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DOCOMO Today

- Aiming for 2020 and Beyond

Technology Reports (Special Articles)

Special Articles on Network Functions Virtualisation – Toward a Robust and Elastic Network –

- Application of Virtualization Technology to Communications Networks
- Activities toward NFV Standardization
- Practical Implementation of Virtualization Platform in NTT DOCOMO Network
- Introduction of SDN Technology for Achieving NFV

Technology Reports

- Deep Learning-based Image Recognition Applications
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- “Linking” Device Functions to Expand the IoT

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- ITU Radiocommunication Assembly 2015 (RA-15) Report – Future Mobile Phone Technologies Standardization –
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Aiming for 2020 and Beyond



Hiroshi Nakamura

**Senior Vice President
General Manager of R&D Strategy Department**

“The new of today, the norm of tomorrow” is NTT DOCOMO’s brand slogan. It declares that NTT DOCOMO will continue to create Smart Innovations. These innovations, including services, are original and may be difficult to approach at first, but all users will use them fluently in their everyday lives when they become aware of them. NTT DOCOMO’s R&D activities are carried out not just for the sake of self-satisfactorily refining technologies. They have the critical mission of realizing Smart Innovations by presenting value and benefits whose allure customers can feel. NTT DOCOMO R&D’s medium- to long-term plan for 2020 and beyond sets forth two worldviews as customer values: (1) liberating customers from all stresses in communication and (2) breaking down barriers that stand in the way of Smart Life. Here I present a vision of 2020 and beyond that depicts these values and technologies to realize them.

- (1) Stresses in communication are inconveniences experienced daily in communication, such as slow service, inability to connect, and complicated and annoying mobile phone operations. We are therefore implementing our unflagging wireless strategy of “improving LTE-Advanced and realizing 5G by 2020,” even as we continue to increase communication data capacity at an explosive annualized rate of more than 150 percent. This will create an environment in which so-called “packet congestion” is eliminated and smooth communication is possible. To reduce connection problems due to temporary spikes in network traffic during phenomena such as events and natural disasters, we are creating networks that connect easily. This is achieved by virtualizing networks so communication processing resources can be flexibly allocated to regions experiencing concentrated traffic. Furthermore, we are creating friendly User eXperience (UX) that are customized according to the proficiency level of users, such as first-time users and the elderly who need time to operate their smartphones, even if they are used to

them. This will enable users to effortlessly use smartphones before they know it. Technological innovations such as 5G, virtualization, and UX improvement will liberate users from the stresses of communication.

- (2) The barriers that stand in the way of Smart Life are inconveniences in daily life, including the inability to find the information you want, difficulty in understanding one another due to foreign languages, and illness as a result of living habits. NTT DOCOMO is therefore offering the ultimate personal agent that presents accurate information needed by our customers at the optimal times. This personal agent analyzes vast amounts of big data, such as each person’s situation, trends, and socially accepted ideas. Also, increases in foreign visitors to Japan and the global expansion of Japanese companies will expand opportunities in mutual understanding with foreigners even more compared with today. However, the language barrier cannot be easily torn down. NTT DOCOMO is working on automatic translation technology that seeks to remove the language barrier by gathering voluminous dialogue corpora and analyzing them with big data technologies to provide accurate and high-speed multilingual translation. Furthermore, avoiding illnesses and leading healthy lives is the dream of humankind. By creating data of individual life habits using wearable devices and combining them with genomic information for big data analysis, individual-specific advice for preventing illnesses can be provided to maintain and improve health. We are working to tear down barriers standing in the way of Smart Life by refining big data analytic technologies adapted to supported markets such as dialogue corpora and genomic information.

In addition to the above, Internet of Things (IoT) and security will be essential technological fields for realizing the two worldviews.

Big data analysis makes use of vast amounts of information stored on servers connected on the Internet (cyberspace information). Meanwhile, IoT, currently a hot topic, creates data from things existing in the real world and from occurring phenomena, greatly expanding the kinds of data that can be used. Furthermore, IoT is broadening its scope of application to include acting on the real world by actuating the results of big data analysis. In this way, the application of big data analysis incorporating IoT can be expanded to a variety of industries. However, there are challenges. Even if the scope of big data grows, if security is inadequate, physical accidents and disasters can occur. To prevent these risks and create a safe and secure Smart Life society, we must engage in the major technological challenge of stronger security measures across a broader range of fields, in addition to authenticating IoT devices and controlling access.

The technologies presented here will be realized by synergistic, collaborative “links of technology” that integrate the two worldviews, which are values that customers experience. Also, as the technologies of future innovations deepen and diversify, NTT DOCOMO will not conduct all R&D by itself, but move forward with the entire range of our partners through open innovation.

Going forward, NTT DOCOMO R&D will continue to create innovations based on the feedback and needs of our customers by linking technologies together with all of our partners. We will continue to realize a Smart Life in which our customers feel the value and benefits of our achievements and command their use naturally.

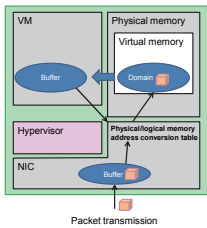
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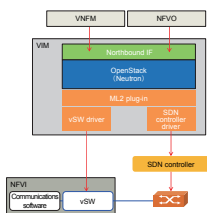
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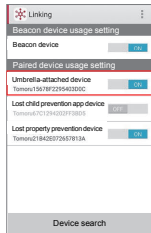


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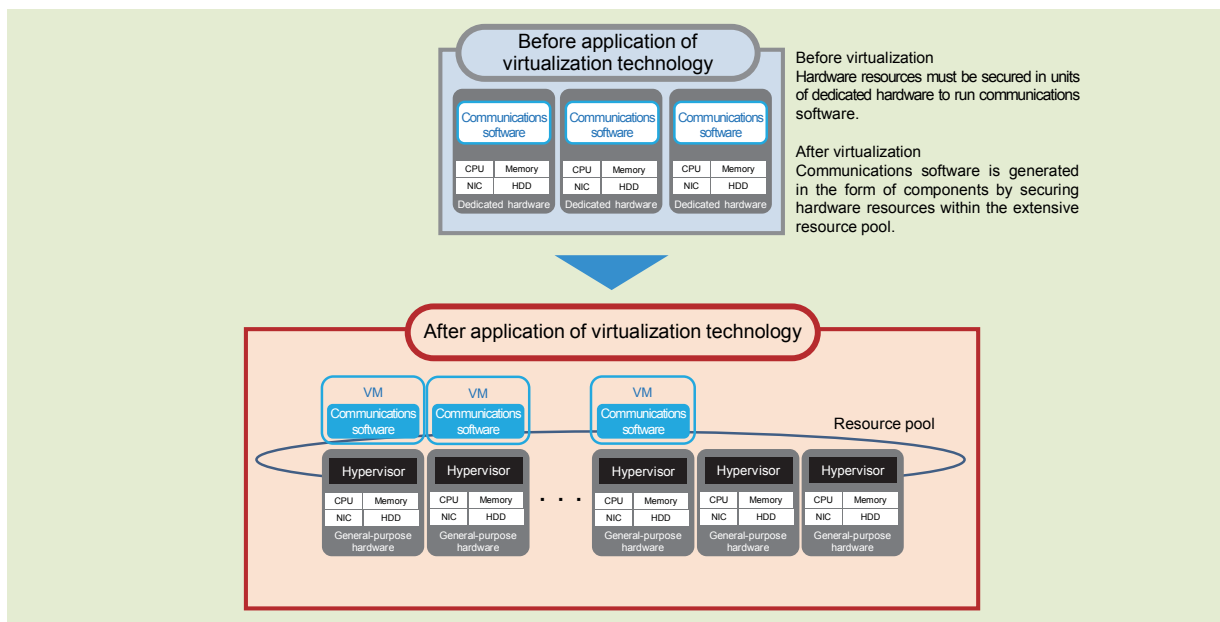
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Special Articles on Network Functions Virtualisation—Toward a Robust and Elastic Network—

Application of Virtualization Technology to Communications Networks

In the face of dramatic increases in data communications traffic and sudden changes in traffic characteristics brought on by the widespread adoption of smartphones, constructing and operating an always-connected network at a reasonable cost has become a common issue for many network operators. NTT DOCOMO has undertaken the development of an always-connected network that can reduce network CAPEX and OPEX by applying virtualization technology. This article describes issues and activities surrounding virtualization technology at NTT DOCOMO.

Core Network Development Department

Hiroyuki Oto**Seiji Fukae****Yasuyuki Uchiyama**

Research Laboratories

Kazuaki Obana

1. Introduction

The volume of data communications traffic continues to increase due to the widespread adoption of smartphones, and the communication characteristics of always-on smartphones is making it difficult to predict traffic fluctuations. Under these conditions, constructing an always-connected network at a reasonable cost to achieve a reliable social infrastructure or prepare for a large-scale disaster has become a common issue for many network operators.

NTT DOCOMO aims to resolve this issue through Network Functions Virtualisation (NFV)^{*1} that applies virtualization technology to a carrier network. Virtualization technology in NFV logically integrates and divides hardware resources (CPUs, memory, and HDDs) to create a resource pool^{*2} irrespective of the physical hardware configuration thereby enabling all sorts of communications software to run on shared general-purpose hardware. With this technology, virtual hardware is configured within the resource pool and

communications software is generated in the form of components on that virtual hardware. In addition, NTT DOCOMO also applies Software-Defined Networking (SDN)^{*3}, a network technology having a correspondence with virtualization technology, to the communications software dynamically deployed on general-purpose hardware to ensure network reachability and secure necessary bandwidth.

During times of normal network operation, these technologies help to improve network usage efficiency, and

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^{*1} **NFV:** Achieving a carrier network on general-purpose hardware through virtualization technology.

at the time of a disaster, they can automatically expand the capacity of network facilities and improve the ease of connection.

Furthermore, in contrast to the conventional method of constructing network facilities beforehand based on predicted levels of traffic, virtualization technology enables resources to be allocated in response to current traffic conditions. This results in network operations achieved by reasonable Capital EXpenditure (CAPEX)^{*4} and Operating EXpense (OPEX)^{*5}.

In this article, we provide an overview of virtualization technology, present current issues facing network operators, and describe a solution based

on the application of virtualization technology. We also describe elemental virtualization technologies and a new network issue associated with NFV.

2. What is Virtualization Technology?

In the past, communications software used by network operators to provide services could run only on dedicated hardware. This was because dedicated hardware optimized to the characteristics of that communications software was needed to satisfy carrier grade requirements such as high reliability and high performance. Virtualization technology, in contrast, enables communications software to be deployed on the

virtual layer (hypervisor^{*6}) installed on a unit of general-purpose hardware with the result that the software can operate irrespective of hardware characteristics.

Virtualization technology makes it possible to regard hardware resources (such as CPUs, memory, and HDDs) constrained by a physical configuration as a resource pool that bundles together a large amount of hardware (**Figure 1**). It enables hardware resources situated on any general-purpose hardware within the resource pool to be used as components in the configuring of a Virtual Machine (VM)^{*7}. In this way, it is no longer a question of securing hardware resources on specific facilities since

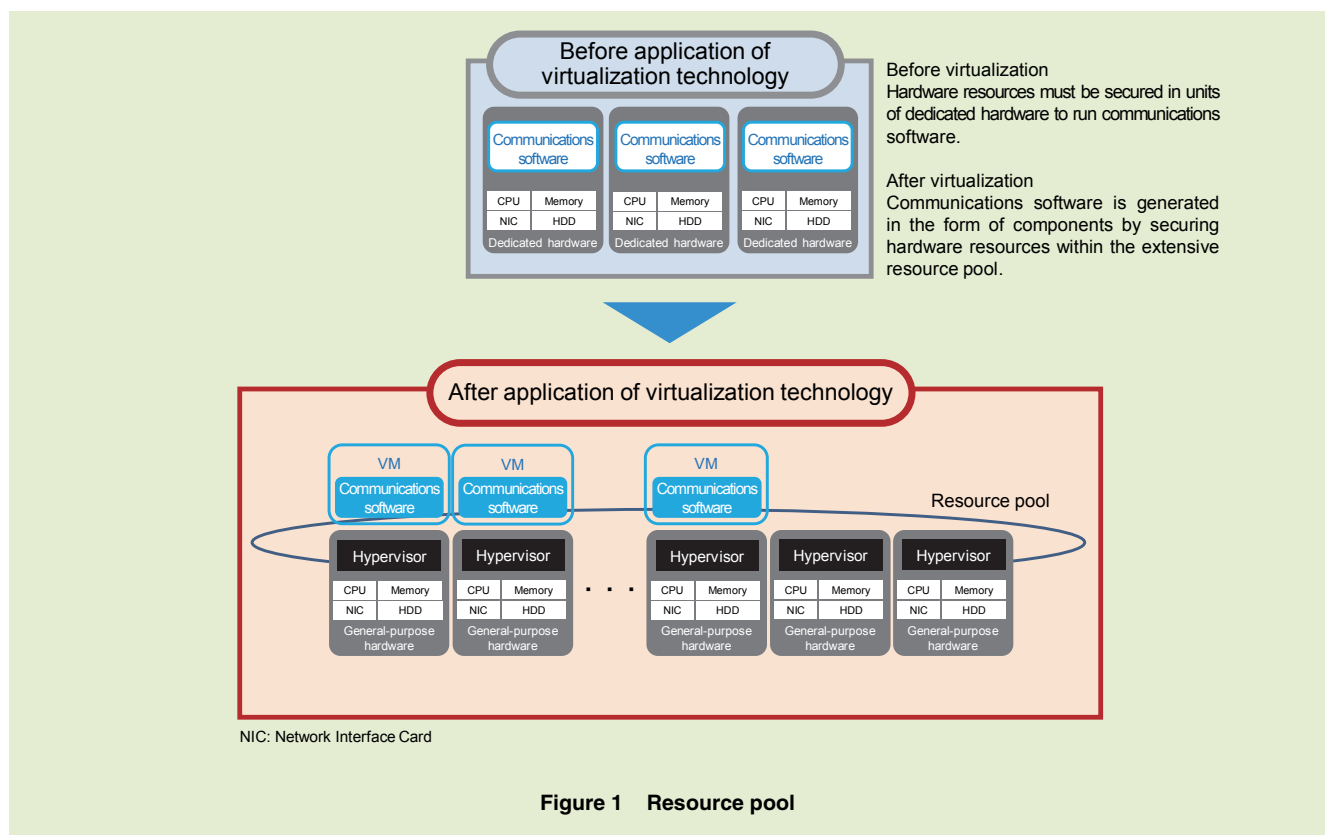


Figure 1 Resource pool

^{*2} **Resource pool:** The bundling of many units of hardware to form a set of resources (CPUs, memory, HDDs, etc.) held by each piece of hardware. Various types of virtual machines can be created from a resource pool.

^{*3} **SDN:** Generic name for technology that ena-

bles centralized control of communications devices through software.

^{*4} **CAPEX:** Amount of money expended for hardware and hardware installation.

^{*5} **OPEX:** Amount of money expended for maintaining and operating facilities.

^{*6} **Hypervisor:** A control program for creating and running virtual machines—a type of virtualization technology.

^{*7} **VM:** A computer created in a virtual manner by software.

they can now be secured from a resource pool, which improves the usage efficiency of facilities. This is why virtualization technology has been attracting attention in recent years as a solution to issues currently faced by network operators.

NTT DOCOMO is making it possible to achieve “easy connection at times of congestion,” “improved reliability,” and “early provision of services,” at a reasonable cost by applying virtualization technology to communications networks.

3. Issues Facing Network Operators

One mission of a network operator is to provide a sense of reassurance in the form of an “always connected” and “always usable” communications network that serves as a social infrastructure. However, there are four issues that need to be addressed to instill confidence in users.

(1) Connection control at times of congestion

When a disaster or other unexpected event causes a massive number of calls to be attempted all at once, the possibility exists that data communications traffic exceeding facility capacity will flow into the network. At this time, some of that traffic will have to be discarded before capacity overload occurs. This is because, if network facilities should reach the point of a system

halt due to congestion, services would be disabled for at least several hours, which would simply magnify the problem. In short, there is no other way in such a situation but to choose the action that would minimize the impact on services.

(2) Risk at times of equipment failure

Systems are given a redundant configuration so that services can continue unimpeded even if some equipment experiences problems or failures. However, in the interval between the occurrence of such problems or failures and the replacement of the faulty equipment, redundancy is lost. Thus, if another failure should occur before that equipment has been completely replaced, service continuity becomes difficult.

(3) Difficulty of prompt facility support

The provision of new services or the addition of facilities in response to increasing traffic demand requires the development of new dedicated hardware and planning, procurement, installation, etc. toward the deployment of new facilities. These measures require time to execute, which makes prompt facility support difficult.

(4) Increase in facility/operation costs

The high price of dedicated hardware for running communications software, which is used by a network operator to provide ser-

vices, increases CAPEX. Additionally, the need for maintenance personnel to replace faulty equipment to restore redundancy as soon as possible drives up OPEX.

4. Solution: Apply Virtualization Technology to Communications Networks

The benefits of introducing virtualization technology to carrier networks are described below for each of the issues described above.

4.1 Connecting at Times of Congestion

In the past, data communications traffic would have to be discarded to prevent a capacity overload in network facilities. From here on, however, it will be possible to apply a method called “scaling” (see section 5.2). In this method, the inflow of traffic large enough to exceed facility capacity will trigger the automatic installation of communications software on general-purpose hardware on which no such software is currently running. This will have the effect of increasing facility capacity in a short period of time. As a result, traffic that in the past would have to be discarded out of necessity can now be processed normally making for ease of connection.

4.2 Improving Reliability of Communications Services

In a conventional network, the oc-

currence of an equipment failure meant that equipment redundancy would be lost until replacement of that unit by maintenance personnel in the field was completed. Now, at the time of equipment failure, a method called “healing” (see section 5.3) will enable redundancy to be restored promptly by automatically moving communications software to good hardware. This approach minimizes the risk of a service shutdown thereby improving reliability.

4.3 Early Provision of Services

Adding new equipment took a relatively long time in the past. In the future network, the shared use of inexpensive general-purpose hardware will enable a variety of communications software to be executed. Specifically, to facilitate the launching of new services and addition of new functions and to

deal with growing demand, a method called “instantiation” (see section 5.4) will enable communications software to be promptly deployed on general-purpose hardware facilities deployed beforehand (**Figure 2**). This is a great advantage for operators who wish to develop and roll out new services promptly or scale down or withdraw services.

4.4 Cost-efficient Network Facilities and Operations

Thanks to technological advances in recent years, it has become possible to lower costs through a transition from dedicated hardware to general-purpose hardware and to reduce the amount of required facilities through effective utilization of hardware resources. As a result, excess facilities can be greatly reduced compared to conventional systems and CAPEX can be lowered. In

addition, equipment redundancy lost at the time of an equipment failure can be restored by the healing method. There is therefore no obstacle to service continuity, which means that the replacement of faulty units can be carried out in batch at a later date thereby reducing OPEX as well.

5. NFV Elemental Technologies

5.1 Differences with Ordinary Virtualization Technologies

In an IT world in which Web services are now mainstream, cloud^{*8} operation based on server virtualization is a sensible approach. In the world of communications, however, communications software often takes on a structure that requires complex coordination within a software group to provide services. Appropriate startup procedures and con-

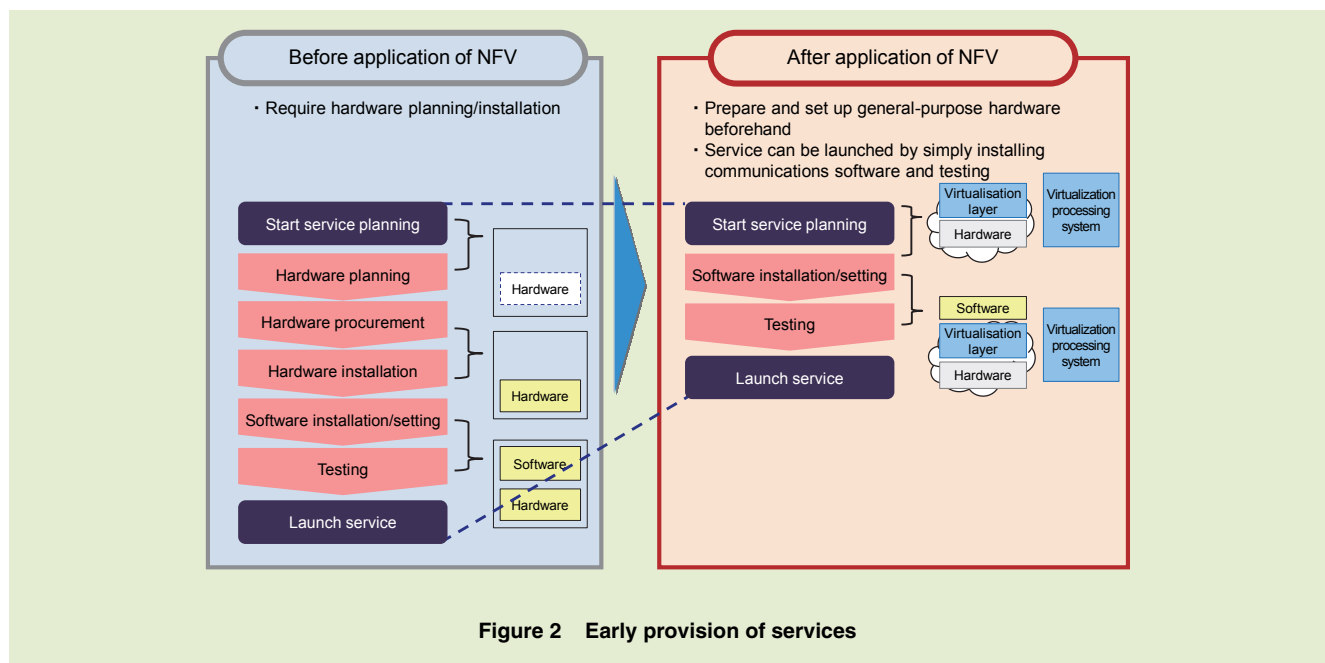


Figure 2 Early provision of services

^{*8} **Cloud:** A format and mechanism for providing services over the network. Server resources can be allocated according to demand making for high scalability.

trol are needed in accordance with the software structure and high reliability is required.

In this regard, the following describes elemental technologies using typical use cases. A more detailed description of architecture and workflow is provided by another special article in this issue [1].

5.2 Scaling

As described above, improving ease of connection at times of congestion can be achieved by a technique called “scaling.” Scaling means increasing or decreasing communications software and VMs according to hardware and VM load conditions to optimize processing power. Specifically, adding VMs to im-

prove processing power is called a “scale-out” operation and deleting VMs to cut back on processing power is called a “scale-in” operation.

In addition, both “auto-scaling” and “manual scaling” are possible. In the former, the system automatically executes scaling, while in the latter, maintenance personnel judge the need for scaling and do so if needed in cases that automatic execution by the system is difficult. An example of auto-scaling is shown in **Figure 3**.

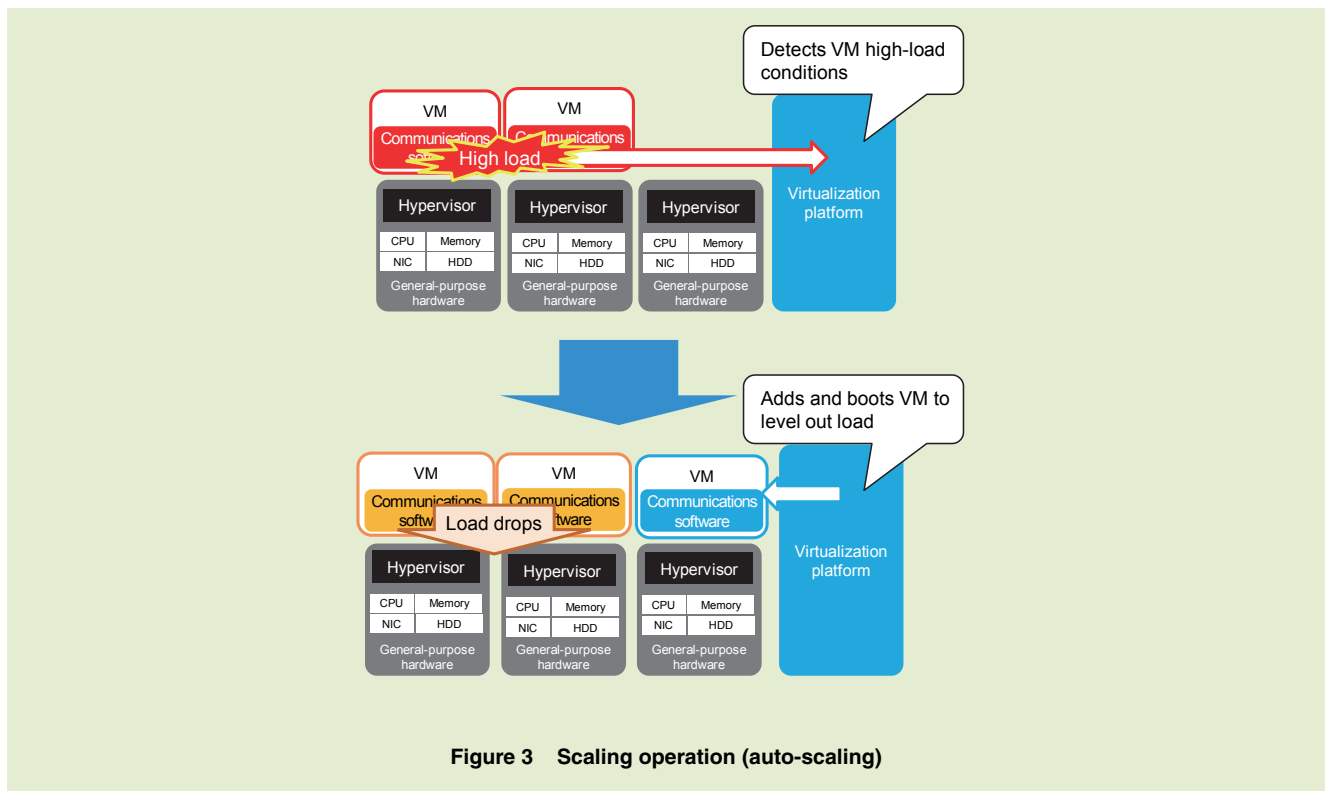
Today, at the dawn of NFV, there is a need for both auto-scaling and manual scaling. In the future, though, expanding the scope of auto-scaling will enable more rapid scaling in response to greater amounts of communications

traffic.

5.3 Healing

Next, improving the reliability of communications services can be achieved by a technique called “healing.” In the event of a hardware or VM failure, this technique moves the VM to (or recreates the VM on) good hardware thereby restoring the communications software to a normal state.

Similar to scaling, healing comes in two types: “auto-healing” in which the system detects a hardware or VM failure and automatically executes a healing process, and “manual healing” in which maintenance personnel judge the need for scaling and do so if needed in cases that automatic execution by the



system is difficult. An example of auto-healing is shown in **Figure 4**.

At present, there is a need for both auto-healing and manual healing, but the aim going forward is to improve reliability even further by expanding the scope of auto-healing.

5.4 Instantiation

Finally, early provision of services can be achieved by a technique called “instantiation.” This technique prepares a VM on general-purpose hardware and launches communications software on that VM. Once the resources needed by the communications software based on resource usage conditions have been secured from the resource pool made

up of many units of general-purpose hardware, the communications software is launched on the most optimal deployment destination.

An example of instantiation is shown in **Figure 5**.

6. NFV and New Network Issue

The ability to launch and move communications software on and to general-purpose hardware through NFV has many advantages. At the same time, dynamically moving communications software having particular communications requirements among general-purpose hardware units raises a new issue. That is, network devices (switches, routers,

etc.) connected to such general-purpose hardware must track this movement of communications software.

In conventional systems, communications software and dedicated hardware operate in an integrated manner. Thus, once the accommodating relationship between the hardware and network devices has been decided, settings (such as Virtual LAN (VLAN)*⁹ trunk port*¹⁰ settings) based on the communications requirements of that communications software can be registered beforehand in the network devices. However, in NFV, there is absolutely no knowledge as to what type of communications software will be launched at the point in time that the accommo-

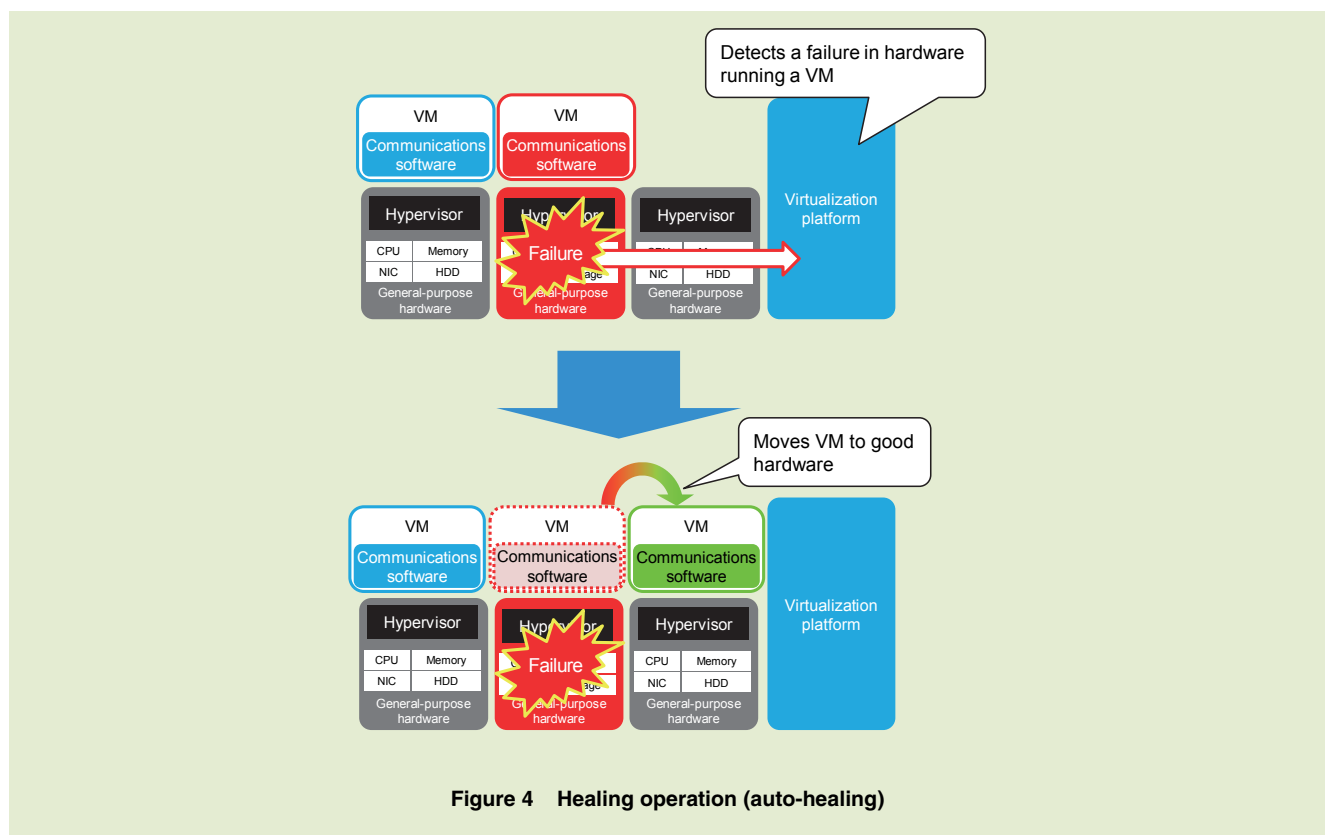
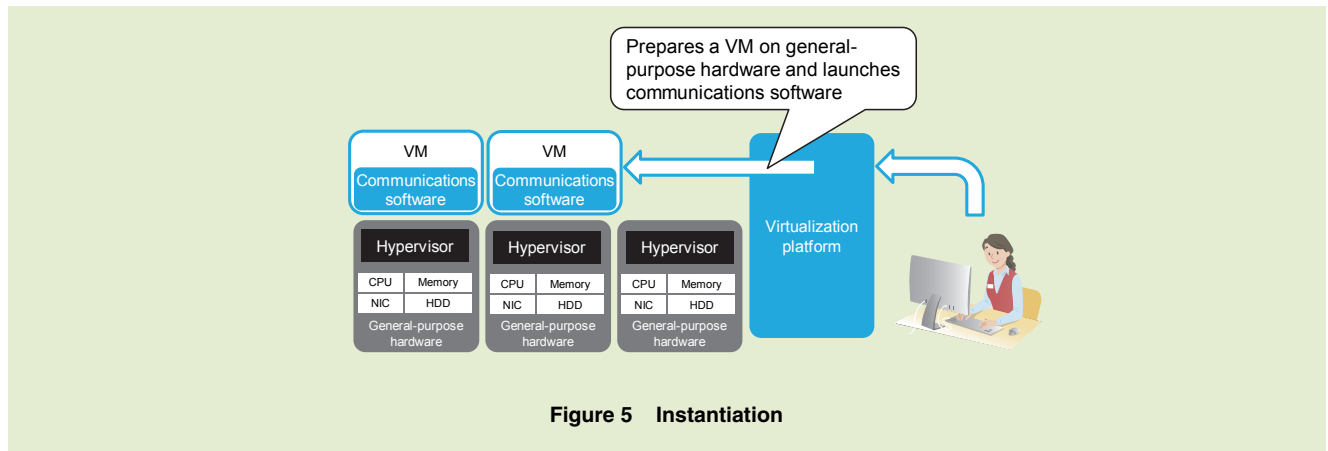


Figure 4 Healing operation (auto-healing)

*⁹ **VLAN:** Technology enabling the creation of a logical network irrespective of the physical connection layout. Since communications software connects to various networks, VLAN can be used to separate those networks appropriately.

*¹⁰ **Trunk port:** A port that belongs to multiple VLANs. The values of the VLANs to which the port belongs to must be set.



dating relationship with hardware is determined. There is therefore a need for a means of dynamically registering settings tied to the launching and movement of communications software.

NTT DOCOMO is introducing NFV combined with SDN to solve this issue. Another special article in this issue describes SDN [2].

7. Conclusion

In this article, we provided an overview of virtualization technology, described current issues faced by network operators, presented a solution based on the application of virtualization technology, described elemental virtualization technologies, and discussed a new issue generated by the introduction of NFV.

The application of virtualization

technology makes it possible to both improve connectivity in the communications network—a key social infrastructure—and reduce CAPEX/OPEX, which has heretofore been difficult to achieve. At present, discussions are being held on standardizing inter-system interface specifications for NFV, which applies virtualization technology to carrier networks. NTT DOCOMO has contributed to dramatic advances in this field by promoting proactive standardization activities and taking up the challenge of developing NFV under a multivendor product configuration. It has also become a world leader in introducing NFV and associated SDN network technology in its communications network.

Through a variety of development activities including the integration of

multivendor products and resource design taking reliability and ease of operation into account, NTT DOCOMO launched commercial services using NFV technology in March 2016.

Going forward, NTT DOCOMO plans to apply the results of its world-leading activities in combining multivendor products to making further contributions to the development of NFV.

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Special Articles on Network Functions Virtualisation—Toward a Robust and Elastic Network—

Activities toward NFV Standardization

As a standardization organization established by ETSI with the aim of achieving NFV in communications services, NFV ISG has been the arena for lively discussions on NFV. This article begins by providing an overview of the NFV ISG organization and activities to date. It then describes NFV reference architecture for virtualizing network functions and for managing and orchestrating the operation of those functions. Finally, it describes interaction and coordination with other standardization organizations and open source communities as relevant activities to promote the use of NFV.

Research Laboratories **Ryosuke Kurebayashi**
Ashiq Khan
Kazuaki Obana

1. Introduction

In November 2012, to find a common answer to the question “What is needed to virtualize telecom networks?”, seven network operators selected the European Telecommunications Standards Institute (ETSI)^{*1} for establishing the Network Functions Virtualisation^{*2} Industry Specification Group (NFV ISG).

At the time of NFV ISG establishment, virtualization technology was already being used by IT service providers, so network operators likewise envi-

sioned that virtualizing their networks could transform the cost structure of their business operations. A telecom network, however, differs from IT services in terms of large and complex Network Functions (NFs) that require high levels of performance and reliability and the need to interface with existing Operations Support System (OSS)^{*3} and Business Support System (BSS)^{*4}. With this in mind, NFV ISG has been building a consensus on common requirements and NFV reference architecture within non-binding (informative) discussions as a

prior step to studying concrete implementation methods. It then plans to broaden the scope of its activities to include formulation of binding (normative) specifications. NFV ISG has been growing and has come to include nearly 300 participating companies from around the world. NTT DOCOMO has been participating in NFV ISG since its very first meeting as a major contributor to NFV ISG architecture and specifications.

In this article, we summarize the history of NFV ISG and describe NFV

^{*1} **ETSI:** A European standardization organization concerned with telecommunications technology.

^{*2} **NFV:** Achieving a telecom network on general-purpose hardware through virtualization technology.

architecture whose standardization is now in progress. We also describe NFV ISG's interaction with other standardization organizations and open source communities as activities to promote the use of NFV.

2. NFV ISG

Led by network operators who actually procure and operate networking devices, NFV ISG aims to disseminate common NFV requirements to the entire Information and Communications Technology (ICT) industry with an emphasis on communications equipment vendors, standardization organizations, and open source communities. To this end, the organizational operation of NFV ISG has been designed to enhance collaboration and information dissemination among network operators. The NFV ISG organization is shown in **Figure 1**.

As of December 2015, NFV ISG consisted of a Technical Steering Committee (TSC) having the role of overall coordination and management, a Network Operator Council (NOC) serving as a liaison to network operators, and five Working Groups (WGs) each performing technology studies in a different field (see Phase 2 in Fig. 1).

The NOC is a key feature of NFV ISG that aims to enhance collaboration and information dissemination among network operators. It provides a forum for discussing needs and use cases with respect to strategic and priority issues of the operators. To date, 37 network operators, which make up nearly all of the major network operators in the world, have become NOC members.

NFV ISG holds a plenary meeting once a quarter. The first meeting held in January 2013 welcomed 150 partici-

pants from 57 organizations, which climbed to 219 participants and 295 registered organizations by the 13th plenary meeting held in February 2016.

NTT DOCOMO has been actively participating in NFV ISG since its launch by making proposals on use cases, architecture, etc. It has also contributed greatly to NFV ISG activities by holding posts such as NFV ISG vice chairman and TSC technical assistant manager.

NFV ISG activities are divided into Phase 1 that began in January 2013 and Phase 2 that began in December 2014. While Phase 1 focused on consensus building on NFV requirements and reference architecture (corresponding to stage 1 of NFV development), Phase 2 deals with the formulation of specifications for architecture and interfaces (stage 2).

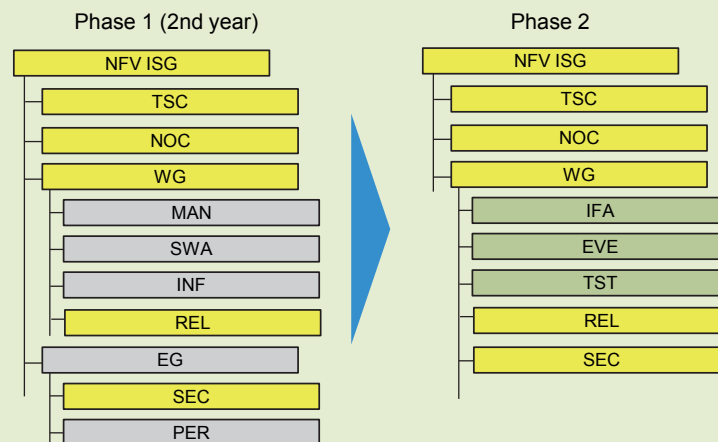


Figure 1 NFV ISG organization

*3 **OSS:** Operations support system of a network operator, responsible for system fault management, configuration management, charging management, performance management, and security management—all or in part—for smooth service operation.

*4 **BSS:** Business support system of a network operator used for customer management, order

management, etc.

2.1 Phase 1

1) Four Basic Documents

In the first year of its existence, NFV ISG published four basic documents (NFV use cases, architectural framework, terminology, and requirements) as Group Specifications (GSs) to serve as guidelines for standardization organizations and the market. These documents are summarized below.

- (1) NFV use cases [1]: This document summarizes NFV application fields as a basis for studying requirements and architecture.
- (2) NFV architectural framework [2]: This document summarizes high-level logical architecture and design concepts toward NFV standardization. It defines the architectural functional blocks and the reference points*⁵ connecting these blocks with the aim of achieving interoperability among multi-vendor products.
- (3) NFV terminology [3]: This document defines terminology used by NFV ISG. A uniform set of terms is essential to achieving a common understanding of new technical concepts in NFV.
- (4) NFV requirements [4]: This document summarizes high-level requirements toward the commercial use of NFV.

The public release of these documents helped the industry to rapidly develop a common understanding of NFV as proposed by NFV ISG.

2) NFV PoC

Another feature of NFV ISG is its Proof of Concept (PoC)*⁶ initiative in which network operators and vendors cooperate in developing PoCs to demonstrate the feasibility of concepts presented in the four basic documents. The NFV PoC framework works as a guide for creating an interoperable NFV ecosystem*⁷ and disseminates the results of joint PoCs to demonstrate the feasibility of NFV ISG-based solution to the world.

3) Expansion of the Basic Documents

In the second year of Phase 1, four WGs and two Expert Groups (EGs) were established and 16 GSs were published expanding upon the results of the four basic documents. These GSs are summarized below.

- (1) NFV Management and Orchestration (MANO) [5]: This document elaborates the NFV Architecture Framework, creates associated specifications to address management and orchestration tasks specific to virtualization, and defines new operations for NFV. The contents developed by NFV MANO constitute the most important result of NFV ISG. Almost all Work Items (WIs) involved in normative

standardization in Phase 2 are concerned with formulating specifications for the functional blocks and reference points defined in NFV MANO.

- (2) Virtual network functions architecture [6]: This document defines the software architecture of individual network functions known as Virtualised Network Functions (VNFs).
- (3) Infrastructure [7] – [12]: These documents define requirements and interfaces for the infrastructure where the VNFs are hosted and executed.

These documents are informative in nature; normative specifications are formulated in Phase 2.

2.2 Phase 2

In ETSI, an ISG is generally active for a maximum of two years. However, while Phase 1 discussions confirmed that interoperability based on open specifications is essential for the expansion and proliferation of NFV, it was generally understood that no standardization organization existed that could appropriately discuss NFV standards that involve many new technical concepts. It was therefore decided to extend the NFV ISG lifecycle for another two years. Phase 2 discussions then commenced toward the formulation of normative specifications by NFV ISG itself.

*⁵ **Reference points:** A conceptual point at the conjunction of two functional blocks defined in a specification.

*⁶ **PoC:** A relatively simple demonstration of the significance or feasibility of a new concept or idea.

*⁷ **Ecosystem:** A mutually beneficial interdependency in which multiple enterprises collaborate within a certain field or for business purposes making use of each other's technologies and resources while involving even consumers

and society. An ecosystem gives structure to a process flow ranging from R&D to sales, advertising, and consumption.

As shown in Fig. 1, Phase 2 consists of five WGs: InterFaces and Architecture (IFA), EVolution and Eco-system (EVE), TeSTing, experimentation, and open source (TST), RELiability, availability, and assurance (REL), and SECurity (SEC). These are summarized below.

- (1) IFA WG: Based on the results of Phase 1, this WG formulates architecture and interface (stage 2) specifications. In contrast to other WGs, the deliverables of this WG include normative specifications. Additionally, for the next step following stage 2, this WG cooperates with other standardization organizations and open source communities in formulating

detailed technical specifications sufficient for product implementation (stage 3) and in developing open source software.

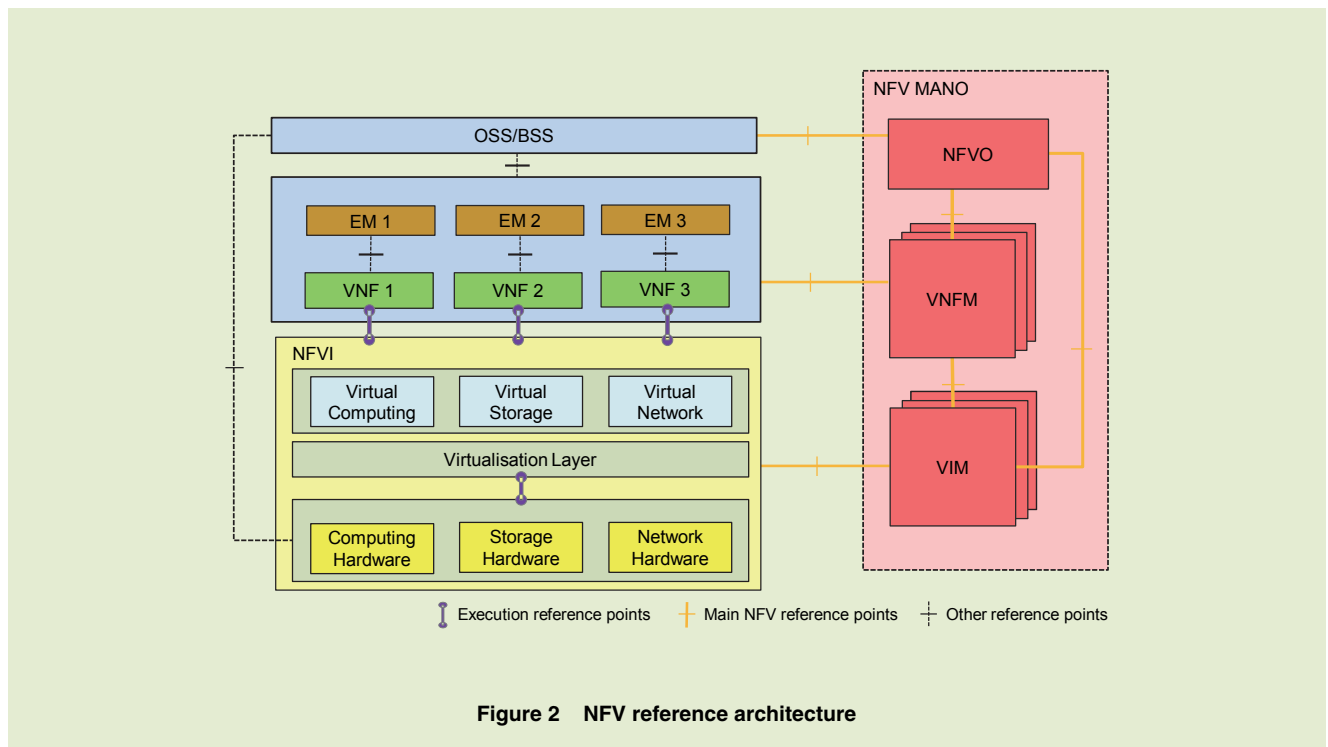
- (2) EVE WG: This WG studies new NFV use cases and the feasibility of new NFV-related technologies. It defines, for example, methods of applying Software Defined Networking (SDN) to NFV.
- (3) TST WG: To ensure the interoperability of multi-vendor products based on NFV specifications, this WG maintains and expands the PoC framework of Phase 1 and performs interoperability tests.

REL WG and SEC WG are carried

over from Phase 1 (although SEC has been moved from EG to WG) as discussions continue on NFV reliability and security.

3. NFV Reference Architecture

NFV ISG proposes the reference architecture shown in **Figure 2** with the aim of achieving a multi-vendor environment consisting of interoperable NFV-compliant products. This architecture defines the functional blocks making up NFV and the reference points between those functional blocks. The NFV architecture document [2], one of the basic documents delivered in Phase 1, defined the framework of this architecture and presented a detailed study on



NFV MANO, the functional block performing management and orchestration. In Phase 2, the IFA WG is mainly formulating stage 2 specifications on the reference point interfaces between these functional blocks.

3.1 Functional Blocks

The main functional blocks of the NFV reference architecture are VNFs, NFV Infrastructure (NFVI), and NFV MANO as described below.

1) VNFs

VNFs are the virtualized implementation of the NFs seen in a communication network. In conventional systems, NFs run on dedicated hardware equipment. However, VNFs are independent of the hardware as virtualization decouples the VNF software from the underlying hardware. A specific example of a VNF is a virtualized mobility management function or a virtualized packet processing gateway in an Evolved Packet Core (EPC)^{*8} mobile system. Such EPC VNFs realize a virtualized vEPC.

Although any virtualized network function implementation can be considered as VNF, there are significant differences in complexity between IT VNFs and telecom VNFs. Most VNFs in IT services can be deployed in a single Virtual Machine (VM)^{*9}. In contrast, most telecom VNFs require multiple VMs and their interconnections. A large scale telecom VNF may consist of sev-

eral hundred VMs.

2) NFVI

NFVI is the infrastructure for hosting and executing the VNFs. It consists of physical hardware resources such as computing, storage, and network devices as well as software called the “Virtualisation Layer” [2]. The Virtualisation Layer virtualizes these physical resources thereby providing virtual resources in the form of virtual computing, virtual storage, and virtual network to the VNFs. A VNF is configured on these resources.

Using virtualization technology to decouple the VNFs from the physical resources in NFVI enables an operator to build its infrastructure by using general-purpose products. It also enables the VNFs to be flexibly deployed without having to worry about the actual location of that hardware.

3) NFV MANO

NFV MANO manages each of the three elements newly introduced in telecom networks by NFV: (1) NFVI, (2) VNFs, and (3) network services in the form of virtual networks realized by interconnecting a set of VNFs. Furthermore, NFV Architecture [2] allows the connection of NFV MANO with OSS/BSS, which makes it possible to operate NFV in the current operation environments of network operators.

3.2 NFV MANO Functional Blocks

NFV MANO is divided into three

functional blocks as described below.

1) Virtualised Infrastructure Manager (VIM)

VIM is the overall manager of an NFVI. It manages the physical computing, physical storage, and physical network resources in NFVI and provides virtual resources based on upper-level requests from VNF Manager (VNFM) and NFV Orchestrator (NFVO).

2) VNF Manager (VNFM)

VNFM is a functional block that controls a VNF that may be complex and large in scale. It is responsible for VNF operations such as instantiation, termination, scaling, and healing, known as VNF lifecycle management events. In addition, the management of Fault, Configuration, Accounting, Performance and Security (FCAPS)^{*10} specific to a VNF is carried out by an Element Manager (EM)^{*11} found in legacy implementations.

3) NFV Orchestrator (NFVO)

NFVO performs two main functions as described below.

- First, as a function related to virtual resources, NFVO uniformly manages virtual resources on multiple NFVIs that are being managed by respective VIMs. For example, it monitors the capacity of each NFVI through their respective VIMs. NFVO is the manager that has a complete view of the whole virtualized network spanning multiple NFVIs and

^{*8} **EPC:** A communications system that accommodates a variety of radio access technologies including LTE and that provides customer authentication, mobility management for uninterrupted data communications while moving, etc.

^{*9} **VM:** A computer created in a virtual manner by software.

^{*10} **FCAPS:** Refers to fault, configuration, accounting, performance, and security as management and monitoring items in a network.

^{*11} **EM:** A functional block that manages and monitors FCAPS with respect to individual network equipment.

VIMs. For VNF instantiation, a VNFM will issue a request to the NFVO, which will then select an appropriate VIM based on location requirements or resource availability.

- Second, regarding network services, NFVO can configure a network service by establishing connections among VNFs and existing non-virtualized physi-

cal network functions, and it can control the lifecycle of that service.

3.3 Basic Process Flow

To give an example of a typical process in NFV reference architecture, **Figures 3 and 4** show the process flow for requesting the creation of a new network service from OSS/BSS to NFVO.

At first, a VNF package that con-

tains the information on VNF structure and configuration, software images of VMs, etc. is uploaded from OSS/BSS to NFVO/VNFM as shown by step (1) in Fig. 3. This uploaded VNF package is shared with the corresponding VNFMs (step (2)).

Next, OSS/BSS instructs NFVO to create the network service as shown by step (1) in Fig. 4. NFVO now selects the VNFs that will make up the net-

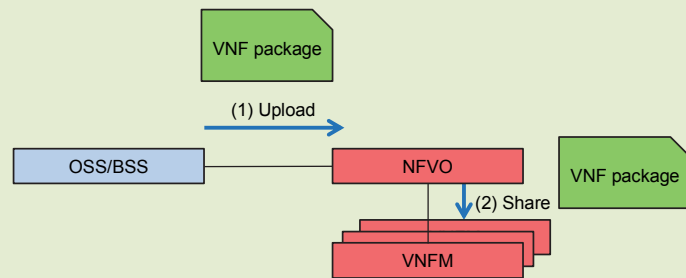


Figure 3 VNF package upload

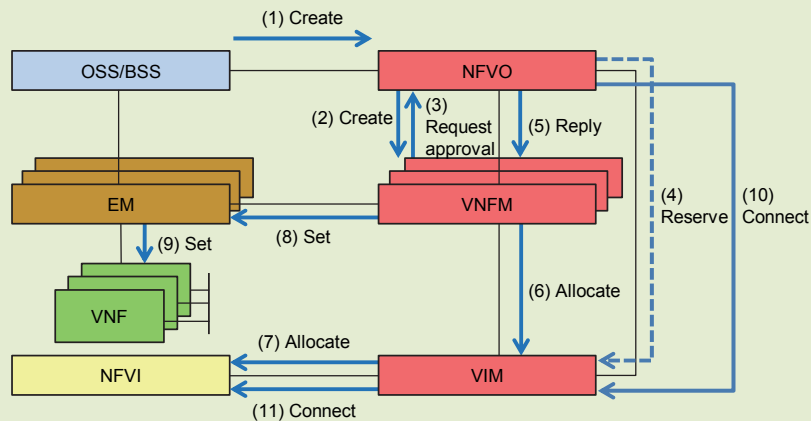


Figure 4 Flow of network service creation

work service and the VNFM to manage those VNFs, and instructs the selected VNFM to create those VNFs (step (2)). At this time, VNFM estimates the virtual resources needed to create the specified VNFs. The VNFM presents the NFVO the list of estimated virtual resources and requests approval for allocating those virtual resources (step (3)). The NFVO judges whether the requested virtual resources are available in the VIMs and replies to the VNFM accordingly (step (5)). Here, the NFVO can request the VIMs to reserve those virtual resources (step (4)) to ensure that the VNFM is guaranteed to use the requested virtual resources during the VNF instantiations.

Now, based on the reply from the NFVO, the VNFM requests the VIMs to allocate the virtual resources as shown by steps (6) and (7) in Fig. 4. This allocation can be requested to the VIMs directly from the VNFM or via the NFVO. Next, the VNFM coordinates with the respective EMs to make the necessary VNF configuration (steps (8) and (9)) thereby completing the instantiation of the VNFs. Finally, the NFVO interconnects the VNFs (steps (10) and (11)) completing creation of the requested network service.

4. Activities for Promoting the Use of NFV

NFV ISG has been actively interacting with other standardization organizations

and open source communities in their respective fields. In particular, collaborating with open source communities reflects a new approach since the conventional approach of developing de jure standards^{*12} can result in a lengthy commercializing period because of the time needed for consensus building among participating institutions. The IT world, in fact, has incorporated open source solutions for some time and has a proven record in promulgating new technologies in a relatively short period of time.

NFV ISG has therefore been fostering ties with other standardization organizations such as Third Generation Partnership Project System Aspects-5 (3GPP SA5)^{*13}, TeleManagement (TM) Forum^{*14}, Next Generation Mobile Networks (NGMN)^{*15} [13], and Open Networking Foundation (ONF)^{*16} [14], and with open source communities including OpenStack^{*17} [15], OpenDaylight^{*18} [16], and Open Platform for NFV (OPNFV) [17]. It has also been concluding Liaison Statements^{*19} and Memorandum of Understanding (MoU)^{*20} agreements with these parties. These activities are enabling prompt launching of services using NFV-related open source software. Ensuring interoperability in this way based on uniform standards and their implementation should facilitate the creation of an effective NFV ecosystem.

4.1 OPNFV

Today, in the field of cloud compu-

ting, open source software (such as OpenStack, OpenDaylight) is becoming mainstream. However, a number of functional differences exist between such open source software and NFV ISG's NFV reference architecture and specification, preventing multi-vendor interoperability.

To solve these differences and guarantee interoperability, OPNFV was established in October 2014 to develop a NFV reference platform that integrates NFVI and VIM. NTT DOCOMO is a founding member, and at present, 19 platinum members consisting of network operators (including NTT DOCOMO) and IT companies, and 42 silver members are participating in OPNFV. Work is progressing on the creation of a NFV reference platform that uses existing open source software such as OpenStack, OpenDaylight, Open vSwitch^{*21} [18], and Kernel-based Virtual Machine (KVM)^{*22}. OPNFV plans to issue two releases a year of its NFV reference platform. The first release called Arno was released in June 2015, and the second release called Brahmaputra was released in March 2016.

OPNFV artifacts are published through an Apache[®] Version 2.0 license^{*23}. All decisions in OPNFV are reached by voting making for rapid consensus building and all meetings and documents are made public. Anyone can participate in OPNFV.

OPNFV promotes new feature de-

^{*12} **De jure standard:** A standard formulated by a public institution such as a standardization organization.

^{*13} **3GPP SA5:** 3GPP is a standardization organization concerned with mobile communications systems. SA5 is a working group discussing OSS/BSS relevant topics in 3GPP.

^{*14} **TM Forum:** A non-profit organization study-

ing industry standards for the management of telecom networks.

^{*15} **NGMN:** An organization that formulates visions and roadmaps for next-generation mobile communications networks. It is composed of vendors and operators including NTT DOCOMO.

^{*16} **ONF:** A non-profit organization promoting SDN-related standardization activities. Open-

flow is a standard protocol formulated by ONF.

^{*17} **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 used by the users. OpenStack is open source software.

velopment in the upstream communities (e.g. OpenStack, OpenDaylight). This reduces code maintenance tasks in OPNFV as the upstream communities can maintain the codes by themselves. Apart from integration of the reference platform, OPNFV also performs gap analysis between standard specifications and open source software and formulates new requirements based on such gaps. Interested parties can then take these requirements for implementation in the respective upstream communities. NTT DOCOMO also leads two projects in OPNFV that formulate two distinct requirements for OpenStack. Brief description of the two projects are given below.

1) Doctor Project [19]

This project aims to achieve fast fault notification from VIM to VNFM to ensure high service availability in telecom nodes. The fault detection and notification requirements are quite stringent for telecom nodes compared to an ordinary IT node. At the time of OPNFV establishment, the time interval from fault detection to notification was on the order of several minutes in OpenStack. This would be a major issue in the event of a fault in a telecom network if fault detection and consequent notification took that long.

The Doctor project proposed and implemented a northbound interface from OpenStack which can notify a VNFM about fault events on computing resources.

It also significantly reduced the notification latency in OpenStack. These features have already been deployed and released in OpenStack Liberty release^{*24}. Specifications for remaining development items for computing resource faults have already been submitted to the OpenStack community. They are expected to be developed and integrated in the OpenStack Mitaka release^{*25}.

2) Promise Project [20]

This project aims to add a resource reservation function to OpenStack in the form of a plug-in as a case study. Once interoperability between this plug-in software module and OpenStack has been achieved, the next step will be to develop the resource reservation function within OpenStack. Completed Promise features have been released in the OPNFV Brahmaputra release.

4.2 Other Open Source Communities

Similar to OPNFV, many other open source communities are being established to achieve the NFV reference architecture defined by NFV ISG. These include Open Source MANO for developing NFV MANO [21], and Open Baton and others for developing NFVO [22], all of which reflect steady progress in the implementation and adoption of NFV through open source initiatives.

5. Conclusion

This article reviewed the history of

NFV ISG, described NFV architecture now under a normative specification process, and explained how NFV ISG is interacting and coordinating with other standardization organizations and open source communities to promote the use of NFV.

The telecommunications industry has high expectations for the results obtained through NFV ISG activities, and NFV-related implementations are moving forward through open source projects and commercial systems. These initiatives will help clarify areas in need of technical improvement in the NFV reference architecture. A well-coordinated implementation-to-standardization cycle is important for the fast adoption of NFV in the ICT industry.

NTT DOCOMO participated in the following two collaborative R&D projects funded by the Ministry of Internal Affairs and Communications (MIC). The experimental results from these projects have been reported to MIC and used in standardization discussions at NFV ISG.

- FY2012 “Experimental challenges for dynamic virtualized networking resource control over an evolved mobile core network - a new approach to reduce massive traffic congestion after a devastating disaster” in collaboration with Tohoku University, NEC Corporation, Hitachi Solutions East Japan, Ltd., and Fujitsu Limited.

^{*18} **OpenDaylight:** Software that provides functions for externally controlling network equipment based on the SDN concept. OpenDaylight is open source software.

^{*19} **Liaison Statement:** A statement that is exchanged when a standardization organization collaborates or exchanges information with another institution.

^{*20} **MoU:** A statement that summarizes an agreement between two organizations.

^{*21} **Open vSwitch:** Software that creates virtual switches for connecting virtual machines in a virtualization environment. Open vSwitch is open source software.

^{*22} **KVM:** Software for achieving virtualization. KVM is open source software.

^{*23} **Apache® Version 2.0 license:** A license format used in open source software.

^{*24} **Liberty release:** The 12th release of OpenStack open source software used for managing a cloud environment. Released on October 15, 2015.

^{*25} **Mitaka release:** The 13th release of OpenStack open source software used for managing a cloud environment. Released on April 7, 2016.

- FY2013 “Research and development of network conversion of communication processing functions in large-scale communication congestion” in collaboration with The University of Tokyo, Tohoku University, NEC Solution Innovators, Ltd., NEC Corporation, and Fujitsu Limited.

In addition to the above, NTT DOCOMO successfully deployed NFV technology in its commercial EPC network in March 2016 using multi-vendor equipment based on NFV ISG specifications. The knowledge obtained by this commercial deployment will be fed back to standardization activities as part of NTT DOCOMO’s ongoing contributions to NFV ISG.

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Special Articles on Network Functions Virtualisation—Toward a Robust and Elastic Network—

Practical Implementation of Virtualization Platform in NTT DOCOMO Network

NFV ISG's proposal of operating communications APLs on the cloud has triggered lively discussions throughout the world. These discussions have uncovered issues that must be resolved to achieve NFV including (1) degradation of APL processing performance due to resource sharing, (2) the need for techniques to maintain fault resilience in applications running on the cloud, and (3) the complexity of troubleshooting on the physical and virtual layers at the time of a fault. This article describes a virtualization platform that NTT DOCOMO has implemented to resolve these issues.

Core Network Development Department

Toboru Kamada**Yuuya Kuno****Hironao Tamura****Hiroshi Iwamiya**

1. Introduction

NTT DOCOMO has been promoting the development of a virtualization platform based on the architectural framework standardized in the Network Functions Virtualisation (NFV)^{*1} Industry Specification Group (ISG). There are a number of items that must be considered toward the practical implementation of such a platform based on the characteristics of the network operator. These include the (1) design and operation of a resource pool, (2) requirements

for operating a communications Application (APL)^{*2} in a cloud environment^{*3}, and (3) change in the network-construction and maintenance/operation formats used by the network operator. The network operator must decide on what course of action to take with respect to these matters based on its own policies and plans, as discussed below.

- (1) The design and operation of a resource pool depends on the facilities possessed by the network operator and its approach to communications APL reliabil-

ity, so the network operator itself must design the resource pool.

- (2) As a critical type of software providing communications services to users, degradation in the performance and quality of a communications APL is directly related to a drop in the quality of user services. The performance, quality, and reliability [1] demanded of communications APLs running in a cloud environment must therefore be maintained.
- (3) Virtualization means the addi-

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^{*1} **NFV:** Achieving a carrier network on general-purpose hardware through virtualization technology.

tion of a virtualisation layer, so the maintenance of communications APLs as in fault troubleshooting is likely to become increasingly complicated. Maintenance operations must be made more efficient to deal with this added complexity.

Based on the needs and requirements described above, NTT DOCOMO clarified the issues to be targeted and took measures to resolve them. Thanks to these efforts, it completed the practical implementation of a virtualization platform and launched a commercial service based on this platform in March 2016.

In this article, we first clarify the issues and requirements surrounding the operation of communications APLs in a cloud environment with the aim of making the most of what virtualization can

offer. We then describe the practical implementation of a virtualization platform that applies measures for resolving and satisfying those issues and requirements. Here, we assume that virtualization can be achieved without changing the software structure of communications APLs so that the cost of their development can be reduced.

2. Issues Surrounding Communications APLs in a Cloud Environment

To make effective use of the benefits that virtualization can provide, certain issues need to be recognized and resolved. These issues are discussed below.

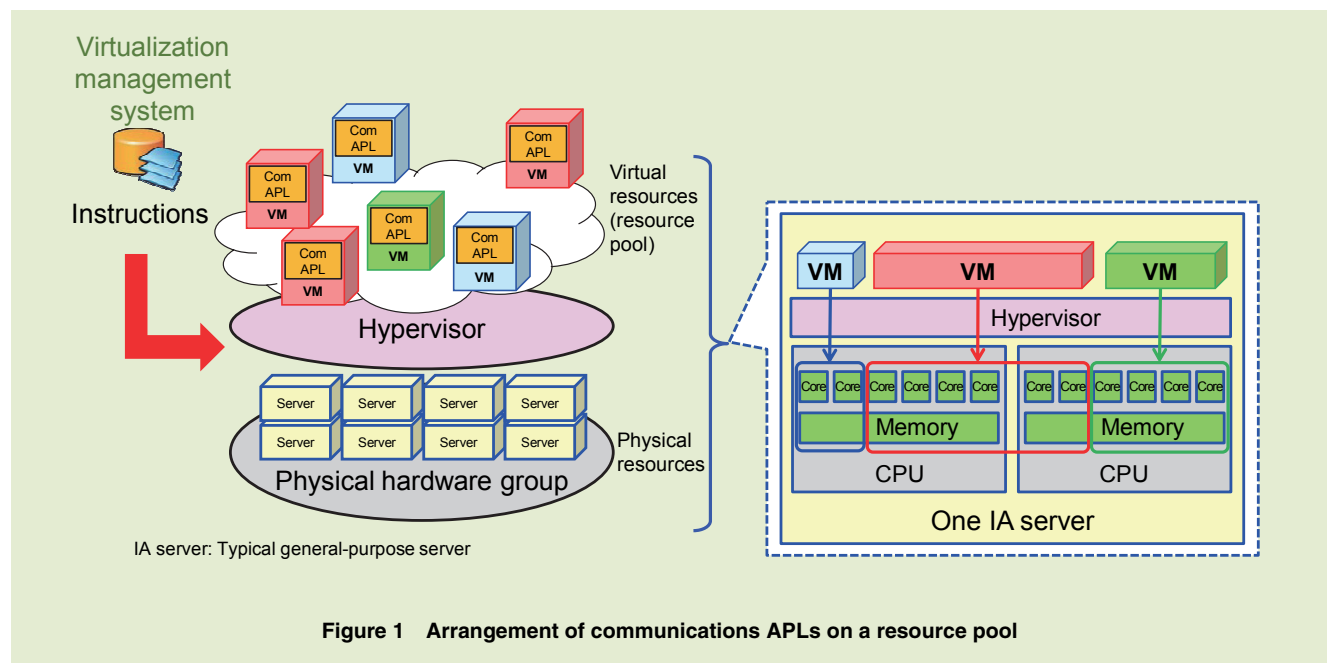
2.1 Resource Sharing (Issues 1 and 2)

In general, virtualization makes it

possible for multiple applications to share virtual resources. This makes resource usage more efficient, which is a benefit to users. In addition, virtualizing physical resources such as computers, networks, and storage through the use of a Hypervisor^{*4} enables the creation of virtual computers, virtual networks, and virtual storage so that physical resources can be hidden from applications. In other words, running a communications APL on virtualized equipment called a Virtual Machine (VM)^{*5} eliminates the need to worry about the physical configuration of equipment and makes development work such as OS upgrading unnecessary when a physical server reaches its End Of Life (EOL)^{*6}.

A conceptual diagram of arranging communications APLs on a resource pool is shown in **Figure 1**.

In the past, the arrangement and de-



^{*2} **Communications APL:** Refers to the functional components making up a necessary function in the provision of telecommunications services. Specifically, it means an application that runs on telecommunications equipment such as switches, transmission equipment, and radio

equipment.

^{*3} **Cloud environment:** A virtualization platform such as VMware and OpenStack for achieving virtualization.

^{*4} **Hypervisor:** A control program for creating and running virtual machines—a type of virtualization technology.

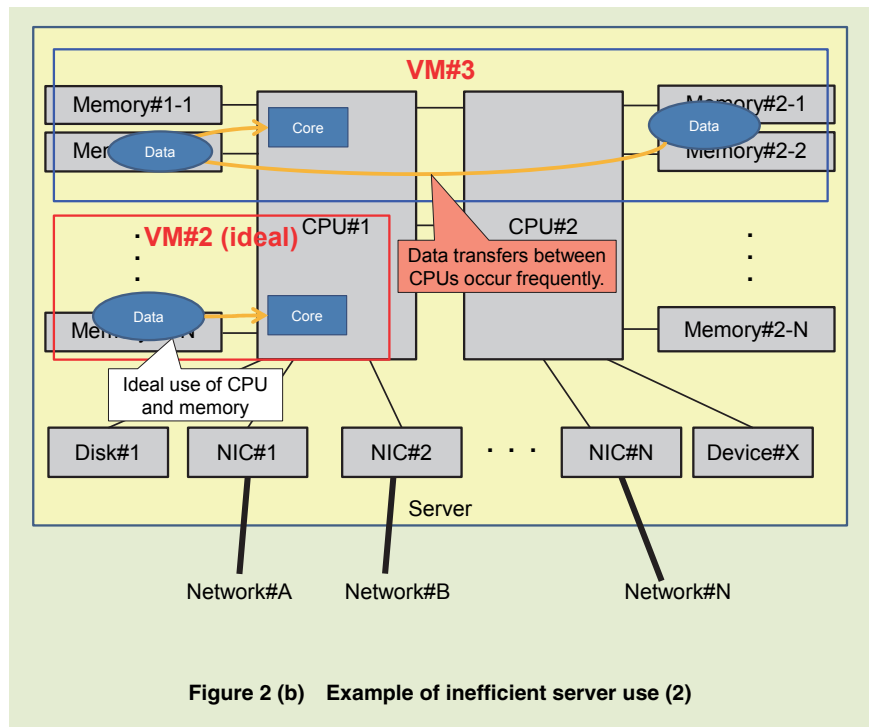
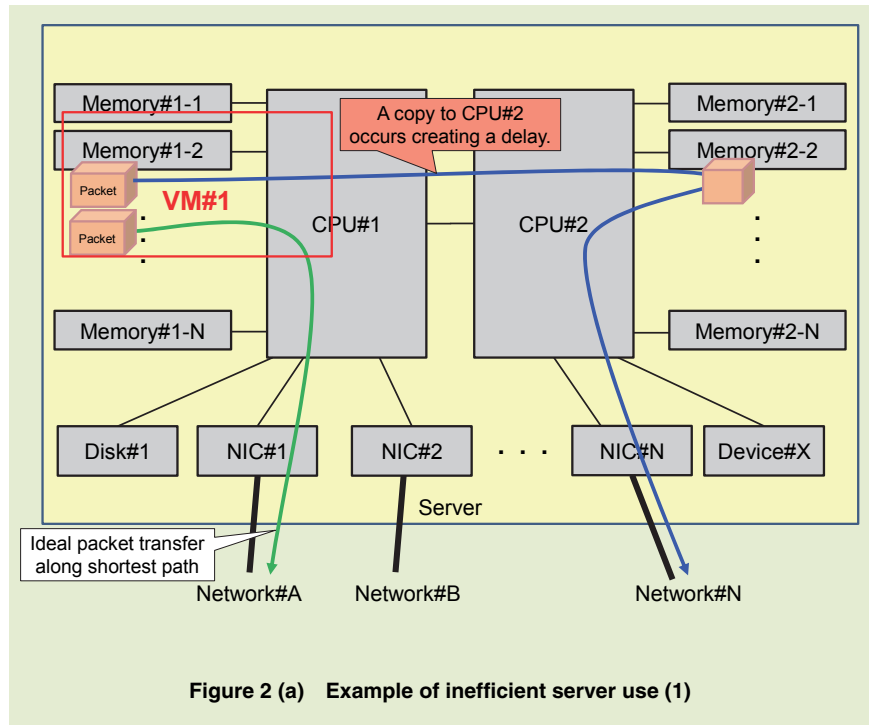
^{*5} **VM:** A computer created in a virtual manner by software.

^{*6} **EOL:** Termination of product support.

sign of the functional components of communications APLs and design work related to processing performance and fault resistance was carried out based on the network's hardware configuration. However, when running communications APLs in a cloud environment, actual hardware is concealed by VMs, which generates new issues such as greater processing delay and degraded fault resistance. These issues are described below.

1) Processing Delay in Communications APLs (Issue 1)

The advantage of concealing physical resources from communications APLs is that applications can be mounted and executed as needed without having to worry about the wiring between servers and network devices, the actual server configuration, etc. On the other hand, arranging applications on a resource pool means that specific physical servers cannot be specified. There is therefore concern that VMs will be unintentionally arranged in such a way that they use physical resources that are a high hop count^{*7} away, or that CPUs or memory will be used in an inefficient manner within the internal structure of a server as shown in **Figures 2 (a)** and **(b)**. In any case, the end result will be a processing delay. When introducing a virtualization platform, an application will be mounted on multiple VMs depending on the configuration of the application's components and the VMs will be placed on free resources in the



resource pool. However, considering that the internal structure or bandwidth of a physical server cannot be optimized

and that variation in processing time will arise due to the introduction of a hypervisor (described below), processing

^{*7} **Hop count:** In a communications network, the number of relays that must be passed through to arrive at the other party in the communication session.

delay will occur.

The issue of processing delay caused by virtualization is shown in **Figure 3**. Compared with the case of “no virtualization,” that is, the direct use of physical equipment, virtualization produces a variation in processing time. This

phenomenon occurs because controlling multiple virtual resources and physical resources by software via the hypervisor results in processing between virtual resources and processing by the hypervisor itself, which generates competition for physical resources (**Figure 4**).

Consequently, a time offset can occur with local time due, for example, to non-uniform delay in time clock processing within a VM. For a similar reason, the Turn Around Time (TAT)^{*8} of communications APL processing can appear to fluctuate wildly to external

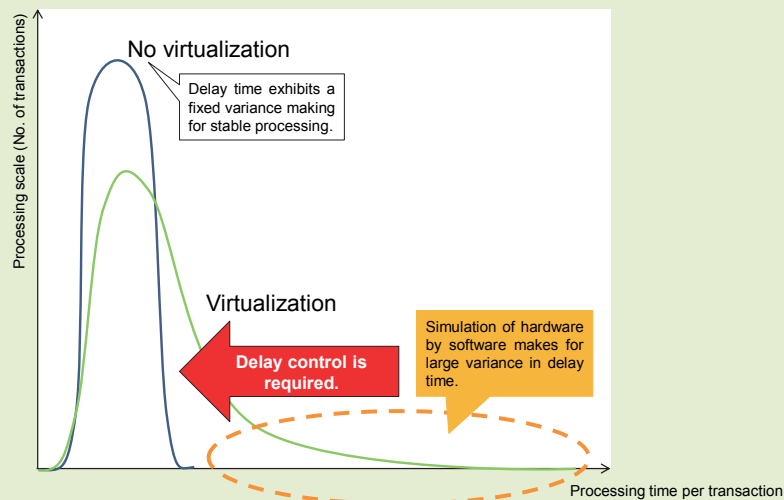


Figure 3 Distribution of processing delay by virtualization

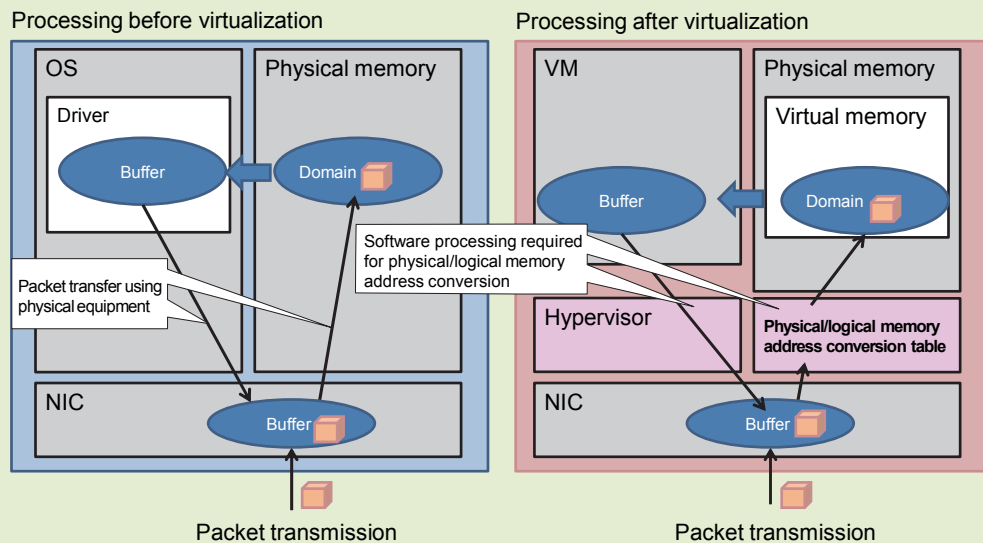


Figure 4 Mechanism of processing delay

^{*8} **TAT:** The time taken from the beginning of application processing to the output of results.

equipment. Under these conditions, virtualization cannot produce stable processing speeds making it difficult to maintain the processing performance of communications APLs. This situation calls for a resource control method independent of hypervisor processing.

2) Fault Resistance in Communications APLs (Issue 2)

Resource sharing means that multiple VMs can be mounted on a single physical server, but doing so means that the failure of one physical server can have a great impact on communications APLs thereby degrading user services.

It is therefore necessary to consider a redundant configuration for each component making up a communications APL as well as a VM arrangement technique that prevents a “double failure” scenario from occurring.

2.2 Maintenance of Virtual Applications (Issue 3)

The addition of virtual applications is expected to expand the cloud environment and resource pool. Moreover, VMs that execute communications APLs will move about the resource pool as part of an auto-healing function provided by the virtualization platform. In short, it goes without saying that maintenance will become increasingly complicated compared with the integrated maintenance of hardware and software in conventional systems. As a consequence, the volume of maintenance operations will increase and personnel with an ex-

panded skill set will be needed to troubleshoot network faults. To facilitate fault troubleshooting based on the state of communications APLs or the NFV Infrastructure (NFVI)*⁹, the operating conditions of VMs and servers need to be visualized.

2.3 Requirements of a Virtualization Platform in a Cloud Environment

To deal effectively with the issues described above, a virtualization platform that accommodates communications APLs must be able to:

- (1) Construct virtual resources that eliminate delay by monopolizing physical resources
- (2) Construct a resource pool enabling definition of a VM arrangement policy
- (3) Visualize the logical and physical configurations of communications APLs

3. Practical Implementation of a Virtualization Platform

3.1 Construct Virtual Resources that Eliminate Delay by Monopolizing Physical Resources

1) Countermeasure to Delay in Data Transfers

The application of paravirtualization technology [2] is a common method for improving performance in a virtual environment. In this method, phys-

ical hardware that incorporates virtualization support functions substitutes for the hypervisor in performing some of its software-based processing. Paravirtualization makes it possible to control the delay associated with hypervisor intermediary processing and avoid the effects of that delay (**Figure 5**).

However, when applying paravirtualization technology, functions are provided by physical hardware, so the communications APL or virtualization platform will have to issue control instructions depending on the functions or system configuration of concern. It will also be necessary to define in detail the relationship between virtual resources and physical resources, which can complicate the construction of a common resource pool. As a result of the above, the application scope of paravirtualization has its limits.

In the case of a communications APL, the location for controlling delay would be mainly the data transfer section. Accordingly, we define the combination of a CPU and Network Interface Card (NIC)*¹⁰ as a cell that can provide maximum communications performance and apply paravirtualization to only those NICs for which delay is not allowed. Here, by applying virtualization to memory and storage as before, we can create a common resource pool by simply choosing which servers and cells to use in arranging VMs and deciding whether to use any NICs that apply paravirtualization (**Figure 6**).

*⁹ **NFVI**: Generic name for general-purpose servers, storage, and network devices making up a cloud infrastructure.

*¹⁰ **NIC**: An extension card for connecting a general-purpose server with a LAN.

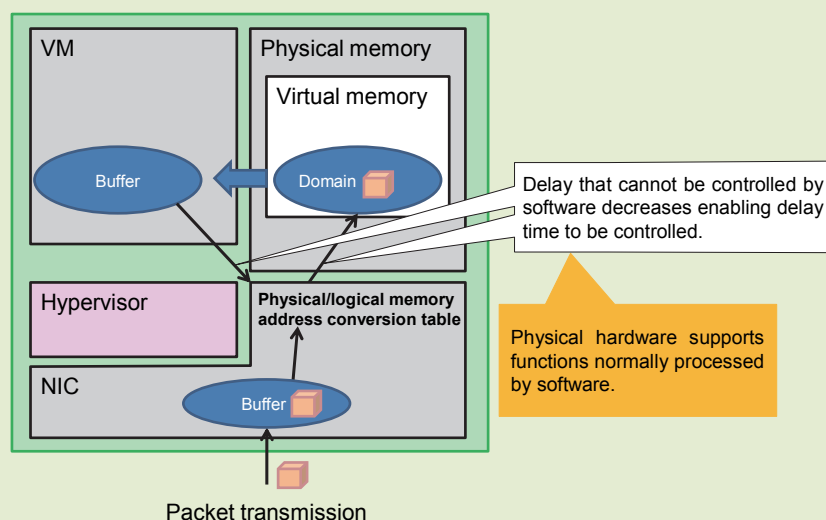


Figure 5 Use of paravirtualization technology

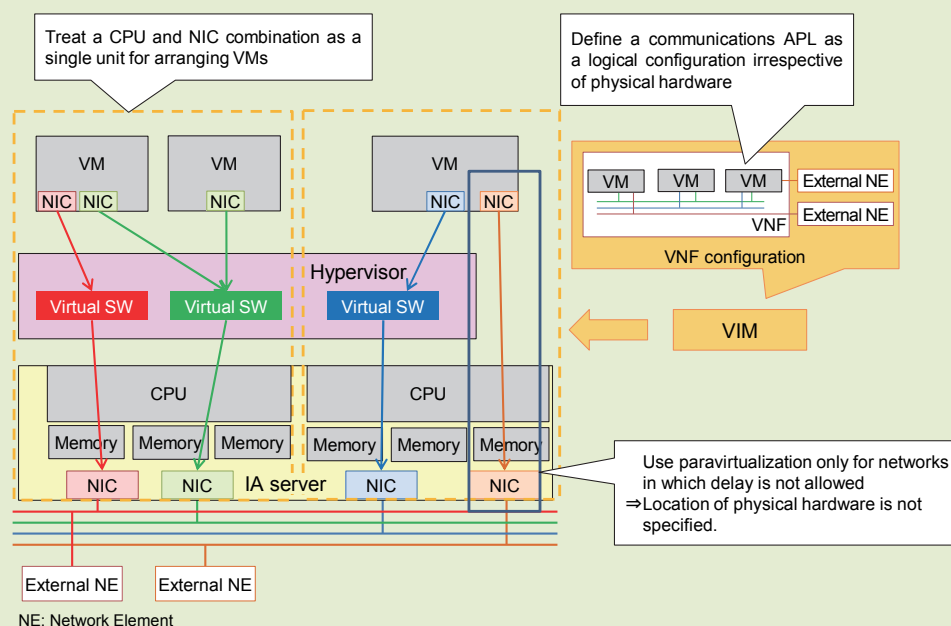


Figure 6 Adoption of paravirtualization technology

2) Countermeasure to Processing Delay in Executing a Communications APL

A communications APL runs on a VM, so a requirement for stable VM operation is CPU monopolization. In

other words, more than one VM must not be allowed to run on the same CPU. We have achieved CPU monopolization by interpreting the CPU/memory/NIC structure of the target NFVI servers and defining a virtual resource as the num-

ber of cores^{*11} in a CPU deemed necessary for VM operation.

Applying the above countermeasures has enabled us to construct virtual resources that satisfy the performance

^{*11} **Number of cores:** The number of units performing processing within a CPU.

requirements of communications APLs.

3.2 Construct a Resource Pool Enabling Definition of a VM Arrangement Policy

In conventional systems, the functional components making up a communications APL were made redundant using an ACT^{*12}-SBY^{*13} configuration or nACT configuration^{*14} to improve reliability and extendibility. However, if a VM with functional components having an ACT-SBY configuration is mounted on a single server, the failure of that server will bring about a double failure (in which both the active and standby systems fail) resulting in a service disruption. There is therefore a need to define VM arrangement rules so that redundant components are not arranged on the same server and to design a resource pool in accordance with those rules. It must be kept in mind here that VM arrangement on physical servers is executed in conjunction with control functions such as scaling^{*15},

healing^{*16}, and instantiation^{*17}.

The following describes resource pool construction, definition of a VM arrangement policy, and the functions of the components making up the virtualization platform.

1) Resource Pool Construction

Resource pools are constructed in units of Virtualised Infrastructure Manager (VIM)^{*18} blocks, with each such unit divided into multiple zones. Zones, in turn, are configured in units of racks that are given a redundant configuration to provide for failures in network devices. The relationship between a resource pool and zones is shown in **Figure 7**. As shown, a configuration that prevents a double failure from occurring at the time of a server failure or zone failure can be achieved by arranging a VM having ACT-SBY redundancy on different zones in the resource pool. In addition, a VM having nACT redundancy can prevent the effects of zone failures caused by multiple failures of network devices. While the

number of required zones is equal to ‘n’ in “nACT,” the specific number can be decided by the network operator based on the conditions of its facilities and the characteristics of its communications APLs.

2) Definition of VM Arrangement Policy

We here describe the allotment of functions in the virtualization platform in relation to defining a VM arrangement policy. The VIM is in charge of defining a resource pool and zones as well as controlling individual physical servers, while the Virtual Network Function Manager (VNFM)^{*19} and NFV Orchestrator (NFVO)^{*20} perform only control operations with respect to the resource pool (zones) [3]. In other words, while VIM would select a server within a chosen zone, VNFM would investigate the redundant configuration of each VM and choose zones according to an ACT-SBY or nACT configuration. The NFVO, meanwhile, would manage the capacity of the resource pool. This divi-

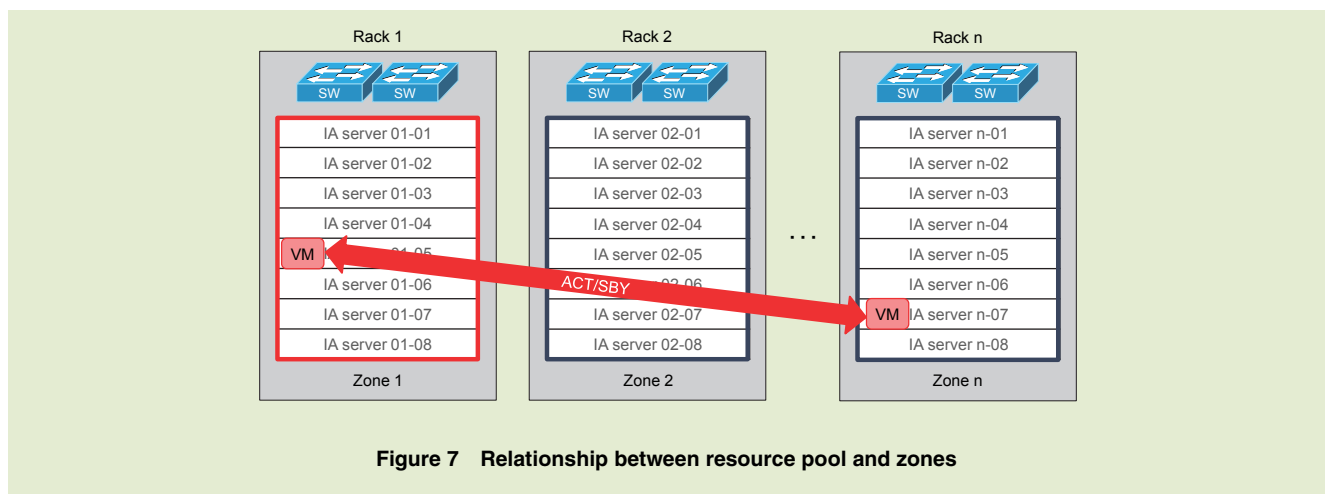


Figure 7 Relationship between resource pool and zones

^{*12} **ACT:** The parts of a redundantly configured communications application that are actually being used.

^{*13} **SBY:** The parts of a redundantly configured communications application that are currently on standby.

^{*14} **nACT configuration:** Distributes the load across n number of servers operating in parallel. If a server malfunctions, its processing can be taken over by another server.

^{*15} **Scaling:** The optimization of processing power by increasing or decreasing VMs that con-

figure communications software whenever processing power is insufficient or excessive according to hardware and VM load conditions.

sion of functions on the virtualization platform enables a VM arrangement that maintains the fault resistance of communications APLs.

3.3 Visualize the Logical and Physical Configurations of Communications APLs

We here describe a method for maintaining communications APLs in a cloud environment. Communications APLs launched in a NTT DOCOMO cloud environment assume the software configuration of conventional communications APLs, which means that the Operation Support System (OSS)^{*21} that monitors and controls communications APLs can inherit conventional monitor and control functions.

The fact that a conventional communications APL has a configuration integrated with hardware enables an OSS that has received an alert from a communications APL to narrow down

the location of faulty hardware. In a cloud environment, however, VMs move about under control of the auto-healing function, which makes it difficult to isolate the faulty VM and the server on which that VM is running. Thus, when troubleshooting a fault in a communications APL or on related equipment by investigating software (logical configuration) and hardware (physical configuration), visualization of the logical configuration and physical configuration is essential to identifying the server on which the VM is running.

In visualization of the logical configuration, we unified the naming rules for communications APL components and VMs so that a correspondence could be attached between those components displayed on the OSS and VM names on the resource pool. This clarifies the relationship between the components making up the communications APL and VMs making up the virtual resources.

Next, in visualization of the physical configuration, knowing that VIM manages the connection between servers and VMs on the resource pool, we pass that information to the OSS to enable the logical configuration and physical configuration of the communications APL in the OSS to be visualized. In this way, conventional monitoring and control methods can be inherited (**Figure 8**).

4. Conclusion

This article presented the issues surrounding the operation of communications APLs in a cloud environment and described the practical implementation of a virtualization platform that resolves those issues.

Network construction and maintenance operations need to be made more efficient to run communications APLs on the cloud. To this end, we plan to study a new network service^{*22} that can reduce the work of having to make var-

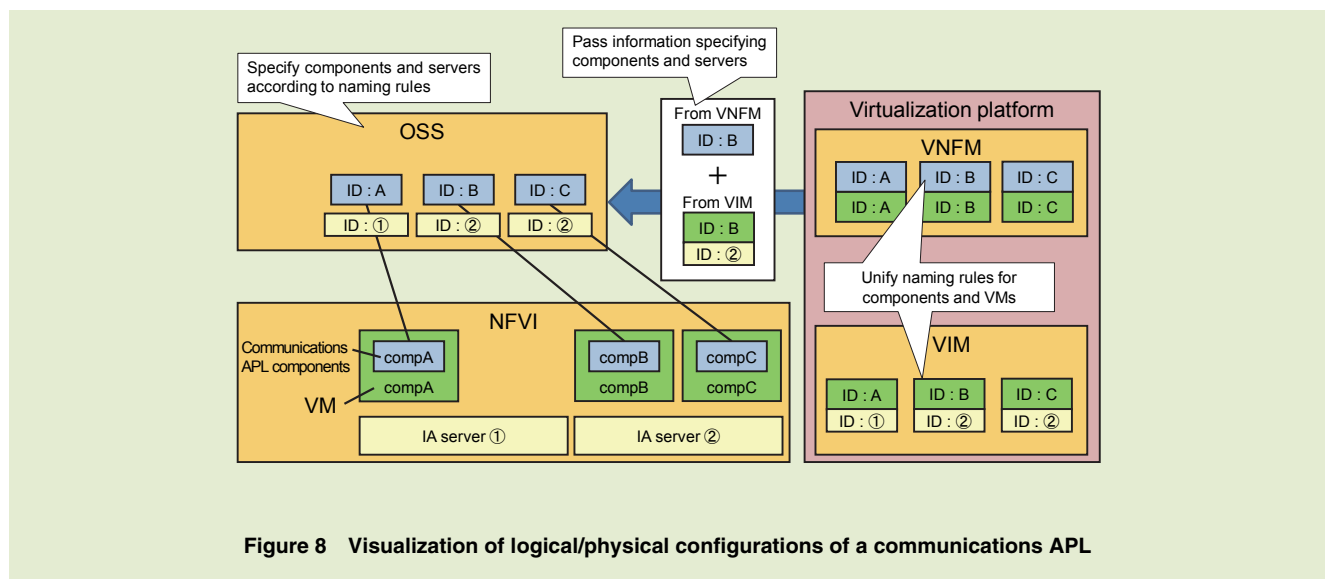


Figure 8 Visualization of logical/physical configurations of a communications APL

^{*16} **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.

^{*17} **Instantiation:** A procedure for launching a

communications APL in a cloud environment.

^{*18} **VIM:** The system that manages the physical resources on the virtualization platform consisting of physical computers, physical storage, and physical networks.

^{*19} **VNFM:** The system that performs VNF control

operations such as launching and termination as VNF lifecycle control.

^{*20} **NFVO:** The system that performs comprehensive management of virtual resources that span multiple VIMs.

ious types of settings at the time of instantiation. We also plan to study automation in maintenance and network operations on a virtualization platform having a multi-vendor configuration.

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***21 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 network or system fault management, configuration management,

charging management, performance management, and security management—all or in part—for operating provided services.

***22 Network service:** A function for generating a virtual network to connect a communications APL launched by instantiation in a cloud envi-

ronment to other communications APLs or virtualized communications APLs. The network service defined by NFV ISG.

Special Articles on Network Functions Virtualisation—Toward a Robust and Elastic Network—

Introduction of SDN Technology for Achieving NFV

The virtualization of network functions by NFV was introduced into the NTT DOCOMO network in March 2016. Since NFV eliminates the binding of communications software to hardware, a method is needed that can dynamically and flexibly change the configuration of the physical network composed of routers and switches. NTT DOCOMO has adopted SDN technology for this purpose. This article describes SDN technology for achieving NFV.

Core Network Development Department **Yusuke Okazaki**
Takuya Kitade
Taisuke Yoshida

1. Introduction

The use of Network Functions Virtualisation (NFV)^{*1} technology is expanding to provide the functions of a carrier network in a virtual manner through software technology on general-purpose hardware instead of dedicated equipment. NFV makes it possible to run a Virtual Machine (VM)^{*2} independent of hardware characteristics by deploying communications software on a virtual layer (hypervisor) installed on general-purpose hardware.

With virtualization, hardware resources (CPU, memory, HDD, etc.) that have heretofore been constrained by a

physical configuration can adopt a logical configuration, which enables resources to be used based on the concept of a resource pool^{*3}. Virtualization also enables the common use of general-purpose hardware instead of expensive dedicated hardware, which facilitates the sharing of hardware resources. This makes for quick and flexible construction of a communications network while enhancing fault resistance.

Yet, it is still difficult to extract the maximum effect of NFV in a network consisting of conventional routers and switches. For example, in a conventional network, communications software runs on dedicated hardware and physical net-

works are individually prepared. In NFV, however, the resource pool contains different types of communications software on general-purpose hardware, so there is a need to prepare a common physical network from the viewpoint of efficient operation.

In addition, a network that accommodates communications software that runs as VMs under NFV must be able to dynamically and flexibly make changes to the network configuration. That is, it must be able to deal with VMs that are created and deleted on any hardware and with the movement of VMs between different pieces of hardware.

As a solution to the above issues,

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^{*1} **NFV:** Achieving a carrier network on general-purpose hardware through virtualization technology.

^{*2} **VM:** A computer created in a virtual manner by software.

NTT DOCOMO has decided to adopt Software Defined Networking (SDN) technology.

In this article, we examine the requirements and issues surrounding a network incorporating NFV, describe how SDN provides a solution to these issues, and touch upon the future outlook for SDN.

2. NFV Requirements and Issues

2.1 Sharing of Network Resources

Implementing different types of communications software on general-purpose hardware means that different types of communications software must also be accommodated on the physical network composed of routers, switches, etc. that accommodate general-purpose hardware.

Consequently, for the network too, it must be possible to share and control the physical network in a flexible manner. Developing a method to do so has become an issue—there is a need for technology that can be used to flexibly construct multiple virtual networks on the same physical network.

2.2 Tracking VM

Creation/Movement

NFV enables VM creation and VM movement on general-purpose hardware. The network is therefore required to track the creation and movement of VMs. To be more specific, a network path must be set up when a VM is created to give that VM a communications

capability. Furthermore, when a VM moves to other hardware, it must carry with it the same IP address*⁴ and Media Access Control (MAC) address*⁵ as before the move, which means that the network path prior to the move must be deleted and a new network path to the destination of the move must be set up.

In a conventional network, however, network paths are fixed, so it is not possible to dynamically switch network paths when a VM is created or moved. As a result, a created or moved VM cannot communicate with the network (**Figure 1**). There is therefore a need for dynamic switching of network paths.

3. Solution to Issues by SDN

3.1 SDN Overview

1) SDN Architecture

Conventional network architecture consists of a combination of routers and switches, each of which incorporates all necessary functions in one piece of hardware. SDN architecture takes a second look at this conventional architecture and divides it into a Control Plane (C-Plane)*⁶ and Data Plane (D-Plane)*⁷. The C-Plane refers to software-based functions such as path calculation and the D-Plane refers to hardware-based functions such as data transfer.

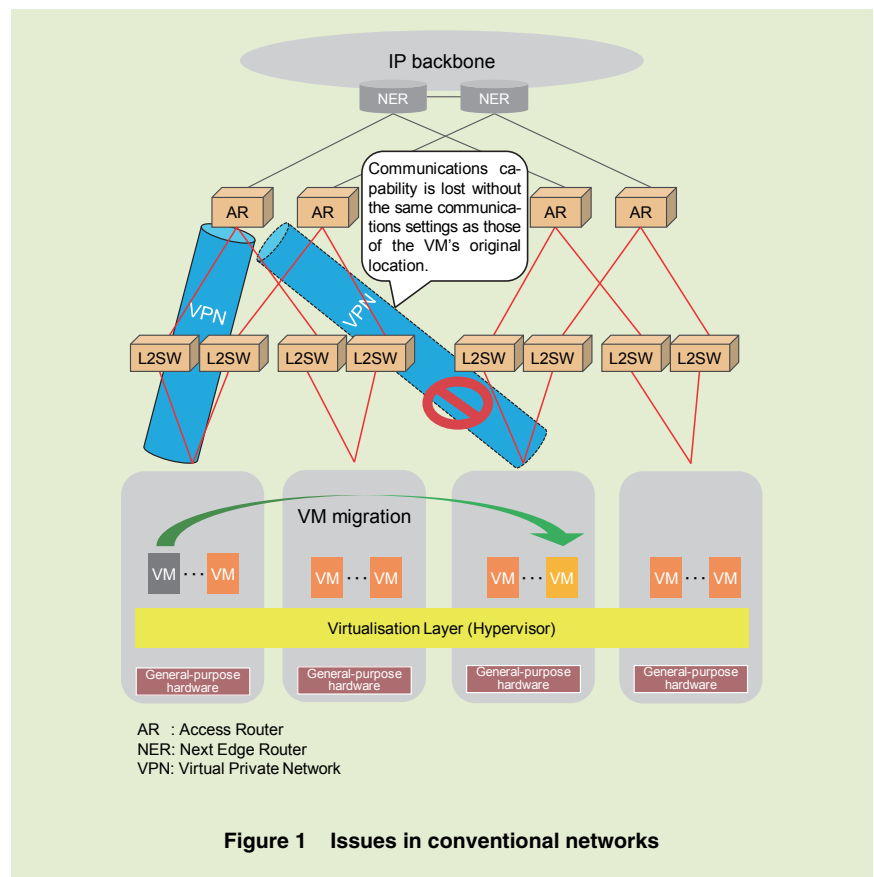


Figure 1 Issues in conventional networks

*³ **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.

*⁴ **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.

*⁵ **MAC address:** A 12-digit fixed physical address allocated to an Ethernet board.

*⁶ **C-Plane:** Network path control function.

*⁷ **D-Plane:** Data transfer function.

While conventional network devices must be set individually, SDN architecture enables network devices to be centrally controlled via a SDN controller (**Figure 2**).

Centralized control can facilitate total optimization, and specifying the Southbound IF*⁸ between the C-Plane

and D-Plane as open source can enable a multi-vendor environment to be achieved and costs to be reduced.

2) Centralized Control and Hybrid Control

SDN architecture can be broadly divided into two types: centralized control and hybrid control. The features of

each are summarized in **Table 1** and their operating schemes are shown in **Figure 3**. In centralized control, the SDN controller collects status information from each switch and performs path calculations. Hybrid control, on the other hand, uses both the SDN controller and a distributed controller mounted on each

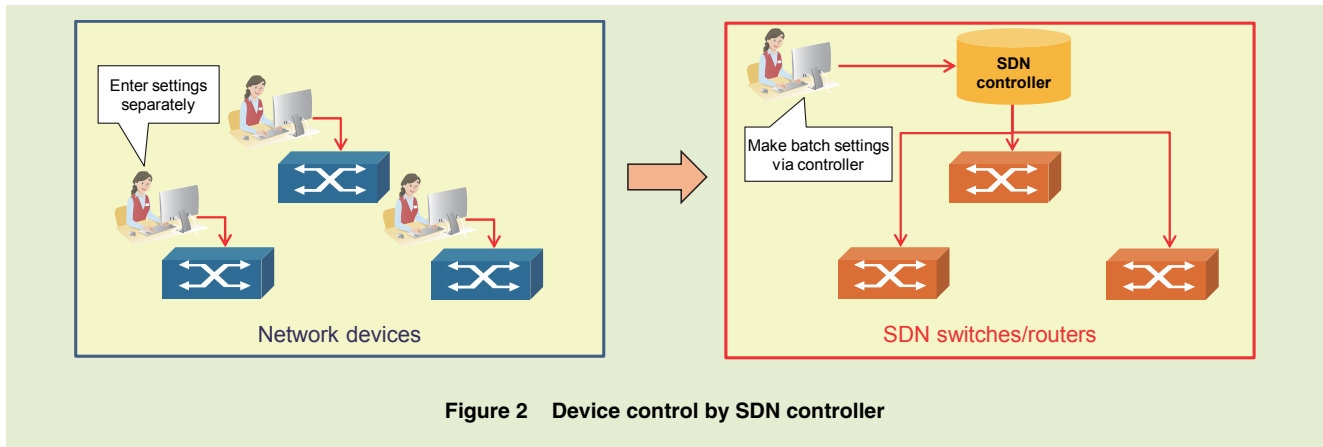
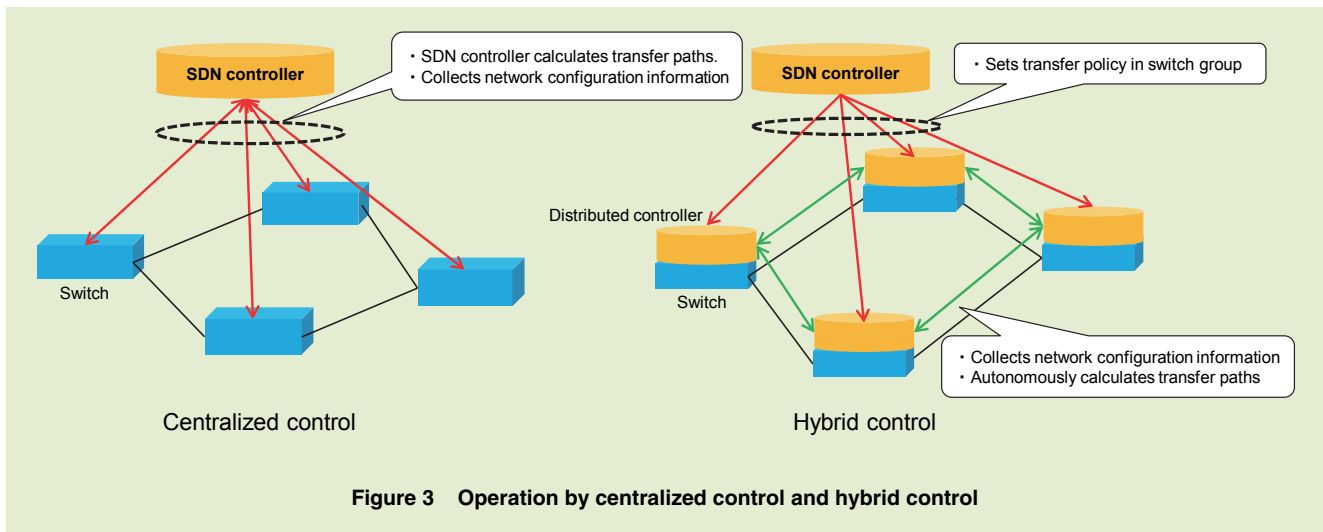


Table 1 Features of SDN architecture

	Centralized control	Hybrid control
C-Plane	Executed only by SDN controller	Executed by both SDN controller and switches
Path calculation	SDN controller collects status information from each switch and calculates paths.	SDN controller sets transfer policy in each switch and each switch autonomously calculates paths.
Path switching	SDN controller mediates in path switching.	SDN controller does not mediate in path switching.



*⁸ **Southbound IF:** The interface that connects the SDN controller and the network devices that it controls.

switch to control the network.

In the beginning, SDN architecture was mostly of the centralized control type, but in recent years, hybrid control solutions have gained in popularity. In hybrid control, the SDN controller sets a transfer policy in each switch so that each individual switch can then calculate routing information on its own. Compared to centralized control in which the SDN controller calculates all paths, hybrid control has the advantage of reducing the load on the SDN controller, which makes for greater extensibility. Hybrid control also means that data transfer and path calculation can continue if the SDN controller should be down, and it enables high-speed switching within the network through autonomous distributed control. For these reasons, NTT DOCOMO has adopted

hybrid control.

3.2 Overlay Network Technology

We use overlay network technology to satisfy the requirement that “multiple types of communications software must be accommodated on the same physical network.” Overlay network technology enables multiple logical L2 networks to be created on the same physical L2 network by applying tunneling techniques such as VLAN or Virtual eXtensible LAN (VXLAN)^{*9} (Figure 4).

However, conventional overlay network technology requires that all network devices used in configuring a logical L2 network be individually set. In response to this constraint, the SDN technology to be introduced defines the settings to be made in network devices for configuring logical L2 networks as a

“transfer policy” and enables this policy to be set from the SDN controller. This approach enables the settings that need to be made in each network device to be executed in batch, that is, all at the same time.

Having the SDN controller make batch settings in this way provides flexibility in handling the movement of VMs (that include communications software) among general-purpose hardware in NFV (Figure 5).

3.3 Tracking of VM Creation and Migration

Next, to satisfy the requirement that “network paths must be dynamically switched when creating or moving a VM,” we link the overlay network that uses SDN technology to the Virtualised Infrastructure Manager (VIM)^{*10} that

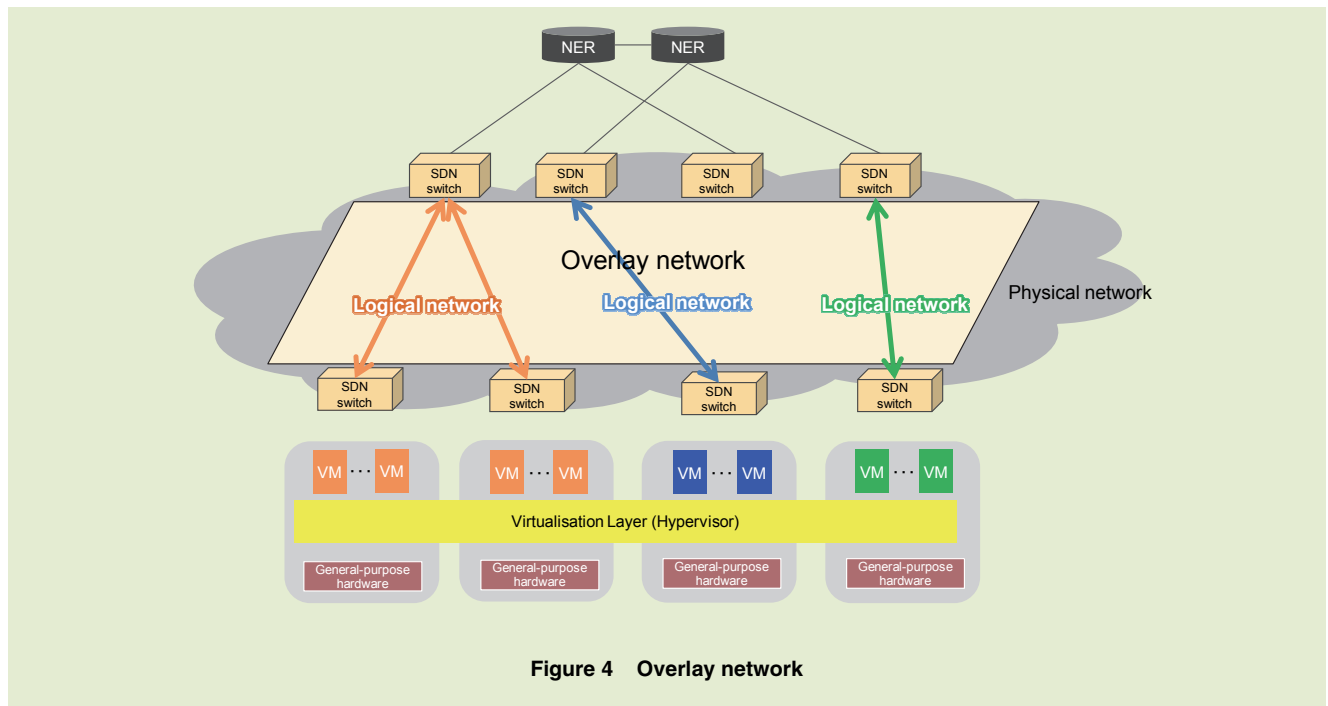
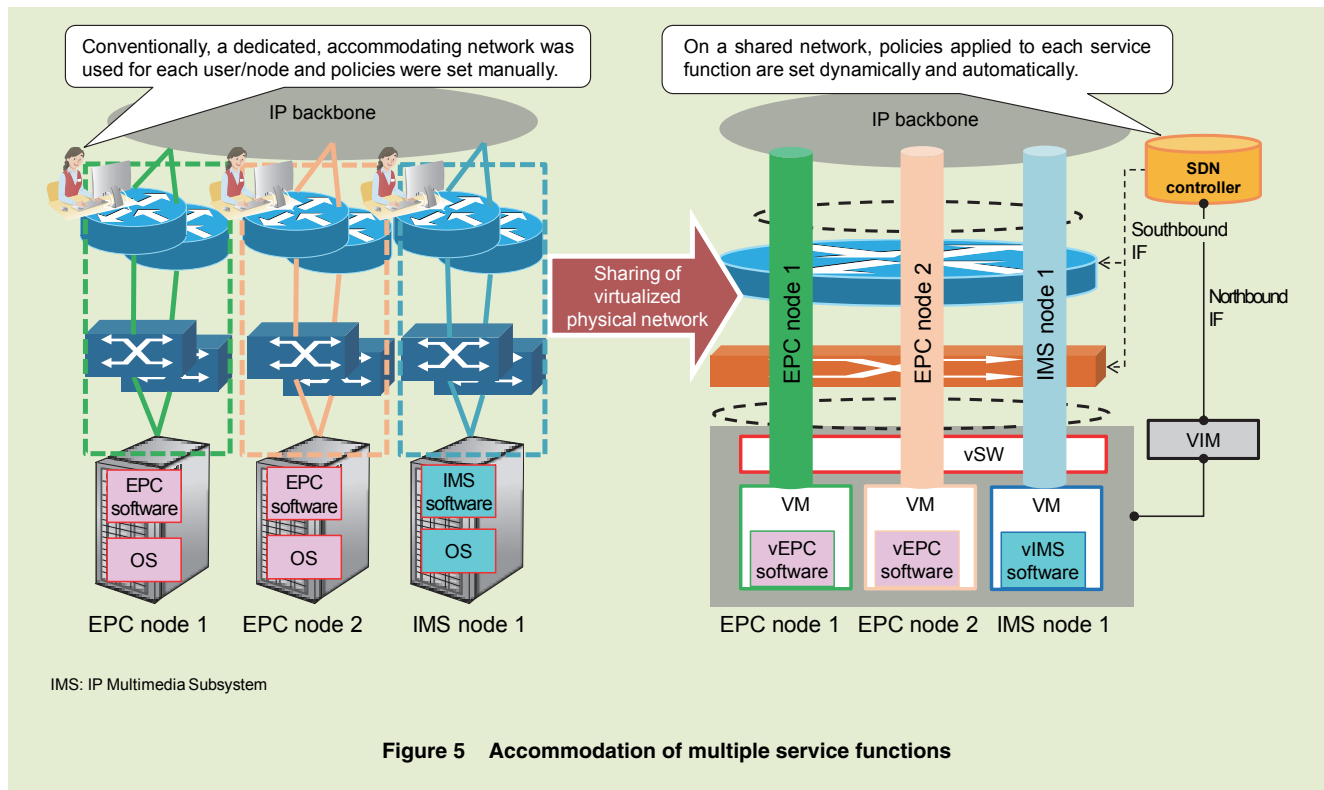


Figure 4 Overlay network

^{*9} **VXLAN:** Technology for configuring logical L2 networks on top of a network configured on L3. While conventional VLAN could only configure 4,094 L2 networks, VXLAN can configure up to 16,770,000 L2 networks.

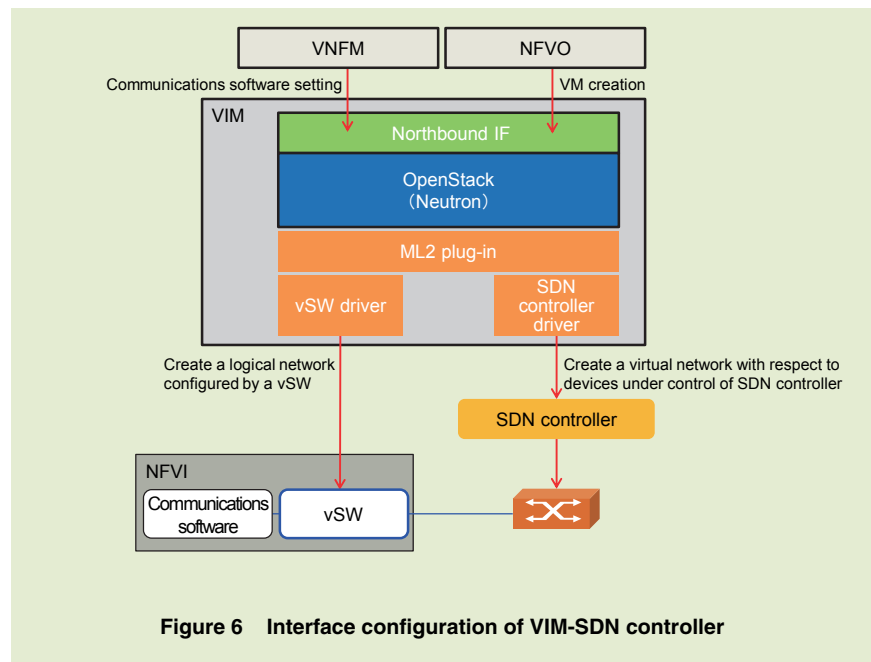
^{*10} **VIM:** Component controlling NFVI (see *14).



controls the creation and migration of VMs.

The connection scheme between VIM and the SDN controller is shown in **Figure 6**. Here, installing the SDN-controller OpenStack^{*11}-based ML2 plug-in on the VIM side achieves a Northbound IF^{*12} for linking purposes. In the resulting configuration, setting of the virtual Switch (vSW)^{*13} on the NFV Infrastructure (NFVI)^{*14} side is performed by VIM without using the SDN controller as an intermediary.

This linking function enables information on VM migration to be conveyed from VIM to the SDN controller and the switching of network paths to be dynamically performed. In the following, we describe linking operations



between VIM and the SDN controller at the time of VM creation or migration, that is, at the time of VM healing^{*15} or

scaling^{*16}.

1) VM Healing/Scaling Support

A requirement applied to the net-

^{*11} **OpenStack:** Cloud-infrastructure software that uses service virtualization technology to virtually operate multiple servers on a single physical server and to allocate a virtual server to each cloud service used by the user. OpenStack is provided as open source software.

^{*12} **Northbound IF:** The interface that connects the SDN controller and upper-level software such as VIM.

^{*13} **vSW:** A virtual switch achieved by software.

^{*14} **NFVI:** Physical resources for executing virtual machines. In this article, NFVI is defined as

general-purpose hardware.

^{*15} **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.

work side at the time of VM healing or scaling is that VM migration that holds on to the same IP/MAC addresses must be dynamically supported. This is because session^{*17} continuity is a requirement characteristic of mobile communications. In SDN, the SDN controller links with VIM and makes on-demand settings to the physical network on receiving notifications of any VM creation or migration from VIM. In this way, the user session can be maintained and communications can continue even when VM switching occurs at the time of a VM failure.

An example of tracking VM migration and switching L2 paths on the network is shown in **Figure 7**. As shown by operation ① in the figure, VIM instructs NFVI to move a VM while simultaneously instructing the vSW side to create and delete L2 paths. A vSW has the role of connecting the NFVI physical port and the VM virtual port. Here,

the network connection between the VM and the VM's source NFVI is deleted and a network connection between the VM and the VM's destination NFVI is created.

Once operation ① completes, VIM instructs the SDN controller side to create and delete L2 paths as shown by operation ② in the figure. On receiving this instruction from VIM, the SDN controller enters settings in SDN switches under its control as shown by operation ③. As a result, the L2 path between the VM's source NFVI and SDN switch (1) and that between SDN switch (1) and SDN switch (0) are deleted and the L2 path between the VM's destination NFVI and SDN switch (2) and that between SDN switch (2) and SDN switch (0) are created.

In short, operations ① to ③ in the figure result in the simultaneous deletion of pre-VM-migration L2 paths and

in the automatic creation of post-VM-move L2 paths.

4. Future Outlook for SDN

4.1 Application of SDN to WAN

Now, in the initial period of NFV deployment, the applicable domain of VM migration is taken to be the hardware existing on the same LAN within a telecom office. In the future, we can envision the migration of VMs across a WAN that interconnects different telecom offices. This capability has the potential of shortening the construction period of telecom offices and of adding/subtracting facilities (as in system recovery after a disaster and resource sharing across telecom offices), all of which will involve changes to WAN settings (**Figure 8**). To this end, the following studies are needed.

- (1) Linking between the WAN Infrastructure Manager (WIM)^{*18} and

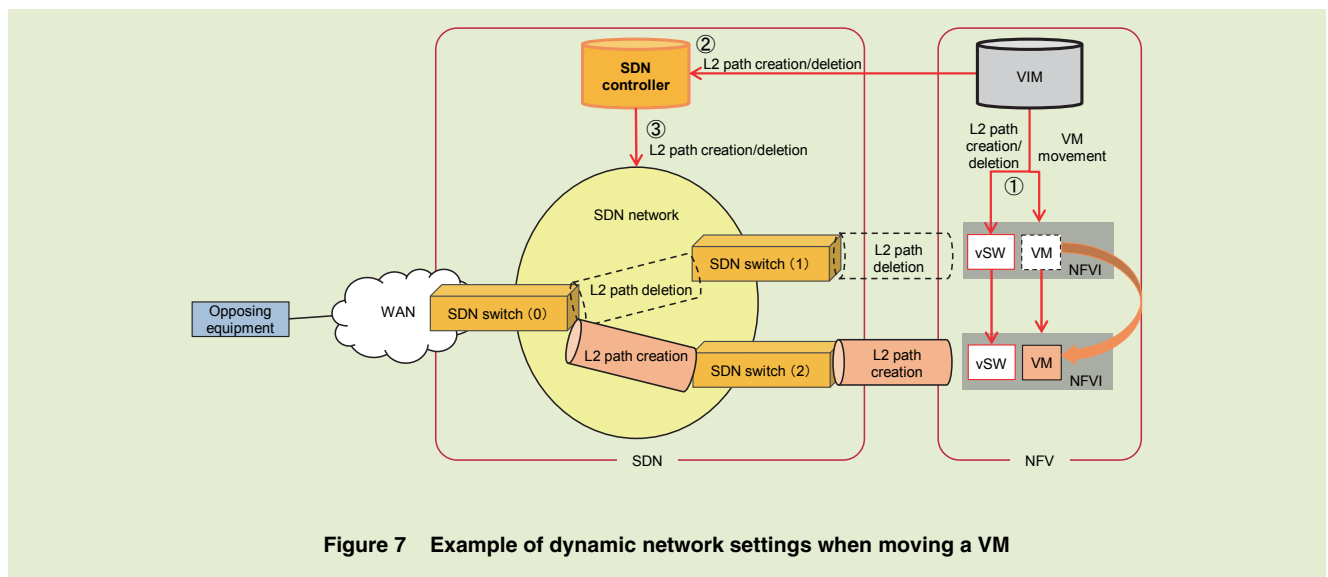


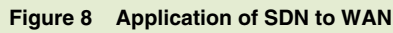
Figure 7 Example of dynamic network settings when moving a VM

^{*16} **Scaling:** The optimization of processing power by increasing or decreasing VMs that configure communications software whenever processing power is insufficient or excessive according to hardware and VM load conditions.

^{*17} **Session:** A virtual communication path for

transmitting data or the transmission of data itself.

^{*18} **WIM:** Component controlling NFVIs or VIMs across a WAN.



NFV Orchestrator (NFVO)*¹⁹
and between VIM and NFVO

- (2) Linking between router equipment and optical transmission equipment under VIM/WIM using a VIM/WIM plug-in structure

5. Conclusion

In this article, we described network requirements for introducing NFV into the NTT DOCOMO network and SDN

as a method for satisfying those requirements. We also touched upon the future outlook for SDN.

This SDN technology was introduced as a network for accommodating virtualised Evolved Packet Core (vEPC)*²⁰, which was commercially deployed in March 2016 [1].

SDN is an essential technology for achieving NFV, and given expectations that virtualization technology will continue to evolve, we consider the further

development of SDN to be just as important. Looking to the future, NTT DOCOMO is committed to developing an increasingly flexible and advanced network while keeping an eye on the latest technology trends.

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***19 NFVO:** Component managing various types of communications software from creation to deletion and performing operations and management across the entire system.

*20 **vEPC:** An IP-based core network specified by 3GPP for LTE or other access technologies. Communications software to enable EPC to function like a virtual machine.

Deep Learning-based Image Recognition Applications

Image recognition services with machine learning have been expanding in recent years. Recognizing abstract concepts from an image by conventional technology is a fundamental task, as in determining the categories of objects appearing in an image (i.e. “food,” “flower,” etc.). Deep learning has also been gaining in popularity among machine learning applications. NTT DOCOMO has developed an image recognition system based on deep learning technology and has publically released a recognition API. This system enables the building of high-accuracy image recognition models to attach various tags to images simply by training image data prepared beforehand.

Service Innovation Department **Toshiki Sakai**
Xinyu Guo

1. Introduction

Deep learning has been increasing in use and has been enjoying success in a variety of fields. Enterprises such as Google and Facebook in the United States and Baidu in China have established research laboratories and acquired deep learning startups since 2013. For example, Google had come to use deep learning in 47 services including image recognition^{*1} and speech recognition as of March 2015 [1].

In image recognition, deep learning has brought significant improvements in accuracy [2] and has progressed greatly

in a variety of tasks (**Figure 1**).

NTT DOCOMO previously released an Application Programming Interface (API)^{*2} for image recognition using conventional image recognition technology [3] [4]. This API can be used to recognize an object in an image if that object has a definite shape such as a “product package.” However, it is incapable of being used for tagging different types of images taken by a user with a smartphone. For this reason, NTT DOCOMO developed image recognition technology using deep learning that can recognize abstract concepts in an image such as the type of scene (wed-

ding ceremony, field day, etc.) or category of an object (food, flower, etc.), names of objects having indefinite shape such as bread and curry rice, and features that have heretofore been dependent on human sensitivities such as the color and pattern of fashion items. This image recognition technology enabled NTT DOCOMO to develop a set of recognition engines capable of high-accuracy tagging. NTT DOCOMO trained these image recognition engines for scenes, fashion items, food, flowers, etc. using a large image dataset and released them in the form of an API in November 2015 [3].

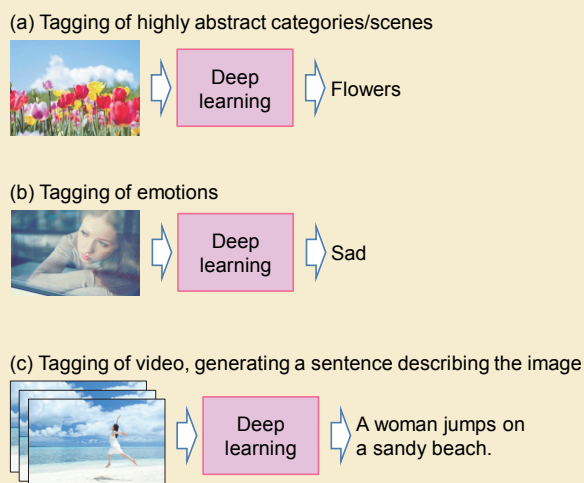


Figure 1 Image recognition using deep learning

In this article, we present an overview of deep learning technology. We then describe the differences between conventional technology and image recognition using deep learning. Next, we list the issues resolved by deep learning. Finally, we define the features of an image recognition API service developed and offered by NTT DOCOMO and introduce applications using this API.

2. Overview of Deep Learning

Deep learning is a branch of machine learning^{*3} technology using multi-layer neural networks. A neural network is a machine learning technique inspired by the information processing mechanism of biological neural networks. Neural networks have been used since the 1950s [5] and have been applied, for example, to the classification task of dividing multidimensional data such

as vector data or images into classes (**Figure 2** (a)). Multi-layer neural networks, that is, neural networks with several intermediate layers, can perform more complex classification and recognition tasks (Fig. 2 (b)). Multi-layer neural networks were popular in the 1980s and 1990s and were used in several types of image recognition tasks. It was shown in 1979 that they could be used to achieve a recognition rate of 98.6% for handwritten numerals [6]. However, classical multi-layer neural networks suffer from the problem that increasing the number of layers makes learning much harder and extremely time consuming. For this reason, difficulties in solving a complex recognition task that needs many layers have prevented multi-layer neural networks from reaching a practical level.

To eliminate this problem, technological improvements were made in

multi-layer neural network algorithms such as by developing parameter initialization techniques and training techniques to prevent overfitting. At the same time, the parallel distributed processing using General Purpose computing on Graphics Processing Units (GPGPU)^{*4} dramatically improved learning speed. As a result of these efforts, learning with deep layers became feasible and deep learning grabbed attention once again in the latter half of the 2000s. In the field of image recognition, deep learning based method competed in object recognition accuracy at ImageNet Large Scale Visual Recognition Challenge 2012 (ILSVRC2012). They gained a recognition rate approximately 10% better than conventional image recognition technology, which only improved 2% from 2010 to 2011. This achievement marked a turning point for deep learning in the field of

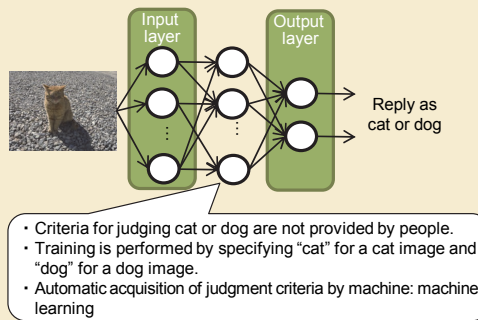
^{*2} **API:** An interface that enables software functions to be used by another program.

^{*3} **Machine learning:** A technology that enables a computer to acquire knowledge and decision-making/action-taking criteria from data much like a human being acquires the same from sensory perception and experiences.

sory perception and experiences.

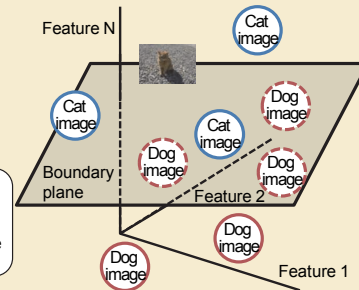
^{*4} **GPGPU:** The use of GPUs generally used for rendering and other types of image processing in computers for other types of applications. GPGPU excels at parallel distributed processing.

(a) Classification of cat or dog by a neural network



Concept of machine learning

- Input a large volume of cat and dog images into the machine and search for the boundary between cat and dog based on image features.



(b) Learning and classification by multi-layer neural networks

- The cat image described above is judged to be a "cat" or "dog" by machine.

Structure that increases the number of steps in the neural network in (a) above.

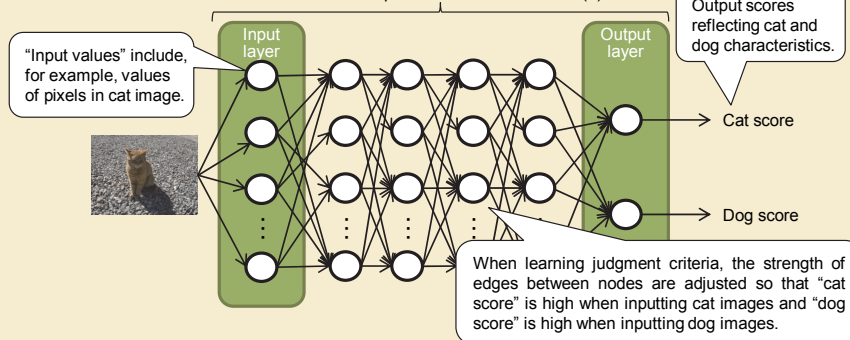


Figure 2 Classification and recognition using machine learning technology based on neural networks

image recognition [2].

3. Differences between Conventional Technology and Image Recognition Using Deep Learning

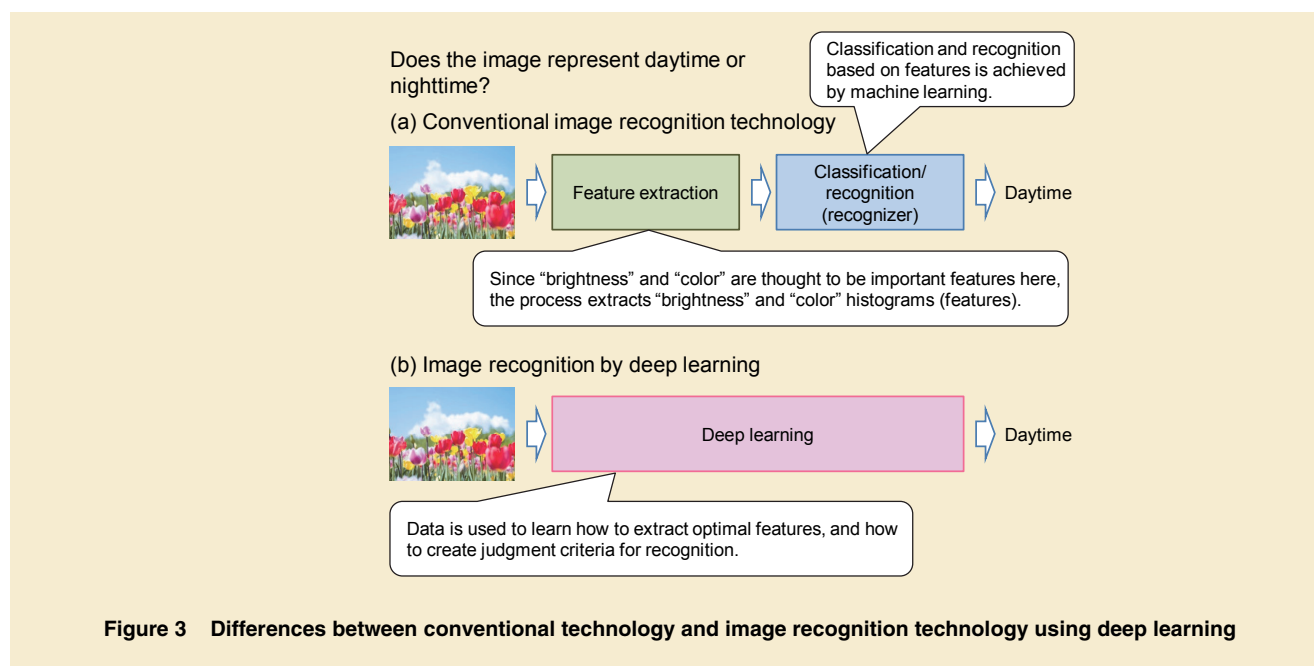
1) Conventional Technology

Image recognition technology before deep learning had a basic two-step configuration as shown in **Figure 3** (a). In step 1, instead of using the image as-is, characteristics of an image is converted into quantifiable features (such as a his-

togram that represents what colors appear at what frequency or how brightness is distributed in the image). Then, in step 2, the image is classified and/or recognized based on those features. The judgment criteria for performing classification and recognition is usually acquired through machine learning (hereinafter, the module that performs classification and recognition by learning judgment criteria is referred to as a "recognizer"). After this learning step, the recognizer recognizes and/or classi-

fies input images based on image features and learned criteria.

In such conventional technology, the image features in step 1 above were manually designed for each recognition task, such as image features appropriate for the detection of people, the recognition of human faces, etc. This process is usually called feature engineering. In the feature engineering step, researchers and developers should consider what features to focus on to give good classification results and what kind of algo-



rithm is optimal.

It is difficult to engineer appropriate features for some tasks, as in the recognition of abstract concepts such as type of scene (wedding ceremony, field day, etc.) or category of object in the image ("food," "flowers," etc.). This situation made it tough to improve recognition accuracy.

2) Deep Learning

In contrast, image recognition using deep learning learns both appropriate features and recognition rules, as shown in Fig. 3 (b). Optimizing features to be used in recognition and creating recognition criteria based on those features are automatically done in the learning process. This approach enables the recognition of abstract concepts when it is not clear to decide which features to focus on and extract.

On the other hand, data is used not

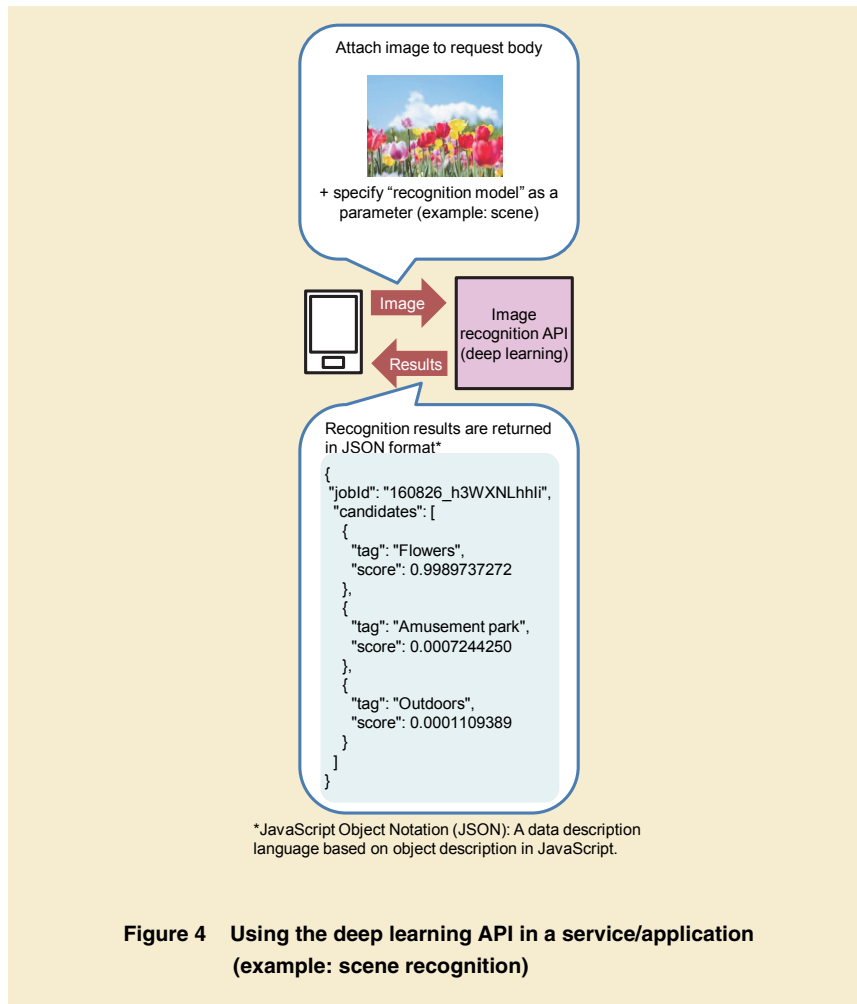
only to learn classification criteria in the final stage but also to learn feature extraction in the initial stage. This requires a huge amount of data for learning, which is a drawback of image recognition using deep learning. Various techniques have come into use to deal with this issue, including pre-training in which a deep learning recognizer is trained beforehand using a common large-scale image database such as ImageNet [7] and data augmentation in which the amount of training data is artificially increased.

4. Image Recognition API and Applications

In November 2015, "docomo Developer support" [2] publically released an image recognition API using the deep learning-based image recognition technologies mentioned above. This

API provides several image recognition models, such as the model for scene recognition, for fashion recognition that can identify type, pattern, and color of a fashion item, and for other kinds of recognition. These models were trained from a huge amount of image data gathered by NTT DOCOMO and can predict suitable tags even for images which has problem to design appropriate features using conventional methods. docomo Developer support is a service which provides useful functions for developing applications and services. Anyone can use a number of APIs including the image recognition API based on deep learning by becoming a registered member of docomo Developer support and submitting a usage application.

Figure 4 shows how a developer of applications and services can use the image recognition API (category recog-



nition) released by docomo Developer support and **Figure 5** shows types of images that can be recognized by the API.

In the image recognition API (category recognition), docomo Developer support provides several trained deep learning models for each "recognition type" such as scene or fashion. Developers who would like to incorporate image recognition in their applications or services can select which models to use. In preparing such a model, NTT DOCOMO collected more

than 1,000 images per tag for training purposes (here, a name or category such as "wedding ceremony" returned as a result of image recognition is called a "tag").

Users of docomo Developer support can immediately incorporate image recognition functions based on deep learning in their applications and services. Because training of these models has already been completed based on the large volume of image data, there is no need for users themselves to gather training data.

4.1 Applications of Scene Recognition

The scene recognition function can recognize the scene displayed in the image (such as wedding ceremony, field day, and birthday) and object categories (such as flower and food).

We can envision a variety of applications using this function, such as an application for saving images in cloud storage, an application for managing images on a smartphone, and an application for automatically creating a photo album. Recognizing images taken by a user and automatically attaching tags to those images simplifies image management for users.

Additionally, using this recognition function on image posting sites and Social Network Sites (SNSs) can reduce the workload in attaching tags when users post images.

4.2 Applications of Fashion Recognition

NTT DOCOMO uses image recognition technology based on deep learning as described above to achieve rapid fashion recognition. Given an input image, the fashion item category can be recognized and the image tagged accordingly.

The following four fashion recognition models are currently provided:

- (1) Type: coat, cardigan, etc.
- (2) Pattern: plain, border, etc.
- (3) Color: pink, yellow, etc.
- (4) Style: business, casual, etc.

This fashion recognition technology can be used to tag query images (images submitted by users) by the four models mentioned above and search for images with similar items (similarity search)

based on these tags (type, pattern, color, etc.). The whole process is shown in **Figure 6**. Developers prepare beforehand a group of images of fashion items and attach tags (color, pattern, etc.) to

each image. These images and tags are stored in a fashion database for displaying the results of a similarity search. Fashion recognition results are tags of a query image. Similar fashion items can



Figure 5 Examples of image recognition when using the deep learning API in a service/application

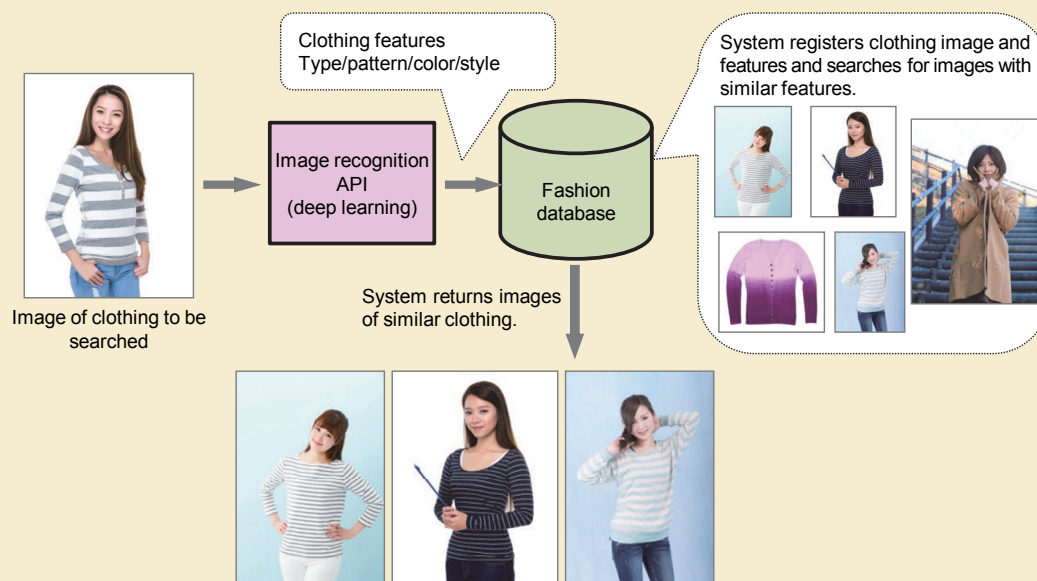


Figure 6 Search for similar images

then be searched by comparing tags of the query image with tags of images in the fashion database.

A similarity search can be applied to various services. For example, let's assume that a person takes an interest in a clothing item appearing in a magazine or catalog, shown in a photo-sharing application (Instagram, etc.) for smartphones, or worn by the main character in a TV drama. Using a similarity search service, he/she only needs to take a photo of the clothing to search for a similar item without clarifying the clothing details. If the URL of Electronic Commerce (EC) site^{*5} for this item can also be provided, it can significantly reduce users' search time.

A similarity search can also be used to discover a new way of coordinating clothes. This could benefit users who would like to select clothes that match well with what they already have, users who always purchase the same type of clothes, or users are not sure how to match and dress in appropriate ways thereby having little chance to wear the clothes they bought. When a user takes a photo for a clothing item, the similarity search service finds similar clothes and recommends a wide variety of clothing items that coordinate properly. Users can decrease wasteful purchasing and greatly reduce time spent in searching for compatible clothing items. It's also an enjoyable way for users to select clothes at home, in a shopping mall, or even on a train.

5. Expanded Application of Image Recognition by Deep Learning

In future image recognition based on deep learning, we envision the expanded use of tags beyond the simple ones used in the recently released API. For example, studies are being performed on predicting the emotion (such as anger or sadness) evoked on seeing an image (Fig. 1 (b)) [8]. Researches are also progressing on video recognition—a technique for attaching a descriptive sentence as a tag to video has been proposed (Fig. 1 (c)) [9].

6. Conclusion

In this article, we presented an overview of deep learning technology, explained how it differs from conventional image recognition technology, described the features of an image recognition API service developed and offered by NTT DOCOMO, and introduced applications using this API.

Research on applying deep learning to fields other than image recognition is moving forward. There are studies on using deep learning in natural language processing and machine translation, in marketing, and in content recommendation on the Web. Deep learning is becoming an essential technology in all sorts of scenarios involving the analysis and use of data.

In the future, NTT DOCOMO will undertake a successive expansion of ob-

jects which can be recognized by image recognition APIs using deep learning. NTT DOCOMO will also focus on the development of recognition techniques targeting data other than images and new recognition technologies which combine images and other types of data.

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^{*5} EC site: A web site that sells products and/or services.

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Implementing Standardized Quantitative Management Processes for Development of Smartphone Applications

In the initial period of development for smartphone applications at NTT DOCOMO, the need to rapidly implement a wide variety of applications and the growing number of vendors led to numerous inconsistencies in development management at the various workplaces. Meanwhile, knowledge of development management processes tended to become limited to certain individuals. To deal with this situation, we created standard forms for vendors to report the development management status. We also created standard forms for application development groups at NTT DOCOMO to report the quality upon completion of development. We also established and implemented in-house standardized quantitative management processes for development. This article describes our initiatives to reform the above processes.

Communication Device Development Department

Takashi Tosaki**Yoshihiro Yamada****Hiroyuki Hattori**

1. Introduction

The rapid shift from feature phones to smartphones in recent years has required NTT DOCOMO to quickly develop and deploy a wide range of applications to meet diverse demands for quality, cost, and delivery times. The vendors conventionally contracted for development (hereinafter referred to as “vendors”) have been unable to meet these demands or else lacked resources, so NTT DOCOMO has sharply increased its adoption of vendors. However, the

need to prioritize quick service launches and the dependence on vendors and in-house application development groups reduced consistency and left only a limited number of people able to handle each development. These inconsistencies in the degree of detail of development management information caused the content of the quality reports used in decision-making meetings for commercial release to differ widely, and the high number of question-and-answer sessions required to reach decisions on quality meant that release judgments

took time. Furthermore, there was a high possibility that quality checks might be overlooked under these circumstances.

To address this problem, the process reform team created standardized forms for the vendor development status reports and quality reports required for commercial release decisions, which were then implemented in the development workplace in various ways. We also engaged in ongoing educational activities to embed the quantitative development management^{*1} processes used

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***1 Quantitative development management:**

A development management method based on objective data and facts. Whether quantitative development management is implemented has a big influence on the success or failure of a development project.

with these forms into the organizations. This article describes our process reform initiatives to date.

2. Development Processes and Issues

2.1 Roles in Development and Organizational Structure Related to Application Development

Figure 1 gives an overview of roles in development and organizational structures related to application development. The major in-house organizations comprise application development groups, a Project Management Office (PMO)^{*2} overseeing developments, and maintenance management groups. Application development groups create definitions

of requirements^{*3} based on the needs of the department in charge of the service and contract with the vendor to develop software (from basic design through to comprehensive testing). Once vendor development and in-house acceptance testing is complete, the organization director, PMO supervisor, and maintenance management supervisor decide whether the software is ready for commercial release.

2.2 Issues to be Resolved

At (1) in Fig. 1, development management between application development groups and vendors entailed regular meetings to share information regarding development status (hereinafter referred to as “information-sharing meet-

ings”). Despite these meetings, inconsistency in development management methods remained, with only a few people capable of managing each development, which meant that the development status information from vendors to NTT DOCOMO was a mixture of quantitative/objective and qualitative/subjective reporting and that large variations occurred in terms of the level of detail. Depending on the development workplace, this could cause major issues, such as NTT DOCOMO being unable to properly grasp the state of development at the vendor or potential risks, leading to concerns over whether suitable countermeasures or risk preventions were being enacted.

Moreover, differences in the level of

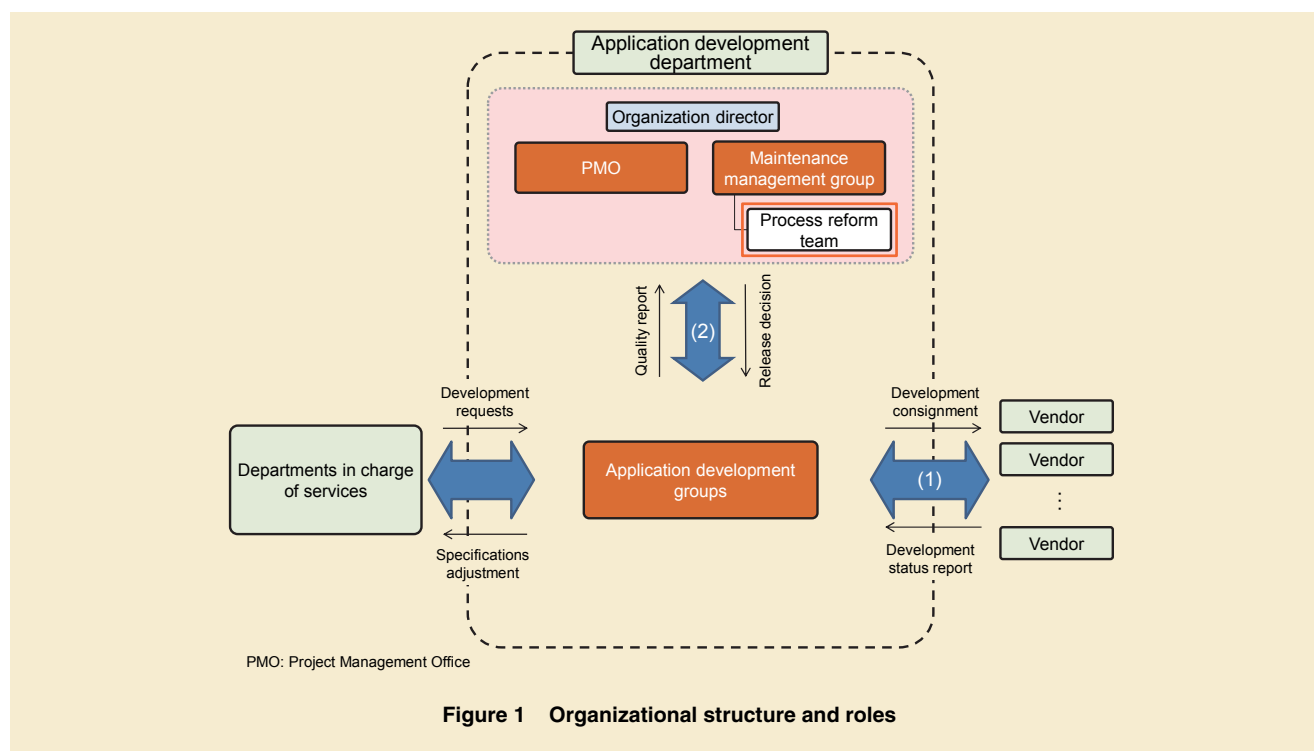


Figure 1 Organizational structure and roles

^{*2} **PMO:** A division dedicated to overseeing, administering and supporting management of individual projects in an organization.

^{*3} **Definitions of requirements:** A document that contains an overview of the functions and specifications that the customer demands etc. A sourcebook for development – products delivered for subsequent processes must meet all of the requirements in the definitions of requirements.

detail presented by vendors led to variable content of quality reporting in release decision processes at (2) in Fig. 1. This meant those involved in making release decisions had to interpret reports appropriately to make objective quality judgments and supplement insufficient information through question-and-answer sessions with reporters. Both issues were serious.

3. Process Reform Activities

Following in-house interviews, the root causes of the variable reporting with development management processes and release decisions were deemed to stem from inconsistencies in vendor development status and quality reports when the time came to make release decisions and a lack of means to develop knowledge and expertise about quantitative management processes for development within an organization. To counter this, we have disseminated quantitative management methods for development throughout the organization using standardized forms that report development status from vendors to application development groups and quality at times of decision-making for commercial release.

3.1 Creating Standardized Forms and Initial Deployment

- 1) Creating Development Status Reports
In creating the development status

report form, considering the need for ten or more diverse vendors to use the form quickly and to keep management costs to a minimum, we determined the minimum number of metrics^{*4} (scale, progress, estimated quality, and actual results) required for the report and adopted the widely-used Microsoft® Excel®^{*5} file format.

Vendors present development status reports to NTT DOCOMO application development groups at weekly information-sharing meetings so that development status can be shared with transparency. Then, using the details in the report, both parties discuss measures against actual and potential risks. Making the most of Excel functionality, alerts are displayed automatically with red or yellow hatching in areas of concern so that both vendors and NTT DOCOMO can be sure that all risks are checked. Also, so that vendors do not get confused or overlook details when filling in the form, areas with input rules and conditional expressions or those requiring entry are shown with hatching.

The form is divided into four sheets – (1) summary, (2) development functions and scale management, (3) expected and actual progress management^{*6}, and (4) expected and actual quality management – depending on objectives. **Figure 2** illustrates the summary and the expected and actual quality management sections of the development status report (for the others, refer to [1]).

- (1) To carry out a limited number of information-sharing meetings efficiently, we have designed the form so that development status and risk can be quickly grasped and shared with a brief look at the summary section, which includes a digest of data on the scale, progress, and quality of the development; current issues; and vendor actions (Fig. 2(a)).
- (2) The development functions and scale section is used for managing the function list, which is split into appropriate management units^{*7}, and the development scale for the management units during development planning and at end of the process. Development risk can be assessed by checking transitions in scale.
- (3) The expected and actual progress management section applies for each management unit. It enables sharing of delayed functions and development processes, their causes, and the period required for countermeasures. Progress is visualized so that risks can be assessed.
- (4) The expected and actual quality management section is used for managing quality index targets and performance for review density^{*8}, test density^{*9} and review identification density^{*10}, bug

^{*4} **Metrics:** Measurement methods and scales defined for quantitatively determining the quality of software and development processes. These include scale of a development, and the time and man-hours required for its processes etc.

^{*5} **Microsoft® Excel®:** A trademark or registered trademark of Microsoft Corporation in the USA and other countries.

^{*6} **Expected and actual progress management:** Managing the differences between plans and actual performance.

^{*7} **Management unit:** Units in software structure for measuring good and bad quality and taking actions as necessary to improve quality.

^{*8} **Review density:** The amount of review per the scale of the product under review. A metric

that indicates the sufficiency of the amount of review. Here, a review refers reading intermediate developmental results (design documents and source code) by a number of people, including the authors. Extracting deficiencies and issues from a number of perspectives in this way raises the quality of products.

Summary section

Application name	Dummy application	Development period	15 Winter period	Android
Company name	Test vendor	Reporter	Saburo Reporter	

Accounting date 2015/3/17 (Tue)

*Progress etc. calculated based on the accounting date

I. Checking action items

Checking open status action items that occurred in the past (to dos, concerns, issue solving, request item etc.) (Action items list is handled on a separate sheet)

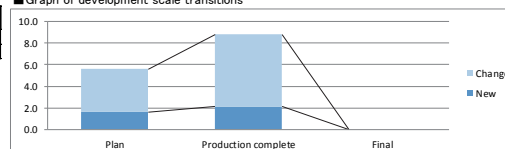
II. Progress, quality summary report

*Summary report on application development progress, the quality perspective. As detailed report sheet as required.

■ Development scale

	Appropriated (base) scale	New scale subtotal	Modified scale subtotal	Development scale (new + modified)	Overall scale	Scale class	Modification rate
With planning	453.7	1.6	4.0	5.6	459.3	Large development scale	1.2%
Latest	453.7	0.6	7.0	7.6	461.3	Large development scale	1.6%

■ Graph of development scale transitions



■ Milestones to release

Milestones schedule	α1 release	α2	β release	β2	Pre-final release	PreFinal1	PreFinal2	Final release	Final1	Final2
Plan (initial)	15/3/17 (Tue)		15/4/7 (Tue)		15/4/24 (Fri)			15/5/8 (Fri)		
Plan (latest)								15/5/15 (Fri)		
Performance	15/3/17 (Tue)									

*Please indicate "α2, α3..." etc. as milestones are added (add columns as required)

■ Progress summary

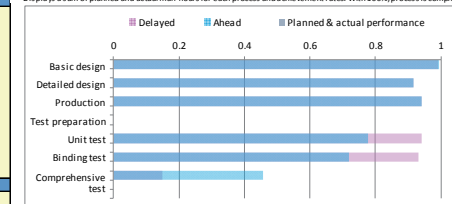
Progress status	Progress status overview
	Dummy data migration/dummy shop/others (XXX, etc.)/server IF handling IT complete, ST started. Mostly as planned. *Reallocation In FD. As planned.
Delay handling clear	
~18.7 man-days	
Action plan (current) * Enter with delays, issues	
Action plan (previous) * Enter with delays, issues	

■ Quality summary

Quality status	Quality status overview *Refer to separate process sheets for details
	Dummy data migration/dummy store/others (LMU, etc.)/IF handling to acquire no. of unread IT process quality analysis described on "binding test" sheet. Please allow data migration (ending 3/16) report the following week. *Reallocation In FD. No quality report available.
NG... cause clear	

■ Progress status graph

*Displays a sum of planned and actual man-hours for each process and achievement rates. With 100%, process is complete



■ Quality status graph

*Tasks outside index values are displayed yellow and red. All blue means measures taken and processes complete. (Horizontal axis shows scale of target task as a percentage for each process)

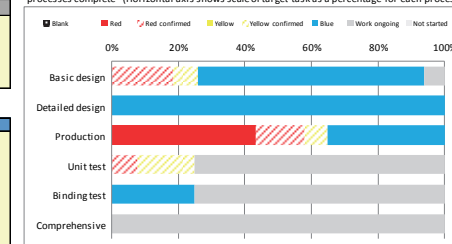


Figure 2 (a) Development status report (summary section)

density^{*11}, and test status in processes from binding tests onward for each development process and management unit. Quality risks can be assessed and handled at an early stage by sharing analysis results and actions to rectify deviations from quality index targets. A visual representation of the zone analysis^{*12} results (Fig. 2 (b)) is provided

as a mechanism for preventing both vendors and NTT DOCOMO from overlooking quality risk actions. Refer to [2] for the creation of the expected and actual quality management section.

Taking into account management costs and the degree of detail of development management, we have created an abridged version of the development

status report form for small-scale development projects that incur fewer risks. A threshold of development scale and cost is exploited to select whether to use the normal or abridged version of the development status report. In general, the more detailed the development status report, the easier it is to quickly uncover and respond to risks as management costs increase. Hence, applying the abridged version of the development

^{*9} **Test density:** The number of test items per the scale of the program development. A metric that indicates the depth of testing for each process. Here, a test means actually running created programs on a computer, and confirming that expected results can be obtained.

^{*10} **Review identification density:** The number of review identifications for the scale of the

product under review. A metric used for the degree of extraction of issue identified from reviews, used to judge the quality of the product under review.

^{*11} **Bug density:** The number of bugs detected for the program development scale. A metric used for the degree of extraction of bugs in processes, used to strengthen tests and judge

whether retesting is required.

^{*12} **Zone analysis:** A method of analysis in which given analysis themes are split up into zones focusing on certain characteristics. Creating zones enables more detailed responses compared to overall actions.

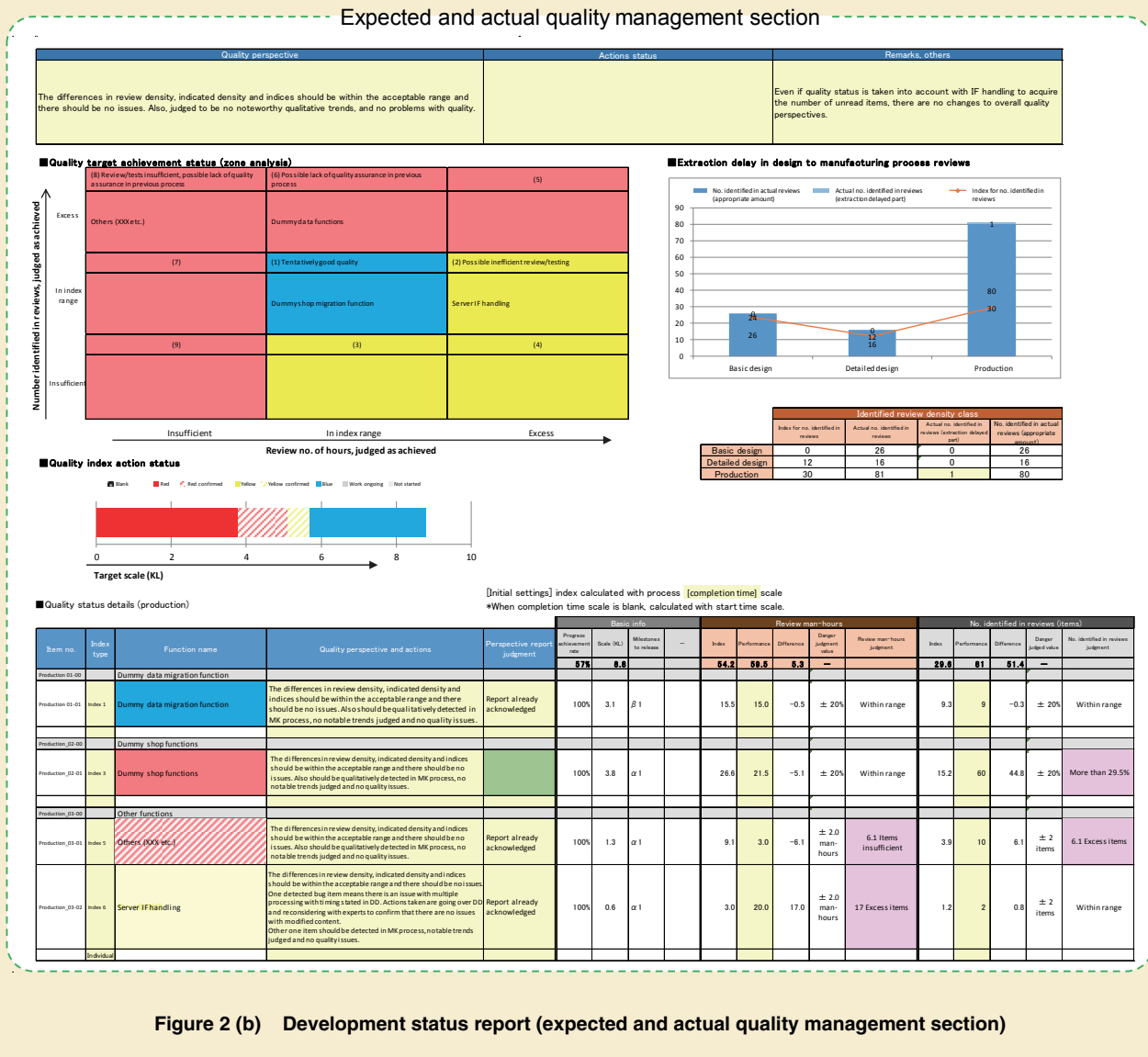


Figure 2 (b) Development status report (expected and actual quality management section)

status report to projects with low development risks puts the focus on cost-cutting rather than detailed reporting, and by simplifying management processes and using simpler quality index values determined by NTT DOCOMO for these low risk projects, all development functions, scale, progress, and quality information can be handled with

brevity on one sheet. For details of the structure, refer to [1].

2) Creating Quality Reports

In creating quality reports as forms to use for judging commercial release, we have adopted the Microsoft Excel file format for its ease of data collection and processing and its affinity with the development status report. We also

considered the minimum amount of data needed to enable those making release decisions to judge quality while avoiding adding to the workload of the application development groups unnecessarily. The quality report source data is limited to the development status report used by the application development group during development plus

acceptance test data regarding the number of test items and failures. Additional information gathering is not required. Furthermore, with performance data contained in the development status report, decision-makers can make comprehensive judgments using information including quality in upstream processes.

Figure 3 shows the quality report form in five sections: (1) an application overview including the provided application name and development scale; (2) a summary of quality data in development processes (omitted with abridged

development status report) based on development status; (3) a reliability growth curve*¹³ created after comprehensive vendor testing and in-house acceptance testing detailing number of tests and failures; (4) the vendor-DOCOMO test/failure ratio; and the qualitative perspective. We have maximized use of the Excel format to devise a form that is easy for decision-makers to read and reporters to complete. For example, the form includes input checks using input rules and conditional expression functions. It also automatically converts

numeric data input to high-visibility graphs and visualizes quality risks by displaying high-risk quality data with yellow or red hatching to alert the reader.

3) Initial Initiatives to Deploy This Form

We have taken both a top-down and bottom-up approach to the implementation of this form (see reference [3] below). First, to deploy the form quickly in all development workplaces simultaneously we used a mandatory top-down approach. For the bottom-up approach, process reform team members participate in information-sharing meetings be-

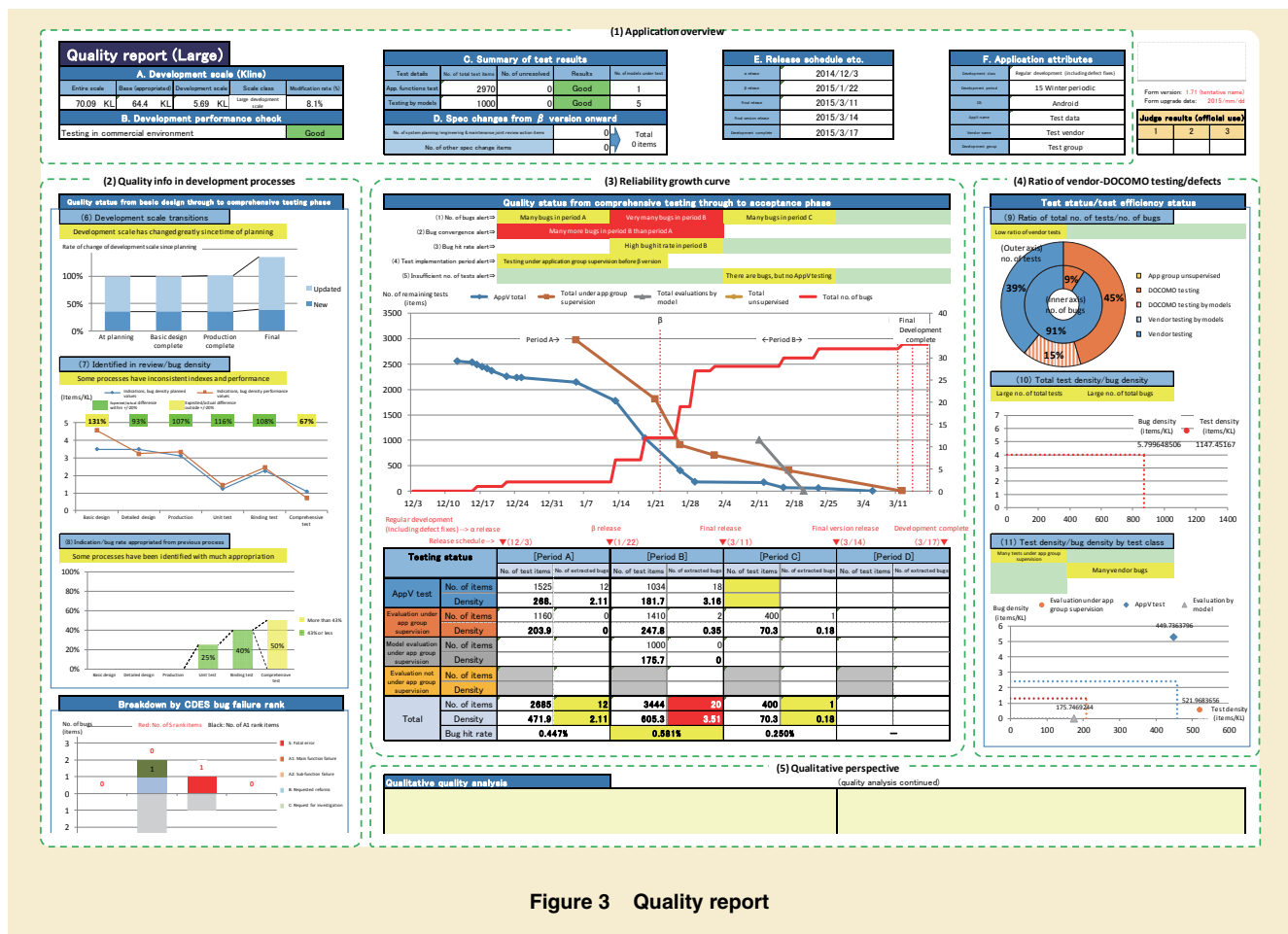


Figure 3 Quality report

*¹³ **Reliability growth curve:** A graph used for confirming project progress and quality status etc. The horizontal axis depicts dates, test time and number of test cases, while the vertical axis depicts the cumulative number of bugs discovered. These are often drawn as an S-shaped growth curve.

tween application development groups and vendors that involve explanations of development backgrounds and form completion methods together with identification and checking of vendor completion methods and report details, including examples to be passed on to application developers. Enabling direct workplace support that includes both application development groups and vendors greatly reduces the feeling of being compelled to participate that stems from the top-down approach, and this significantly reduces resistance to incorporating the reforms. The combination of these approaches enabled us to deploy the forms in all development workplaces within approximately six months.

3.2 Embedding Quantitative Development Management

After implementation of the form was complete, we engaged in the three actions below by focusing on firmly establishing the quantitative development management methods and undertaking ongoing improvements.

1) Further Upgrading Forms and Other Documentation

We continued to improve the forms so that vendors can complete forms easily and progress and quality can be grasped regardless of development group management skills. To accomplish this, we interview application development groups and vendors, both officially and unoffi-

cially, and take proactive steps to hear opinions and suggestions from the development workplace so as to foster awareness of participation in process reform activities, taking into account ease of acceptance of any changes made. Furthermore, we provide comprehensive reference documentation to enable effective use of the forms. For vendors, we provide guidelines for completing development status reports, and for application development groups, we provide a know-how reference for the practice of quantitative development management including information on how to interpret development status and quality reports.

We have also enabled more objective quality judgments of projects by accumulating development performance data and using statistical data on past performance for quality alerts on the quality report. For example, in the reliability growth curve at (3) in Fig. 3, for each period, bug density in the 75 to 85 percentile^{*14} of past statistical data is shown as a yellow alert while bug density in the 85 to 100 percentile of past statistical data is shown as a red alert, indicating high-level quality risks.

2) Implementation of Support Tools for Application Development Management

After this form was launched and spread in the development workplace, the demands of workplaces that wanted to manage development with greater accuracy and efficiency and the load on

process reform team members to collect and aggregate main development data for all projects (including reliability, productivity, scale, and man-hours) increased. To counter this, we created support tools comprising two functions: (1) development management support for application development groups and (2) data aggregation support for process reform teams. **Figure 4** shows an overview of these application development management support tools. The tools use Agile development^{*15} so that functions can be added quickly and flexibly while measuring the progress of process reforms.

(1) Development management support functions are aimed at assisting application development groups and contain functions to solve development management issues that come to light through interviews and observations in the development workplace. Specifically, the functions analyze development plans based on the expertise of the process reform team and in-house experts while extracting factors of quality and slow-progress risks; clarify differences from recent development status reports for greater efficiency in information-sharing meetings; automatically create quality reports based on development status reports; analyze information on failures that oc-

^{*14} **Percentile:** Units created by rearranging the distribution (variation) of measured values from small to large and displaying them as percentages so that measurement can be made from a value position on a percentage scale. For example, the 65th percentile indicates a value positioned at 65% counting up from the minimum value.

^{*15} **Agile development:** A development methodology based on the Agile development declaration, a generic name for light development methods for rapid and adaptive software development.

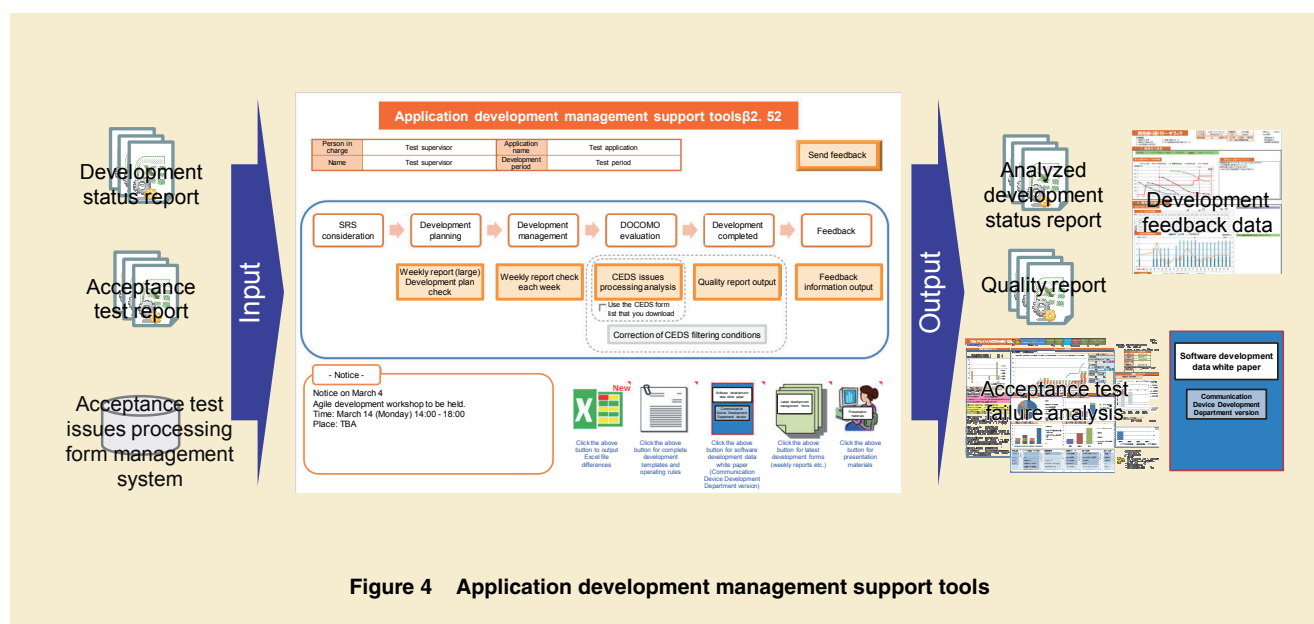


Figure 4 Application development management support tools

cur with acceptance testing; and provide development feedback from project development data analysis and other areas. These functions have made development management more efficient, promoted a more voluntary approach, and embedded quantitative development management in the workplace. Tool usage logs are also automatically collected from application development groups and log analysis mechanisms are included for easy verification of tool effectiveness and workplace diffusion. This enables individual briefings in workplaces where tool diffusion is low and quick decision-making to improve underused functions.

- (2) The data aggregation support functions are used to collect, ac-

cumulate, sort, and output data in development status reports. These functions enable quick, easy collection and accumulation of data for statistical purposes from a variety of development workplaces.

3) Full Human Support

Now that the support enabled through improved tools and documentation and an accumulation of know-how and experience in the workplace has accelerated the shift to proactive, autonomous quantitative development management, the process reform teams have gradually begun to reduce their participation in development workplaces. Nevertheless, whenever new versions of the forms are released or new functions added to the development management support tools, briefings are held for the entire department to educate people about the need

for quantitative development management, introduce specific expertise for analyzing development risks using the development status and quality reports, and share both best and worst practices regarding development management.

In this way, while intentionally reducing the need for human support in the development workplace, we remain aware that process reform essentially relies on people. To this end, we still provide full support in the development workplace in high-risk situations, such as projects with high development risks from the perspective of degree of difficulty and scale or phases in which the personnel have changed.

4. Results of Process Reform Activities

Below, we describe the results of process reform activities.

4.1 Optimized Development Management and Objective Release Judgments

Using objective, quantitative indices, vendors and application development groups can now share development status, which enables mutual awareness of risks and early responses in terms of progress and quality. Also, implementing uniform quality reporting and setting conditions for quality alerts based on past statistical data for all development projects has made it possible to judge the quality of development projects objectively using side-by-side, chronological comparisons.

Figure 5 shows specific results of progress management reforms. The progress delay rate is defined as the percentage of information-sharing meetings involving delays greater than one day from among all such meetings for all projects in which development status reports were implemented. Although the progress delay rate exceeded 55% in the first six months after implementation, the improvements that followed have brought it down below 20% in recent times, indicating that the process reform actions have improved progress management.

Figure 6 shows specific results of quality reforms. We created two box plots^{*16} from bug density data aggregated from all tests after comprehensive vendor testing for all projects in the first six months and the most recent

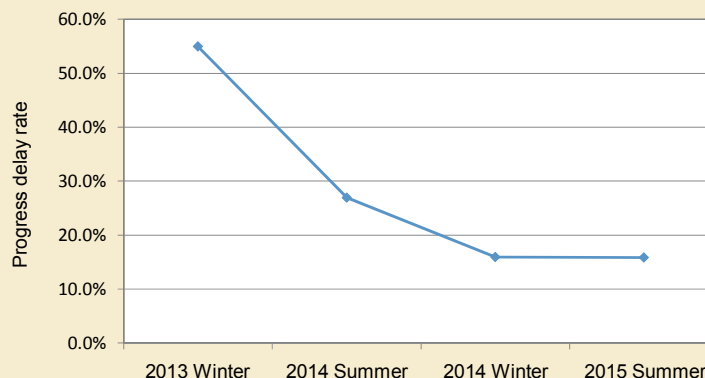


Figure 5 Reform achievements with progress management

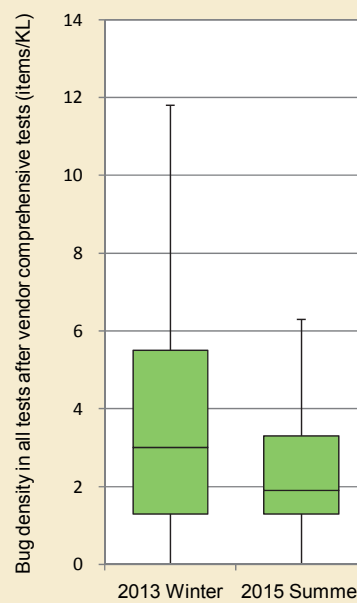


Figure 6 Quality reform achievements

six months, and found that the median values in the former fell to two-thirds of those in the latter. Popularizing the quantitative management of development helps incorporate quality in upstream processes and enables confirmation of software quality improvements.

4.2 Maintaining Development Data Statistics

Using data aggregation support functions with application development management support tools, we created a white paper on software development data by aggregating and sorting main

^{*16} **Box plot:** A type of graph used in statistics to display data with a lot of variation in a way that is easy to understand. In general, these graphs express the 1st quartile, the median, the 3rd quartile, and the maximum. The 1st, 2nd (median) and 3rd quartiles are represented as a “box,” while the minimum and maximum values are represented by the “whiskers” attached

to the box.

development data for all projects (including reliability, productivity, scale and man-hours) to publish in our department. For the content and structure of the white paper, we referenced software development data white papers [4] issued by the Information-technology Promotion Agency, Japan/Software Reliability Enhancement Center (IPA/SEC)*17. Along with the addition of the latest data, the software development data white paper (in-house version) has had three past revisions, and a restructured, derivative version is also available for vendors. The software white paper has been sent out to all application development groups and managers in our department, gets cited in feedback on completed developments and confirmation of adequacy for development plans, and is contributing to reinforcing the development PDCA cycle.

4.3 Structures of Mechanisms for Application Development Groups to Autonomously Optimize Development Management

Quality reporting has been implemented so that accurate quality reports can be output if development management is correct while alerts will be frequently displayed in quality reportage to indicate quality risks - a fact that is now well understood by application development groups - if the development management is faulty. Providing development management support func-

tions with application development management tools has enabled application development groups to easily, instantly, and automatically output quality reports during the intermediate stages of application development. This provides them with quality report alerts during development and enables them to distinguish risk in vendor progress and quality reporting while promoting discussion of suitable additional responses to issues, thus leading to proper and autonomous development management in the development workplace.

4.4 Spreading Development Management Systematically with Application Development Management Support Tools

While combining usage log analysis of management support tools for application development with interviews in the development workplace, we have continued to upgrade functionality and expand the number of people using these tools by reinforcing application development groups' understanding of the tools' merits through presentations and other means. We have rolled out systematic development management to an assumed 20% of users after three months from initial deployment, expanding to 80% after six months. As a result of the ongoing popularization of tool usage, all application development members currently know about and are using the tools.

5. Conclusion

This article has described process reform initiatives for developing smartphone applications. We quickly embedded new form usage by creating standardized forms of development status report forms designed to be used by a wide range of vendors and standardized forms of quality report. We also established processes for quantitative development management in our department through document and tool upgrades and efficient human support. These process reform initiatives have brought about major improvements in the quality of development management and have therefore enabled better quality software development with fewer progress delays.

We also organized approximately two years of these process reform initiatives and presented the findings at the Japanese Software Quality Symposium*18 [1]. The forms we designed to be used by many different vendors became a central feature of the NTT DOCOMO presentation and attracted high levels of interest from symposium participants, who asked many questions about their details. It is unusual for a company that orders software development to give a presentation at this symposium, but it was effective in promoting knowledge sharing between ordering companies and vendors, which contributes to the advancement of the software development industry.

*17 **IPA/SEC:** An organization that studies and creates standards and visualization methods for development processes as well as quantitative quality management methods etc. with the aim of spreading quantitative project management in software development.

*18 **Software Quality Symposium:** The largest software quality related event in Japan, held to share practical technologies, experiences and research findings and exchange opinions related to software quality. As well as presentations and panel discussions by celebrities, the symposium also accepts presentations from general participants.

Going forward, we intend to take initiatives to improve in areas of concern by enabling closer linking between accumulated data, lifting the level of managerial skills and awareness, and handling Agile development processes.

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“Linking” Device Functions to Expand the IoT

With the expansion of the IoT device market of recent years, many companies have been developing products in this field, although not many consumers have taken up using these products in their daily lives. Therefore, by establishing “Project Linking” between various companies nationwide, NTT DOCOMO has set up a platform called “Linking” to make it easier to develop IoT devices and services linking with these IoT devices. This article describes a summary of Linking, examples of its practical application and how they are deployed.

Communication Device Development Department **Katsuki Kiminami**
Yuji Tamiya
Kouen Koh
Sadaatsu Kato[†]

1. Introduction

With the rapid spread of smartphones of recent years, many wearable devices that can link with smartphones such as smart watches, smart glasses and wristband-style healthcare devices have appeared. In addition, with the advocacy of the IoT concept [1], in which various devices used in daily life is connected to the Internet such as home appliances, automobiles and smart meters, and various devices with sensors, many companies are proactively developing products for the wearable and IoT fields as growth and expansion of markets for these devices (hereinafter referred to as “devices”) are predicted [2].

However, many consumers are not

using devices as often as they use smartphones. This is likely due to the following causes:

1) Devices are too Expensive

Many of the devices currently on the market cost tens to hundreds of dollars, so consumers are reluctant to buy them. Hence, the price of the devices is an impediment to their popularization and the growth of the IoT.

2) There are Few Killer Applications Available

Various IoT services are already on offer by many companies. The ‘smart home’ in which various consumer appliances are controlled with a smartphone is one example of such an IoT service. However, consumers in general do not feel the need for such devices and ser-

vices in their daily lives, and there are not many killer IoT services that a majority of people would find attractive enough to want to use.

3) Developers Face Hurdles to IoT

Service and Device Development

Most of the devices currently available for use with smartphone applications (hereinafter referred to as “service apps”) connect using the unique specifications of individual manufacturers, which means these service apps must be developed to match each device, and service app developers have to also understand the specifications of each device.

To counter these problems, Application Programming Interfaces (API)^{*1} for

connecting devices with smartphones using Bluetooth®*2 etc. have been published, such as Android Wear™*3[3] and Google Fit™*4[4] provided by Google, and Apple Watch™*5[5] and HomeKit®*6[6] provided by Apple. However, these specifications require devices to have operating systems installed or high-spec RAM*7, which means compatible devices are limited to those with high functionality. Thus, developing devices compatible with those specifications requires a greater amount of development, making it more difficult to provide devices.

Thus, to expand the IoT market, NTT DOCOMO developed the Linking platform to make it easier to develop IoT devices and service apps, by prescribing simplified, general-purpose specifications for connecting devices with service apps. This article describes an overview of Linking, examples of its practical application and how they are deployed.

2. Overview

Linking is a platform that makes it easy to connect devices and smartphone service apps. Developing with the interface prescribed by Linking enables device and service app development in which device developers need not be concerned with service app specifications or operations, and similarly service app developers need not be concerned with device specifications. Furthermore, so long as there is compati-

bility with the Linking interface, connection is possible regardless of the type of device or service app. Linking also enables multiple devices to connect to multiple service apps.

2.1 Configuration of Linking on Android

Figure 1 shows the configuration of Linking on Android™*8. Note that the configuration of Linking on Android differs from iOS*9. The configuration on iOS is described later.

As shown in Fig. 1, connections between devices and service apps are achieved by the Linking app. The Linking app supports the interface for devices (hereinafter referred to as “device IF”) and the interface for service apps (hereinafter referred to as “service app API”). To connect devices with smartphones, we adopted the Bluetooth Low Energy (BLE)*10 standard for its particularly good energy-saving characteristics, and because Bluetooth has become a standard inclusion in smartphones and a range

of other devices such as PCs.

The Linking app also centrally manages settings such as service app or device connectivity, device connection status, and provides detailed user settings for how to combine devices and service apps. By using the Linking app, users do not need to operate individual service apps or devices to make service app-device connections, which raises the level of user convenience, especially when using multiple devices and service apps.

Furthermore, since the Linking app runs on the Android application layer, it can be used by simply downloading and installing it in a smartphone, and can also be used on smartphones provided by NTT DOCOMO and other companies.

2.2 Device IF

1) Linking Supported Devices

As of April 2016, devices compatible with Linking are those equipped with LEDs, vibrators and buttons, and acceleration, gyro, orientation, humidity and

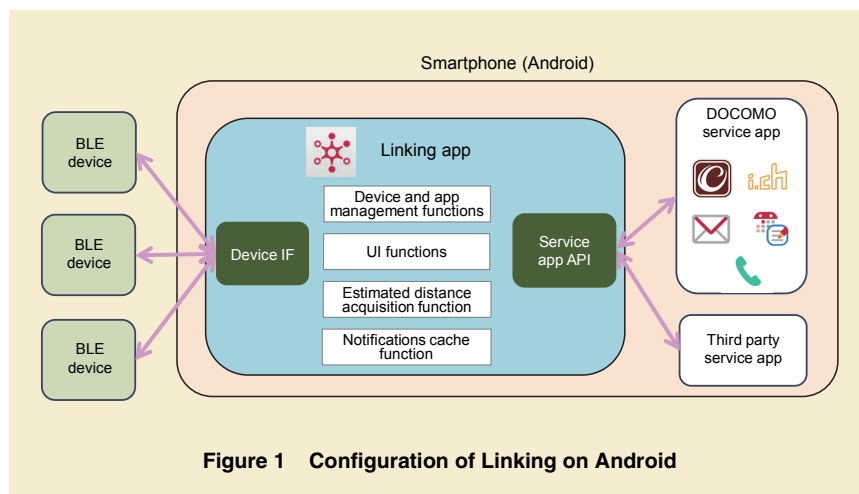


Figure 1 Configuration of Linking on Android

*2 **Bluetooth®**: A short-range wireless communication standard for interconnecting mobile terminals such as cell phones, notebook computers and PDAs. A registered trademark of Bluetooth SIG Inc. in the United States.

*3 **Android Wear™**: An Android OS-based operating system for smart watches. A trademark of Google Inc.

*4 **Google Fit™**: The name of Google's health management and health care applications, and their platform. A trademark or registered trademark of Google Inc.

*5 **Apple Watch™**: The smart watch provided by

Apple Inc. A trademark or registered trademark of Apple Inc.

*6 **HomeKit®**: The platform provided by Apple Inc. for connecting iOS devices with home appliances etc. A registered trademark of Apple Inc.

*7 **RAM**: High-speed read/write access memory.

air pressure sensors. We selected these functions so that simple devices with no operating systems or small RAMs of several hundred kilobytes like those discussed above can be connected. This approach enables use of inexpensive devices in daily life, and hence should provide impetus for the expansion of the IoT.

As the format of the BLE advertisement packet^{*11} is also defined in Linking, devices that support the format can be used as beacons^{*12}.

2) Device IF Overview

Table 1 describes the device IF specified with Linking for connecting with service apps. The device IF is specified as a BLE communications profile^{*13}, and sends and receives service information on the Generic Attribute profile (GATT)^{*14}.

Although standard profiles such as Alert Notification Profile (ANP)^{*15} and Health Device Profile (HDP)^{*16} are prescribed in Bluetooth SIG^{*17} for different purposes, there are no generic profiles that enable communications between a range of devices with different characteristics. Thus, as shown in Table 1,

the minimum BLE profiles are specified in Linking for various communications with a range of devices. Also, because the maximum service data size that can be transmitted in one communication is 20 bytes in BLE, a number of communications are required to transmit large amounts of data. Hence, devices notify the Linking app of their functional capabilities. Then, by specifying that only information that the device can handle be used in exchanges with the Linking app, the number of communications can be minimized, and unnecessary communications between the device and the Linking app can be avoided. These approaches mean that devices with a variety of characteristics can connect generically and with low power.

Also, devices compatible with the Linking can be used regardless of whether the operating system is Android or iOS.

2.3 Service App API

Table 2 describes the service app API required to connect service apps and devices. The service app API on Android are composed of standard and

basic functions such as Android intent^{*18} and Content Provider^{*19}, which make it easy for service app developers to use the API if they have basic app development skills. For example, in the Notification API as shown in Table 2, various notifications can be made to devices without concern about device specifications, by only sending intent for those parameters set according to API specifications from the service app to the Linking app.

2.4 Linking App

The main Linking app functions are described below.

1) Device and App Management

Functions/UI Functions

The Linking app centrally manages settings such as app/device connectivity and device connection status, and provides detailed user settings for combining devices and apps. **Figure 2** shows an image of the Linking App Management screen.

- (1) As shown in Fig. 2 (a), With “Device Management screen,” the Linking app enables management and connectivity with a

Table 1 Device IF

Service name	Details
PeripheralDevicePropertyInformationService	Obtains device information (device name, device ID, device capabilities etc.)
PeripheralDeviceNotificationService	Provides device with information from various service apps (notification ID, service app name, notification patterns etc.)
PeripheralDeviceSensorInformationService	Obtains sensor information from device (sensor type, status, data values etc.)
PeripheralDeviceSettingOperationService	Exchanges operational information between devices and service apps (information about device buttons being pushed etc.)

^{*8} **Android™**: A software platform for smartphones and tablets consisting of an operating system, middleware and major applications. A trademark or registered trademark of Google Inc., United States.

^{*9} **iOS**: A trademark or registered trademark of Apple Inc. in the U.S.A. and other countries.

^{*10} **BLE**: Also called Bluetooth version 4.0, a Bluetooth standard that enables communications with low power consumption.

^{*11} **Advertisement packets**: Packets used in BLE by devices to transmit their device information.

^{*12} **Beacon**: A device that periodically transmits

information.

^{*13} **Profile**: Inter-device protocols formulated on a service-by-service basis for use in communications by Bluetooth and BLE.

^{*14} **GATT**: A profile used for transmitting the data in BLE.

list of paired devices. Users can also activate or deactivate beacon devices.

- (2) Users can select the service apps to be used with devices on the “Service App Management screen” at Fig. 2 (b), by selecting a device on the Device Management

screen. For example, “a device attached to an umbrella” is connected to the “i-concier app” in Fig. 2 (b).

- (3) Selecting a service app from the Service App Management screen transitions to “Preferences screen” at Fig. 2 (c), where users can se-

lect information to be notified to devices or make detailed service app settings such as LED patterns and illumination time. In the Preferences screen, the available settings items depend on device or service app specifications, for example, “Notification de-

Table 2 Service app API

API name	Details
Notification	Sends notifications (title, content, icon etc.) to devices
General notification	Sends more detailed information other than “Notification” to devices
Get device information	Acquires device information (device-specific information, connection status, device capabilities etc.)
Receive device information	Receives a range of device information (button info etc.)
Distance notification	Notifies distances between devices and smartphone
Sensor information	Starts/Stops acquisition of sensor information
Beacon information	Starts/Stops search for beacon devices
BLE connectivity information	Notifies BLE connection/disconnection between smartphones and devices

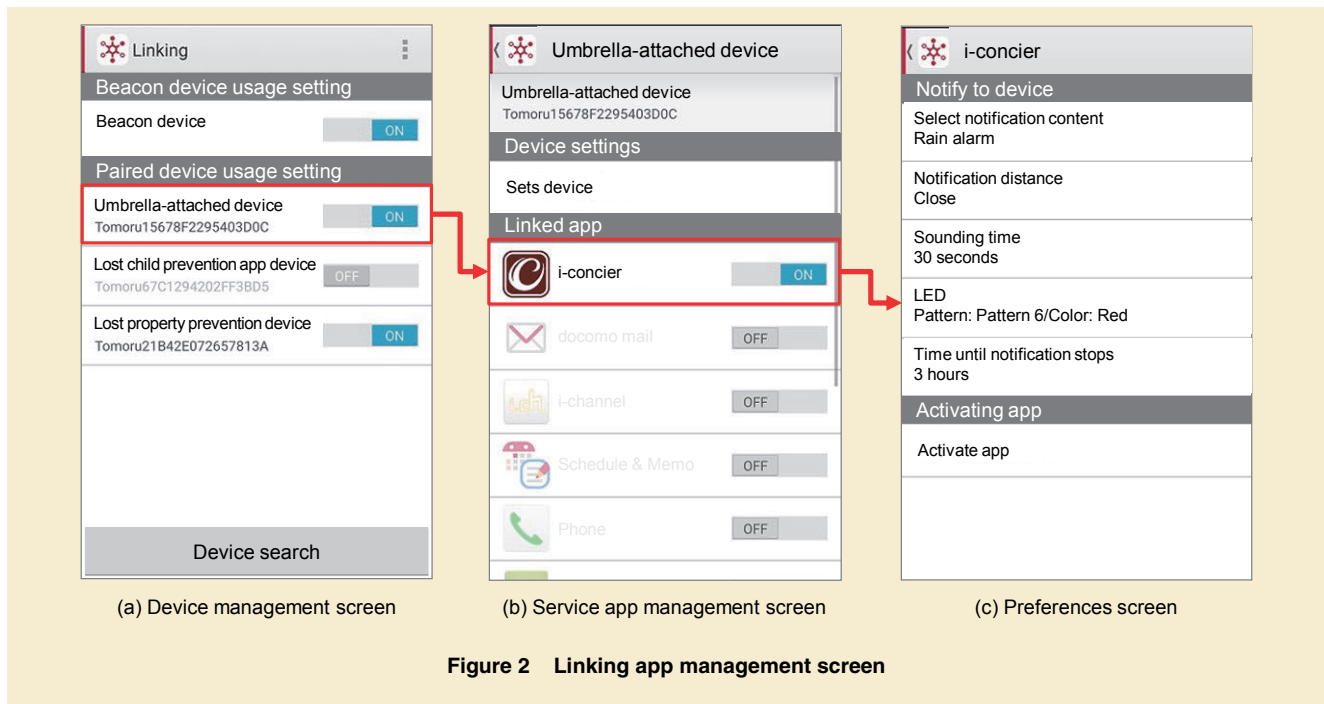


Figure 2 Linking app management screen

***15 ANP:** A profile standardized by Bluetooth SIG (see *17). for notification of an incoming phone call or SMS.

***16 HDP:** A profile standardized by Bluetooth SIG (see *17). for connecting medical and healthcare management devices.

***17 Bluetooth SIG:** Bluetooth Special Interest Group. A non-profit industry group that represents the Bluetooth standard and oversees the development and licensing of Bluetooth technology.

***18 Intent:** A function provided by Android OS to exchange parameters. Used between components

within an application, or between applications.

***19 Content Provider:** A function provided by Android OS which handles storage and searching of data related to general image, audio or video files, personal or other information. Content Provider enables applications to easily access various kinds of data.

tails” and “LED” are only displayed if the device or service app is equipped those functions. Therefore, users can easily understand settings because unavailable items are not displayed.

2) Distance Acquisition Function

(1) Function overview

The Linking app periodically estimates physical distances between each device and smartphone, and sends the estimated data to connected service apps. This function enables service app operations that are dependent on the distance between the smartphone and the device, such as acquisition of device sensor information only when devices are close, or alerts when the device and smartphone become too far apart.

(2) Calculation method

In the Linking app, the estimated distance d [m] between the device and the smartphone is calculated from the Bluetooth radio intensity from the device (Received Signal Strength Indicator (RSSI)^{*20}), using the equation below.

$$d = 10^{\frac{A - \text{RSSI}}{10 \times n}} \quad (1)$$

Where A is the RSSI value one meter from the device, n is the attenuation ratio, and RSSI is the measured value of the Bluetooth radio intensity [dBm]. However, the measured RSSI value will change due to conditions in the environments in which the device and smartphone are being used, or the way the user is hold-

ing the device or smartphone etc. Therefore, by calibrating the variable A in the equation (1) for the actual usage environment, Linking mitigates the effects of variations in RSSI values on the calculated distance.

(3) Notifications cache function

If the Bluetooth is disconnected between the device and smartphone, or the device is too far away from the smartphone, the Linking app can temporarily save (cache) notifications from the service app, and automatically send them to the device when the Bluetooth connection is reestablished. These specifications include settings for individual service apps about whether to cache notifications and how long they should be cached. By using these functions, service apps can notify devices of various information when the user becomes close to the device, which means users can in turn get available information about the places they are in, in step with their own move-

ments, without having to operate the smartphone.

2.5 Linking Configuration on iOS

Figure 3 describes the configuration of Linking on iOS.

Because iOS does not have the same kind of functions as the Android intent and Contents Provider, and because iOS only allows limited resident applications to operate, connections between devices and service apps cannot be achieved in the same way as Android.

Nevertheless, since it is important to be able to use devices regardless of the type of smartphone, we provide a library^{*21} of Android Linking app functions for iOS (hereinafter referred to as “Linking library”), which makes it easy for iOS service app developers to develop apps to connect to devices by incorporating the Linking library into each service app (as shown in Fig. 3). Device developers can also use the device IF mentioned earlier, which is compati-

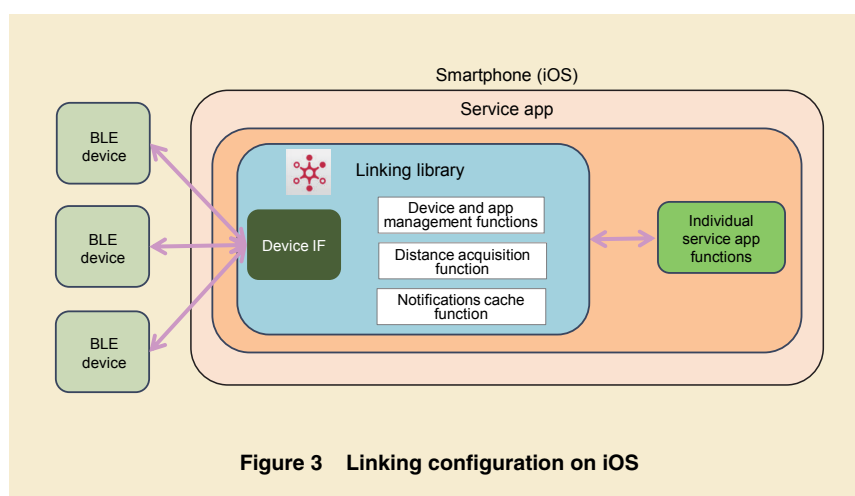


Figure 3 Linking configuration on iOS

^{*20} **RSSI:** The intensity of the signal received at the receiving device.

^{*21} **Library:** A collection of high-versatility programs in a reusable form.

ble with both Android and iOS.

3. Examples of Application

Linking enables devices and apps to be combined according to user preferences. The following describes examples of device usage with Linking in two different scenes (a carry rain gear alert and lost property prevention), and describes the processing sequences in the devices, Linking app and service apps.

3.1 Alert to Carry Rain Gear

It is possible to connect a device to “Rain alarm,” one type of information available with NTT DOCOMO’s i-concier app. Rain alarm warns the user’s smartphone when rain clouds are approaching user’s current location.

For example, a device could be at-

tached to the umbrella at entrance of the user’s house. Then, when the smartphone receives a rain alarm, and the user is about to go out, and the smartphone comes close enough to the device, the smartphone automatically sends the rain alarm to the device, which then alerts the user. In this way, the user need not check the smartphone to know that it is going to rain when they are about to leave the house, and can be intuitively alerted to the need to take an umbrella (Figure 4).

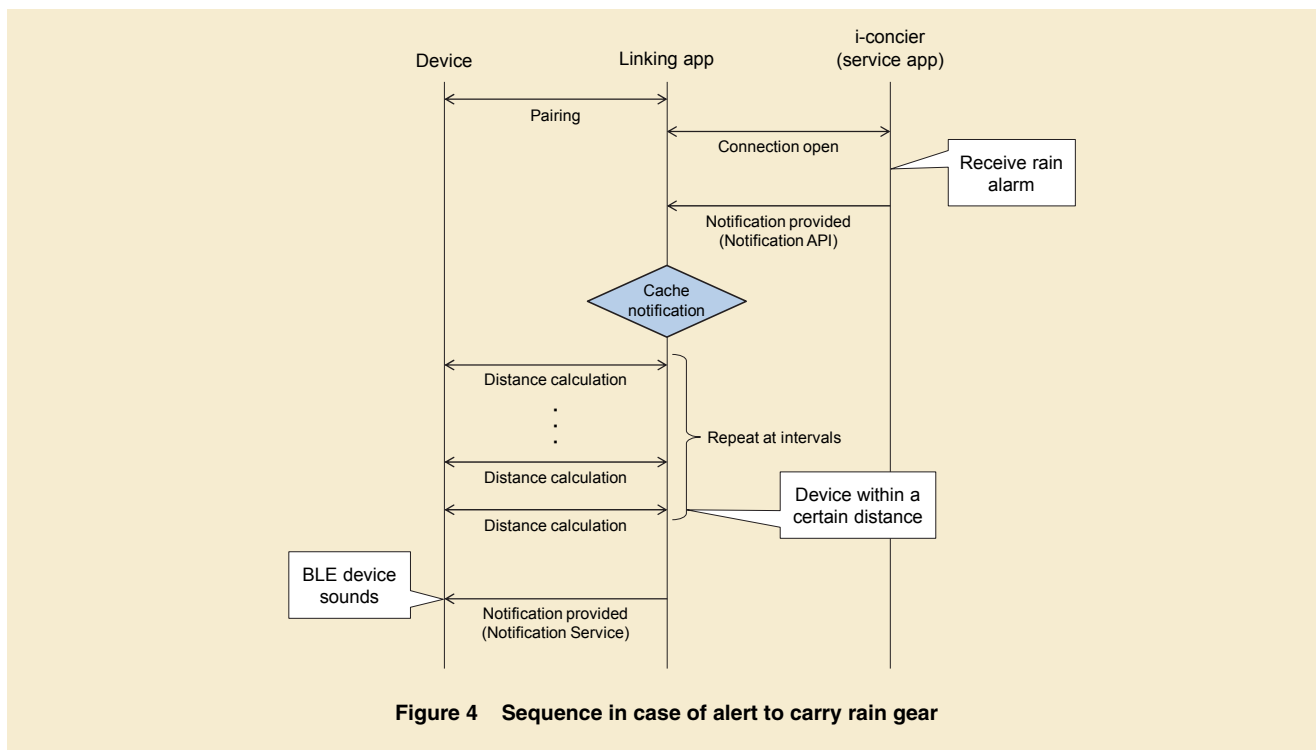
3.2 Lost Property Prevention

This describes a service app that alerts users to prevent lost property. To prevent users from leaving their wallets or bags somewhere, user can attach devices to things they don’t want to lose.

When the device and smartphone become separated by a certain distance, the service app can sound an alarm on the user’s smartphone as well as the device to alert the user (Figure 5).

4. Linking Deployment

To increase the use of Linking-compatible devices and service apps, and likewise expand the IoT, NTT DOCOMO has established “Project Linking” in partnership with several other Japanese companies, and is taking initiatives to spread and promote Linking [7] [8]. Also, device IF and service app API specifications for developers are published on the company web site [9], which device and service app developers can use free of charge. Also for service app developers, NTT DOCOMO provides a Soft-



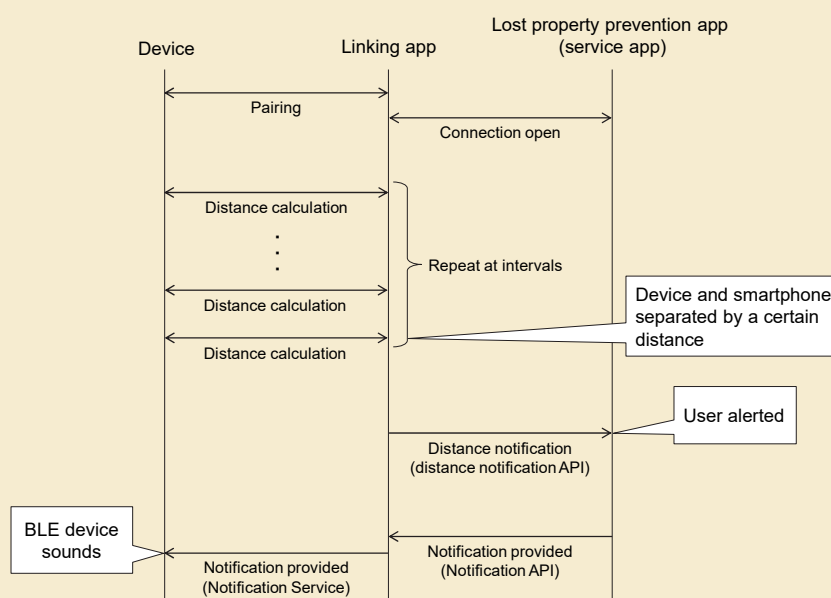


Figure 5 Lost property prevention sequence

ware Development Kit (SDK)^{*22} to simplify Linking-compatible service app development.

5. Conclusion

In this article, we have described an overview of Linking, which we developed with the aim of expanding the IoT market, as well as some practical examples of its deployment methods and usage.

In the future, we intend to continue to upgrade the development environment with such measures as expanding sample code for developers, and adding to and upgrading the device IF and service app API to provide and maintain a development environment for businesses and individuals to utilize. Also, Link-

ing will support device WebAPI [10] to enable both native service apps and web apps to access devices via the Linking app. We aim to expand and promote Linking compatible devices and service apps, and hence improve the convenience of user's daily lives with smartphones linked to various devices.

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^{*22} SDK: A tool or set of tools used for software development.

ITU Radiocommunication Assembly 2015 (RA-15) Report —Future Mobile Phone Technologies Standardization—

The ITU-R Radiocommunication Assembly was held from October 26-30, 2015 in Geneva, Switzerland, to reconsider ITU-R study structures and working methods, and approval of ITU-R Resolutions, Recommendations and Questions. This article focuses on the topics related to future of mobile phones, and their outcomes.

Network Department *Masayoshi Tachiki*
Takumi Togi

Radio Access Network Development Department *Hiroyuki Atarashi*

Wireless Technology Standardization Department *Akira Hashimoto*[†]

1. Introduction

The International Telecommunication Union (ITU) Radiocommunication Sector (ITU-R) has jurisdiction over standardization of radiocommunication technology specifications and spectrum utilization etc. As shown in **Figure 1**, ITU-R studies radiocommunication technologies and spectrum utilization etc. by establishing Study Groups (SGs) responsible for specific areas of radiocommunication and Working Parties (WPs) under each of the SGs. WP5D under SG5 is the working party responsible for studies on International Mobile Telecommunications (IMT), which covers mobile phones from 3G beyond.

The association that discusses the overall activities of the ITU-R is the Radiocommunication Assembly (RA),

which normally convenes once every three to four years. As shown in Fig. 1, RA is the parent organization of the SGs, and in relation to ITU-R study structure, deliberates on the structure of SGs, appoints chairman and vice-chairmen to the SGs, deliberates on working methods such as approval processes for various ITU-R documents, and deliberates on approval for individual ITU-R Resolutions, Recommendations and Questions. 2015 was the first year that RA was held since 2012. Dubbed RA-15, the assembly was held from October 26 to 30, 2015.

This article provides an overview of RA-15, and reports on its deliberations and their outcomes, such as approval for new ITU-R study structures and ITU-R Resolutions on IMT.

2. RA-15 Overview

RA-15 was attended by some 460 people from a range of associations such as various administrations of 107 of the 193 member states of the ITU and international organizations. There were 30 attendees from Japan, from the Ministry of Internal Affairs and Communications, telecommunications operators and research institutions. Four staff from NTT DOCOMO attended.

Figure 2 shows the RA-15 conference structure. As is customary, the RA plenary meeting chairman is appointed from a retiring SG chairman from the corresponding study session. Following this tradition, Dr. Akira Hashimoto (one of the authors of this article), who had served as the chairman of SG5 for two study peri-

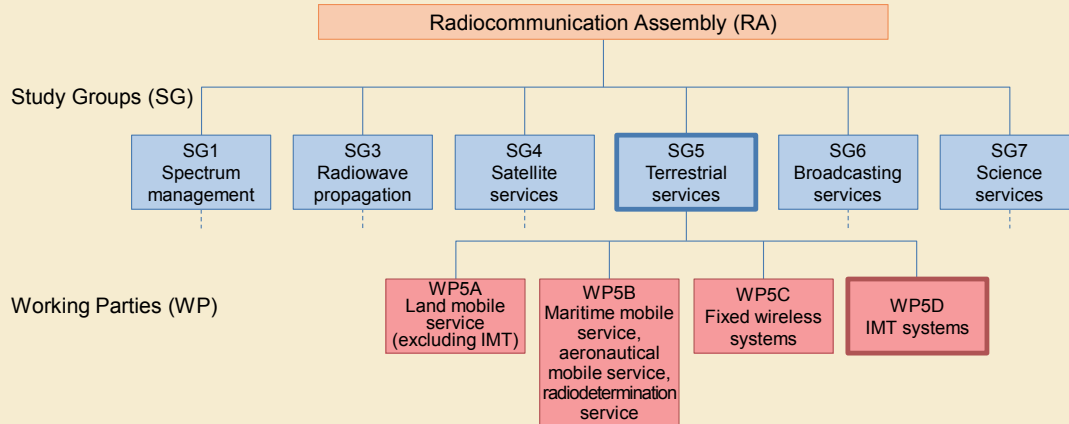


Figure 1 ITU-R study group structure

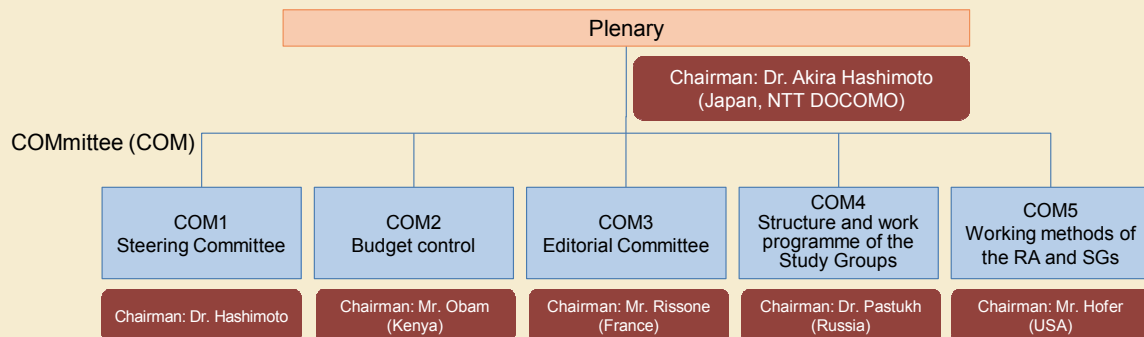


Figure 2 RA-15 conference structure

ods from the 2007 Radiocommunication Assembly (RA-07), was appointed to the position.

3. RA-15 Content of Deliberations

3.1 SG Structure and Appointment of SG Chairman and Vice-chairmen

There were no proposals to re-

structure SGs at RA-15, hence, the SG structure described in Fig. 1 was maintained.

Table 1 is a list of the SG chairmen appointed at RA-15.

Being in their second period, the existing chairmen of SG1 (Spectrum management) and SG4 (Satellite services) were reappointed, while new chairmen were appointed to SG3 (Radiowave propagation), SG5 (Terres-

trial services), SG6 (Broadcasting services) and SG7 (Science services). From Japan, NHK's Dr. Yukihiro Nishida was appointed to chairman SG6.

SG vice-chairmen were also appointed from candidates from various nations. From Japan, Dr. Hiroyuki Atarashi (one of the authors of this article) was appointed as vice-chairman of SG5, and KDDI's Mr. Nobuyuki



Table 1 Study Group chairman and vice-chairman appointments

SG	Scope	Chairman	Vice-chairmen
SG1	Spectrum management	<u>Dr. Pastukh (Russia)</u>	14 persons
SG3	Radiowave propagation	Mrs. Wilson (Australia)	9 persons
SG4	Satellite services	<u>Mr. Hofer (ViaSat (USA))</u>	15 including Mr. Kawai (Japan, KDDI)
SG5	Terrestrial services	Mr. Fenton (U.K.)	18 including Dr. Atarashi (Japan, NTT DOCOMO)
SG6	Broadcasting services	Dr. Nishida (Japan, NHK)	14 persons
SG7	Science services	Mr. Zuzek (USA)	8 persons

Underlined: Reappointed

Kawai was reappointed as vice-chairman of SG4.

This means that Japan has kept the same numbers of chairmen and vice-chairmen from the previous period (formerly one SG chairman (SG5 chairman Dr. Hashimoto) and two vice-chairmen (SG4 vice-chairman Mr. Kawai and SG6 vice-chairman Dr. Nishida)).

3.2 Review of ITU-R Work Methods

There were discussions on revising ITU-R Resolution 1, which defines working methods in all ITU-R groups (SGs, WPs etc.), and approval procedures for ITU-R documents (Resolutions, Recommendations, Reports etc.). This revision at the RA-15 mainly focused on reviewing the structure of the Resolution, such as separating descriptions of approval procedures for documents and working method into different chapters, but be-

cause controversies on adopting ITU-R Recommendations have often occurred due to unreached consensus, expressions about provisions on “reaching consensus” were reviewed and clarified.

Also, to make studies and considerations in ITU-R more efficient, revision of ITU-R Resolution 2, which defines ITU-R working methods, was approved. This includes integrating the special committee (SC) set up to study World Radiocommunication Conference (WRC)*¹ agenda from the perspective of regulatory matters, with the WRC Conference Preparatory Meeting (CPM)*², and slightly shortening the CPM session.

3.3 IMT-related Deliberations

Regarding mobile phones, radio interface specifications, unwanted emissions provisions and spectrum usage methods etc. for IMT-2000 systems corresponding to 3G mobile phone

systems and the successor development system IMT-Advanced systems, which are successor development systems of IMT-2000 systems, are defined in ITU-R Recommendations. Based on these Recommendations, various countries have established mobile phone technological standards etc., which has contributed to the international spread of mobile phones in terms of roaming, equipment and terminal procurement. WP5D, which is the responsible working party for studies on IMT systems, has begun studying mobile phone systems for 2020 and beyond, in view of the rapid increase in mobile traffic and the expansion of usage scenes with the Internet of Things (IoT)*³ etc.

In addition to the terms of “IMT-2000” and “IMT-Advanced,” the term “IMT-2020” was officially approved as the mobile phone systems for 2020 and beyond, which was reflected in ITU-R Resolution 56, relating to IMT

*1 **WRC:** A conference that reviews, and if necessary, revises Radio Regulations, the international treaty governing the use of radio-frequency spectrum, and the orbits of geostationary and non-geostationary satellites. The conference normally meets once

every three to four years, and is attended by the administrations of various countries, and related organizations including operators which are registered to ITU.

*2 **CPM:** The Conference Preparatory Meeting. A meeting to develop a report for con-

sideration by the WRC, which summarizes ITU-R SG study results and other WRC-related discussions.

*3 **IoT:** A General term for controls and data communications between various “things” connected via the Internet or cloud services.

terms. In this Resolution, the term “IMT” is used as the root name for all international mobile phone telephony, which is appended as IMT-2000, IMT-Advanced and IMT-2020 system designations, depending on radio interface specifications.

Also, a new draft Resolution to define the principles of IMT development processes for 2020 and beyond were deliberated, and ITU-R Resolution 65 was approved for developing ITU-R Recommendations for IMT-2020 requirements and radio interface specifications and so forth in future ITU-R activities. IMT-2020 usage scenes and draft requirements have already been established in Recommendation ITU-R M.2083.

In addition, other ITU-R Resolutions regarding IMT were revised, ITU-R Recommendations on IMT were approved after the conclusion was carried forward to RA-15 having had adoption shelved in SG5, while maintenance of Questions on IMT was

approved.

3.4 Others

Apart from IMT, various other radiocommunication systems were deliberated in RA-15, 33 ITU-R Resolutions were approved (six new, 22 revisions of existing, five abolishments), seven ITU-R Recommendations for which consensus was not reached in SGs were approved (four new, three revisions of existing), and Questions were approved etc.

Mobile services related items include new Resolutions defining IoT-related studies in ITU-R (Resolution ITU-R 66), and new Questions on visible light communications.

4. Conclusion

This article has provided an overview of RA-15, and reported on its deliberations and their outcomes, such as approval for new ITU-R study structures and ITU-R Resolutions on IMT.

As ITU-R Resolutions on the term “IMT-2020” and principles of IMT development processes for 2020 and beyond have been approved in RA-15, standardization of IMT-2020 radio interfaces will take place in WP5D, which is the working party responsible for studies on IMT systems under SG5.

Also, since many administrations are highly interested in IMT, regardless of whether they are in developed or developing countries, there is the important issue of Japan maintaining its leading role in standardization of IMT radio interface specifications and spectrum usage while cooperating with the administrations of the various countries and regions around the world to decide how to reflect these standards in ITU-R Recommendations and so forth.

With the appointment of the SG5 vice-chairman from Japan, Japan must continue its proactive contribution to this standardization work.

2015 ITU World Radiocommunication Conference (WRC-15) Report —Standardization of Mobile Phone Spectrum—

ITU World Radiocommunication Conference was held in Geneva, Switzerland, from the November 2 to 27 in 2015, to deliberate on revisions of the ITU Radio Regulations, under which the international treaty governing the use of the radio-frequency spectrum, procedures for radio station operations and technical standards etc. are prescribed. This article provides an overview of the conference, its deliberations on matters related to mobile phone spectrum, and their outcomes.

Radio Access Network Development Department **Hiroyuki Atarashi**
Network Department **Takumi Togi**
Masayoshi Tachiki
Wireless Technology Standardization Department **Akira Hashimoto[†]**

1. Introduction

The International Telecommunication Union (ITU) defines the international treaty governing the use of the radio-frequency spectrum, procedures relating to radio station operations, and technical standards etc. in the Radio Regulations. The regulations are necessary because radio frequencies are a limited resource, and countries have to use radio frequencies while accommodating each other and maintaining mutual order to prevent interference etc. The countries of the world have ratified the Radio Regulations in international treaties, and make decisions about

using radio frequencies domestically based on the provisions in the Radio Regulations.

Revising the Radio Regulations is done by the ITU World Radiocommunication Conference (WRC), which is normally convened once every three to four years. Held over a four-week period from November 2 to 27 in 2015, the World Radiocommunication Conference (WRC-15) entailed deliberations on revising regulations pertaining to radio-frequency spectrum usage.

Identification of the frequency bands for International Mobile Telecommunications (IMT) has been conducted since the introduction of 3G

mobile phones, and efforts to identify the frequency bands for IMT in the Radio Regulations are ongoing. Having all nations of the world use the identified bands for IMT is beneficial for standardization of mobile phone spectrum, because these identifications enable mobile phone frequencies to be common and interference to be avoided while conferring advantages with device development and procurement. IMT identifications for the 800/900 MHz, 1.7 GHz, 2 GHz, and 2.5/2.6 GHz frequency bands widely in use with mobile phones around the world are the result of past WRC deliberations.

This article provides an overview

of WRC-15, and focuses on deliberations pertaining to additional IMT spectrum identification, and the outcomes of those deliberations.

2. WRC-15 Overview

WRC-15 was attended by some 3,800 people from a range of associations such as administrations of 162 of the 193 member states of the ITU and various international organizations. There were 82 attendees from Japan, including attendees from the Ministry of Internal Affairs and Communications, telecommunication operators, vendors and research institutions. Four staff from NTT DOCOMO

attended.

Figure 1 shows the WRC-15 conference structure, while a list of agenda items discussed at WRC-15 is shown in **Table 1**. Mr. Daudu of Nigeria was appointed as the Chairman of the Plenary, making it the first time in its history that it has been presided over by a member from the African region. Under the Plenary, there were seven COMmittees (COMs). In addition, under COMs 4 to 6, there were Working Groups (WGs), which were allocated agenda items for consideration in each field of study. Depending on the agenda item, Sub-Working Groups (SWGs) were also

set up under Working Groups for more detailed discussions.

3. WRC-15 Agenda Item 1.1 (Additional IMT Spectrum Identification)

This agenda item was set in the 2012 World Radiocommunication Conference (WRC-12) with acceptance that mobile communications traffic would increase, and was widely supported by many countries. After WRC-12, research was carried out by the ITU Radiocommunication Sector (ITU-R), in which 19 frequency bands were cited as candidates, as shown in

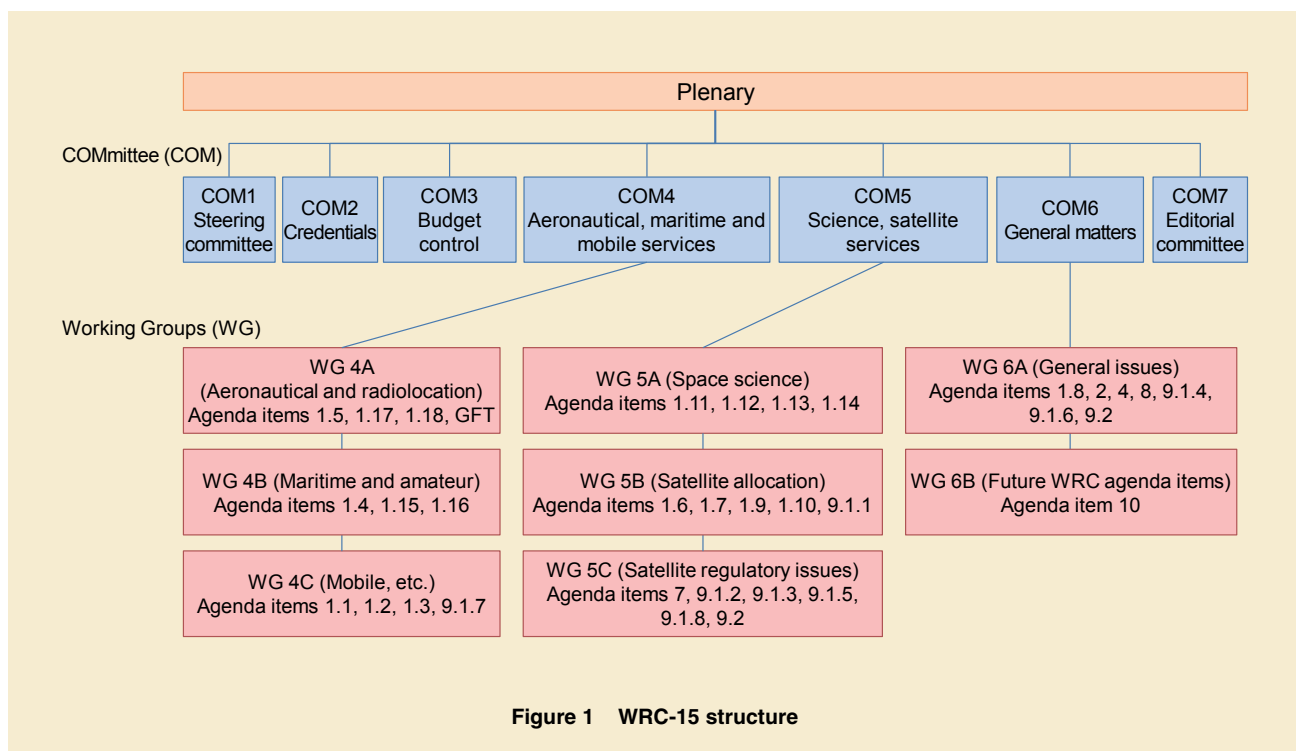




Table 1 WRC-15 agenda items list

Agenda items	Overview
1.1	Additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for IMT
1.2	Use of the frequency band 694 - 790 MHz by the mobile service in Region 1
1.3	Broadband Public Protection and Disaster Relief (PPDR) implementation
1.4	Allocation to the amateur service on a secondary basis within the band 5,250 - 5,450 kHz
1.5	Use of frequency bands allocated to the fixed-satellite service for the control and non-payload communications of Unmanned Aircraft Systems (UAS)
1.6	(1) Additional primary allocation to the fixed-satellite service of 250 MHz in Region 1 within the range between 10 - 17 GHz (2) Additional primary allocation to the fixed-satellite service of 250 MHz in Region 2 and 300 MHz in Region 3 within the range 13 - 17 GHz
1.7	Review of usage of the 5,091 - 5,150 MHz band in the fixed satellite service
1.8	Review of the provisions relating to Earth Stations located on board Vessels (ESVs)
1.9	(1) Allocations to the fixed-satellite service in the frequency bands 7,150 - 7,250 MHz (space-to-Earth) and 8,400 - 8,500 MHz (Earth-to-space) (2) Allocations to the maritime-mobile satellite service in the frequency bands 7,375 - 7,750 MHz and 8,025 - 8,400 MHz
1.10	Spectrum requirements and possible additional spectrum allocations for the mobile-satellite service within the frequency range from 22 GHz to 26 GHz
1.11	Primary allocation for the Earth exploration-satellite service in the 7 - 8 GHz range
1.12	An extension of the current worldwide allocation to the Earth exploration-satellite (active) service within the frequency bands 8,700 - 9,300 MHz and/or 9,900 - 10,500 MHz
1.13	Expansion of communications usage between manned spacecraft
1.14	Review of Coordinated Universal Time (leap second insertion)
1.15	Spectrum demands for on-board communication stations in the maritime mobile service
1.16	Regulatory provisions and spectrum allocations to enable possible new Automatic Identification System (AIS) technology applications and possible new applications to improve maritime radiocommunication
1.17	Support of Wireless Avionics Intra-Communications (WAIC)
1.18	Primary allocation to the radiolocation service for automotive applications in the 77.5 - 78.0 GHz frequency band
2	Examine the revised ITU-R Recommendations incorporated by reference in the Radio Regulations
4	Review of the resolutions and recommendations of previous conferences
7	Review of procedures for frequency assignments pertaining to satellite network
8	Country name deletions from footnotes
9	Report of the Director of the Radiocommunication Bureau
9.1.1	Protection of the systems operating in the mobile-satellite service in the band 406 - 406.1 MHz
9.1.2	Possible reduction of the coordination arc and technical criteria
9.1.3	Use of satellite orbital positions and associated frequency spectrum for international public communications services in developing countries
9.1.4	Updating and rearrangement of the Radio Regulation
9.1.5	Support of existing and future operation of fixed-satellite service earth stations within the band 3,400 - 4,200 MHz, as an aid to the safe operation of aircraft and reliable distribution of meteorological information in some countries in Region 1
9.1.6	Studies towards review of the definitions of fixed service, fixed station and mobile station
9.1.7	Spectrum management guidelines for emergency and disaster relief radiocommunication
9.1.8	Regulatory aspects of nano and pico satellites
9.2	Any difficulties or inconsistencies encountered in the application of the Radio Regulations
9.3	Studies on measures for prescriptions in Resolution 80 (WRC-07 revision)
10	Agenda for future World Radiocommunication Conferences
GFT*	Introduction of global flight tracking (systems for tracking civilian aircraft using satellites)

*An emergency agenda set following the disappearance of the Malaysian Airlines MH370 passenger jet in 2014, not assigned a normal agenda number.

Table 2.

This was also a high-profile agenda item in WRC-15, and was a large scale meeting with full-time participation from some 500 people, even at the SWG level. Dr. Atarashi (one of the authors of this article) was appointed as the chairman to carry out proceedings in this SWG.

Initial SWG discussions were aimed at eliminating candidate fre-

quency bands that had little support, resulting in consensus to remove nine of the 19 bands (the Radio Regulations will not be revised for these frequency bands), which was reported to, and approved by the SWG parent groups. These frequency bands included the 3,800 - 4,200 MHz and 4,500 - 4,800 MHz bands that Japan had been advocating.

Following, regarding the remain-

ing ten frequency bands, discussions on identification of IMT spectrum in the Radio Regulations continued, but as each country expressed different opinions, and agreeable opinions could not be reached, an informal meeting with the Chairman of WRC was held. This informal meeting was held to coordinate opinions for each Region, Region 1 (Europe, Commonwealth of Independent States (CIS), Africa

Table 2 Candidate frequency bands under WRC-15 agenda item 1.1

No.	Frequency bands	Frequency bands supported by Japan	Results of WRC-15 deliberations
1	470 - 694/698 MHz		Refer to Table 3
2	1,350 - 1,400 MHz		No Radio Regulations revision
3	1,427 - 1,452 MHz	Y	Refer to Table 3
4	1,452 - 1,492 MHz	Y	Refer to Table 3
5	1,492 - 1,518 MHz	Y	Refer to Table 3
6	1,518 - 1,525 MHz		No Radio Regulations revision
7	1,695 - 1,710 MHz		No Radio Regulations revision
8	2,700 - 2,900 MHz		No Radio Regulations revision
9	3,300 - 3,400 MHz		Refer to Table 3
10	3,400 - 3,600 MHz	Y	Refer to Table 3
11	3,600 - 3,700 MHz	Y	Refer to Table 3
12	3,700 - 3,800 MHz	Y	No Radio Regulations revision
13	3,800 - 4,200 MHz	Y	No Radio Regulations revision
14	4,400 - 4,500 MHz	Y	No Radio Regulations revision
15	4,500 - 4,800 MHz	Y	No Radio Regulations revision
16	4,800 - 4,990 MHz	Y	Refer to Table 3
17	5,350 - 5,470 MHz*		No Radio Regulations revision
18	5,725 - 5,850 MHz*		No Radio Regulations revision
19	5,925 - 6,425 MHz		No Radio Regulations revision

*Under consideration for additional spectrum for wireless LAN

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and Arabia), Region 2 (North and South America) and Region 3 (Asia-Pacific), after which proposals for solutions were submitted for final consensus from each Region. As a result, initiatives to coordinate opinions were entrusted to regional groups rather than on a nation-by-nation basis.

Finally, consensus to revise the Radio Regulations was reached on the night before the final day of WRC-15, based on proposals coordinated by the regional groups. **Table 3** provides a summary of the results of new IMT spectrum identification, including proposed revisions.

3.1 470 - 694/698 MHz

Because these frequency bands are used in countries around the world to broadcast terrestrial television, many countries and regional groups were against identification of the bands for IMT. Nevertheless, with the aim of diverting the 600 MHz band to mobile broadband applications that will cover IMT, there was strong rallying mainly by the US for plans for an incentive auction^{*1}. Finally, consensus was reached to identify the frequency bands for IMT for the North and Central American countries and some countries from the Oceania region (just over ten) after coordination with their surrounding countries.

3.2 1,427 - 1,452 MHz, 1,452 - 1,492 MHz, 1,492 - 1,518 MHz

Many countries supported IMT identification of these frequency bands, including Japan which is already using them for mobile phones, although regulatory methods regarding coexistence with aeronautical mobile telemetry systems^{*2} and broadcast satellite communications systems in some countries have become an issue.

As a result of discussions, identification for Region 1 1,452 - 1,492 MHz was limited to around 50 countries, although consensus was reached for other Regions for identification as IMT frequency bands. This means that 1,427 - 1,518 MHz is now almost completely recognized internationally as an additional spectrum for mobile phones.

3.3 3,300 - 3,400 MHz

While some countries asserted that this frequency band is suitable for IMT identification because usage with existing systems is limited, countries mainly in Europe expressed the opinion that it is not suitable because of usage with radar.

As a result of discussions, consensus was reached for identification as an IMT frequency band for some countries in the regions of Africa,

Central and South America, and Asia (just over 40 countries) with the conditions that IMT radio station usage not interfere with radar, and conversely, protections from interference from radar not be sought.

3.4 3,400 - 3,600 MHz, 3,600 - 3,700 MHz, 3,700 - 3,800 MHz

Since these frequency bands are widely used with satellite communications systems, countries in which these systems constitute important infrastructure have consistently expressed opposition to their IMT identification. In the 2007 World Radiocommunication Conference (WRC-07) also, similar discussions were held on these frequency bands, and as a result, only 3,400 - 3,600 MHz was identified for just over 90 countries in Regions 1 and 3 (including Japan). In WRC-15, discussions followed a similar pattern, and the scope of the identification of 3,400 - 3,600 MHz was expanded in regions as an additional IMT spectrum, meaning that is now almost completely recognized internationally. Regional discussions were as follows.

- (1) In Region 1, European countries supported IMT identification of 3,400 - 3,800 MHz, although support from others

^{*1} **Incentive auction:** A new spectrum auction technique to encourage spectrum diversion that returns some of the auction revenues to the original spectrum license holders.

^{*2} **Aeronautical mobile telemetry system:** A communication system that transmits data for aircraft meter readings etc, and enables aircraft monitoring and remote control.

Table 3 New IMT frequency band identification at WRC-15

Specified spectra	Region 1 (Europe, CIS, Arab, Africa) 122 countries	Region 2 (North and South America) 35 countries	Region 3 (Asia-Pacific) 36 countries
470 - 694/698 MHz (Section 3.1)	—	<ul style="list-style-type: none"> • 470 - 608 MHz Identified for 5 countries (US, Canada, Mexico, Bahamas, Barbados) • 614 - 698 MHz Identified for 7 countries (US, Canada, Mexico, Columbia, Bahamas, Barbados, Belize) 	<ul style="list-style-type: none"> • 470 - 698 MHz Identified for 4 countries (Micronesia, Solomon Islands, Tuvalu, Vanuatu) • 610 - 698 MHz Identified for 3 countries (New Zealand, Bangladesh, Maldives)
694/698 - 790 MHz (Chapter 4)	Identified for entire Region (Agenda item 1.2)	Identified for entire Region (Identified in 2007)	Identified for 26 countries (Newly identified for 16 countries. Remaining 10 countries identified in 2007 (including Japan))
1,427 - 1,452 MHz (Section 3.2)	Identified for entire Region	Identified for entire Region	Identified for entire Region
1,452 - 1,492 MHz (Section 3.2)	Identified for 54 countries (Arabic, African countries)	Identified for entire region	Identified for entire Region
1,492 - 1,518 MHz (Section 3.2)	Identified for entire Region	Identified for entire Region	Identified for entire Region
3,300 - 3,400 MHz (Section 3.3)	Identified for 33 countries (African countries)	Identified for 6 countries (Mexico, Columbia, Argentina, Costa Rica, Ecuador, Uruguay)	Identified for 6 countries (Cambodia, India, Laos, Pakistan, Philippines, Vietnam)
3,400 - 3,600 MHz (Section 3.4)	Identified for entire Region	Identified for entire Region	<ul style="list-style-type: none"> • 3,400 - 3,500 MHz Identified for 11 countries (Newly identified for 2 countries. Remaining 9 countries identified in 2007 (including Japan)) • 3,500 - 3,600 MHz Identified for 10 countries (Newly identified for 2 countries. Remaining 8 countries identified in 2007 (including Japan))
3,600 - 3,700 MHz (Section 3.4)	—	Identified for 4 countries (US, Canada, Columbia, Costa Rica)	—
4,800 - 4,990 MHz (Section 3.5)	—	<ul style="list-style-type: none"> • 4,800 - 4,900 MHz Identified for 1 country (Uruguay) 	Identified for 3 countries (Cambodia, Laos, Vietnam)

countries was limited. While 3,400 - 3,600 MHz was identified for IMT for the entire region, IMT identification above 3,600 MHz was postponed.

- (2) In Region 2, 3,400 - 3,600 MHz was identified for IMT for the entire Region, only four coun-

tries including the US and Canada consented to IMT identification for the 3,600 - 3,700 MHz band. Also, IMT identification for the frequency band above 3,700 MHz was postponed.

- (3) In Region 3, Japan initially

aimed for IMT identification for 3,400 - 4,200 MHz, although after determining difficulty in identifying 3,800 MHz and above, this was narrowed down to 3,400 - 3,800 MHz, and supported in partnership with Korea, which supports the

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same frequency band. However, the majority of countries advocated for protection of satellite communications systems. As a result of discussions, in Region 3, Australia and the Philippines were added as new countries for identification of 3,400 - 3,600 MHz, although IMT identification above 3,600 MHz was postponed.

3.5 4,400 - 4,500 MHz, 4,800 - 4,990 MHz

These frequency bands are supported for IMT identification by Japan, China, the CIS and some African countries. However, because these spectra are used for radio communications in aircraft etc. in European and some other countries, there were demands that strict conditions be met, such as restricting radio wave intensity so that signals emitted from implemented IMT radio stations stay within national borders, and that signals not exceed a certain level on the high seas. Also, since the effects of interference on aircraft radio altimeters using 4,200 - 4,400 MHz from the adjacent 4,400 - 4,500 MHz spectrum have not been studied, many voiced opposition due to safety concerns.

As a result of discussions, for these frequency bands, 4,800 - 4,900

MHz is only identified for IMT in one country in Region 2, and 4,800 - 4,990 MHz is identified in only three countries in Region 3. IMT identification for 4,400 - 4,500 MHz was postponed.

4. WRC-15 Agenda Item 1.2 (Use of the Frequency Band 694 - 790 MHz by the Mobile Service in Region 1)

This agenda item was set because, in WRC-12, 694 - 790 MHz was identified for IMT in Region 1, and new prescriptions and procedures for its technical and regulatory requirements would be made in WRC-15. As a result of discussions, regarding IMT station operation, official consensus was reached on requirements to protect terrestrial television broadcasting below 694 MHz, and protect radio communications systems for 645 - 862 MHz aeronautical radio navigation mainly used in CIS.

Also in the above WRC-15 agenda item 1.1, consensus was reached to newly identify the 698 - 790 MHz band for IMT in 19 countries in Region 3.

From the above, since IMT identification for Region 2 was already done in WRC-07, 694/698 - 790 MHz is now almost completely recognized internationally as additional mobile phone radio frequencies.

5. WRC-15 Agenda Item 10 (Future WRC Agenda Items)

As well as deliberations on revising the Radio Regulations, WRC also deliberates on selecting agenda items for the next two future WRCs. The following describes future WRC agenda items agreed upon through discussions at WRC-15.

5.1 Additional Identification of IMT Spectrum between 24.25 - 86 GHz (WRC-19 Agenda Item 1.13)

Studies on IMT identification in WRC have so far targeted frequency bands below 6 GHz, including the aforementioned WRC-15 agenda item 1.1. However, technical developments that enable higher frequency use than the conventional mobile phone radio-frequencies are progressing with 5G mobile communications systems. In light of these developments, various countries and regional groups proposed to set an agenda item for IMT identification above 6 GHz for WRC-19.

This quickly led to consensus being reached on setting a new agenda item for IMT identification for WRC-19, and discussions focused on which frequency ranges above 6 GHz should be targeted and the relevant studies

that should be carried out in ITU-R in the lead up to WRC-19. A list of the frequency bands proposed from the regional groups is shown in the upper part of **Figure 2**. In general, the regional proposals take into account the usage of existing radio communications systems (satellite communications, fixed communications etc.), and many of these proposals target the frequency bands above 25 GHz, because they can be secured for future IMT usage.

However, if studies are limited to

frequency bands higher than 25 GHz, there are concerns about constraints being added to future development and deployment of the mobile communications systems. Therefore, Japan asserted that studies between the 6 - 20 GHz range should also be included. While there was support for this Japanese proposal from some African and Northern European countries, the majority of opinion was that the 6 - 20 GHz frequency bands could not be secured for future mobile phone use

due to their dense use in many countries, hence, consensus was not reached.

Similarly, regarding 27.5 - 29.5 GHz advocated as a new frequency band for 5G mobile communications systems by the USA and Korea, having been originally secured as spectra for satellite communications systems, the majority of opinion was that there is not much potential for the frequency band to be used with mobile phones, hence, consensus was not reached.

In light of the above discussions,

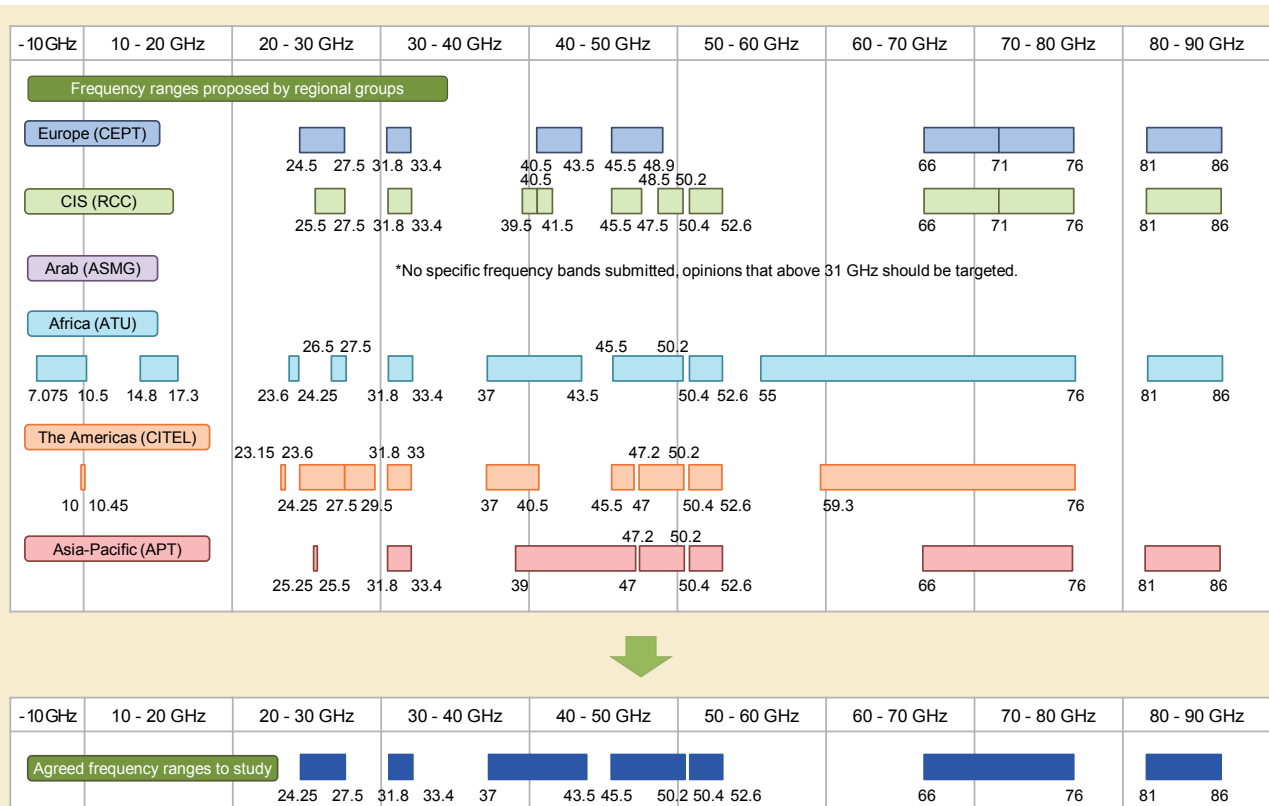


Figure 2 Frequency ranges to study for IMT identification in WRC-19

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to identify IMT frequency bands at WRC-19, it was agreed that a number of frequency bands between 24.25 - 86 GHz, shown in the lower part of Fig. 2, should be studied in ITU-R in the lead up to WRC-19.

5.2 Other Future WRC

Agenda Items

Other mobile phone and wireless LAN-related agenda items agreed upon for WRC-19 are as follows.

Based on proposals from the USA and others, for spectrum of wide-band radio access systems including wireless LAN, it was agreed that studies be carried out and conclusions reached at WRC-19 for the potential use of the new 5,350 - 5,470 MHz, 5,725 - 5,850 MHz, 5,850 - 5,925 MHz and the existing 5,150 - 5,350 MHz bands with outdoor wireless LAN systems (WRC-19 agenda item 1.16).

Also, based on proposals from the Arabic countries, regarding the Internet of Things (IoT)^{*3} concept, it was agreed that wide and narrow-band frequency bands for M2M communications infrastructure be studied in ITU-R, and be studied as required in WRC-19 (one of the issues in WRC-19 agenda item 9.1).

6. Conclusion

This article has provided and over-

view of WRC-15, and reported on its deliberations regarding additional identification of frequency bands for IMT, and the results of those deliberations. Through the agreements made at WRC-15 to revise the Radio Regulations, the 694/698 - 790 MHz, 1,427 - 1,518 MHz and 3,400 - 3,600 MHz frequency bands already in use or planned for use (partially) with mobile phones, even in Japan, were identified as additional IMT frequency bands, which means these bands are now mostly recognized for mobile phone use internationally. Going forward, the use of these bands in various countries will bring about commonalities with everything from components through to whole radio devices, which will confer benefits such as cost reductions.

In contrast, Japan's advocacy for additional identification of 3,600 - 4,200 MHz and 4,400 - 4,900 MHz as IMT frequency bands was met with opposition from countries focusing on applications other than mobile phones, meaning that only some of those bands were identified for IMT for some countries. This is because usage varies from country to country, and inevitably some candidate frequency band would be difficult to co-exist with incumbent systems between adjacent and peripheral countries, a fact which has made identifying frequen-

cy bands for IMT even more difficult. Furthermore, although IMT identification in the Radio Regulations is usually done at the global and regional levels, it was apparent that this WRC was an opportunity to review the positioning and objective of IMT identification, as there were examples of identifications also being made under conditions set down at the level of a few countries.

Heading towards WRC-19, studies on new IMT identification between 24.25 - 86 GHz will proceed. In the week following WRC-15, the 1st session of the Conference Preparatory Meeting for WRC-19 (CPM19-1) was held, in which a new dedicated group was set up in ITU-R. In the group, relevant experts will come together to drive study of spectrum sharing between IMT and existing radio communications systems. At WRC-19, to revisit the original purpose of IMT identification in the Radio Regulations, it will be necessary to further cooperation in technical studies between many of the countries and regions of the world, and deepen mutual understanding about IMT identification in this coming three-year preparatory period. NTT DOCOMO also intends to continue various technical studies for presentation in discussions on identification of new IMT frequency bands.

^{*3} **IoT:** A General term for controls and data communications between various "things" connected via the Internet and cloud services.

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Editorial Correspondence

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

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