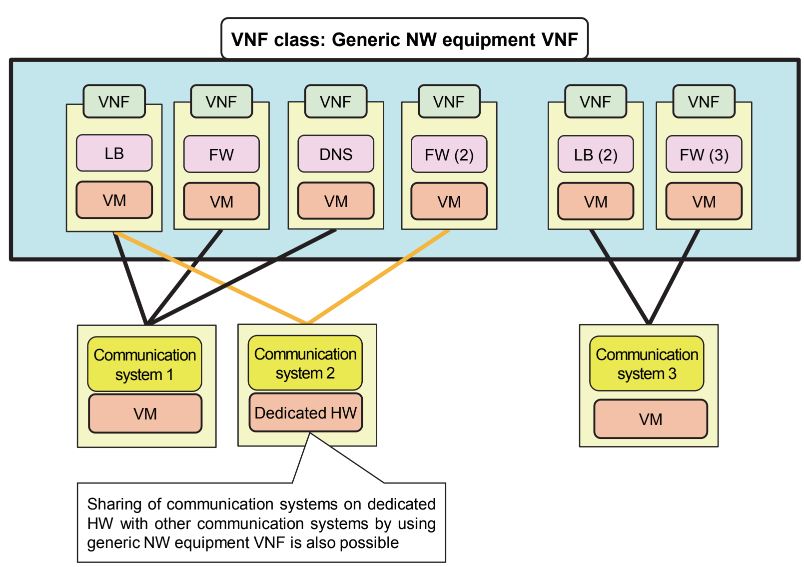

Figure 4 Generic NW equipment VNF application example

we anticipate further progress with conversion of on-premises generic NW equipment to virtualized generic NW equipment and sharing in DOCOMO's mobile network communication systems. Going forward, to share various communication systems like those in the application example in Fig. 4, we will formulate optimized VM layout design policy for sharing or adding VMs to systems based on the characteristics of individual generic NW equipment functions and communications traffic.

REFERENCES

[1] T. Kamata et al.: "Practical Implementation of Virtualization Platform in NTT DOCOMO Network," NTT DOCOMO Technical Journal, Vol.18, No.1, pp.20-28, Jul. 2016.

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