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DOCOMO Today

Technology Reports

NTT docomo

Promoting the Evolution of Solutions

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The Solution Service Department is in charge of technology sales and technology management in relation to business-operation services for enterprise customers. To provide solutions that satisfy our customers now and into the future, we support a variety of processes, from making proposals to developing, constructing, and deploying systems (kitting*1), as well as operations monitoring and Business Process Outsourcing (BPO). We also support a wide range of commercial products from terminals to area/network equipment, business-operation service systems for enterprise customers and Software as a Service*2). All in all, our aim is to provide a "one-stop" service in line with customer needs.

The solutions that we provide are diverse and include voice and data systems, but each provides a service essential to a customer's business operations. It is therefore important that we meet basic requirements such as good quality and stable operation. At the same time, solutions must continue to evolve if they are to make the best use of advanced technologies and help solve social problems. To this end, I would like to introduce three initiatives described by the keywords (1) template creation, (2) proactive operation, and (3) application of advanced technologies.

(1) Template creation

"Template creation" means establishing, expanding, and using know-how. There are several types of templates:

- Process checking that checks the content of a project at process milestones such as when making the proposal (presenting an estimate) and deciding when to launch the service.
- Visualization of processes and knowledge and creation of tools to improve the efficiency and quality of technology sales activities such as calculating estimates and surveying the quality of radio signals.
- Packaging (combining) of multiple products according to solution objectives.

In this way, we are visualizing diverse experiences and personal knowledge accumulated over the years and storing and sharing know-how to make business operations more efficient. One example of these activities is the Project Proposal Council that we hold when making an estimate for a System Integration (SI) contract [1]. This is a forum that evaluates and tests the feasibility, risks, etc. of an SI contract customized to individual user needs while taking into account external conditions and internal resources and capabilities. The Project Proposal Council is held about 2,000 times every year under the management of specialized quality control teams. More than 30 check items have been formalized and continuously improved based on a Project Management Body Of Knowledge (PMBOK)*3. Performing rule-based checking of each process in this way ensures the quality of SI products and fosters the evolution of solutions that form the foundation of NTT DOCOMO's know-how.

(2) Proactive operation

"Proactive" means assessing in real time whether a service used by a customer is running in a stable manner, maintaining the quality of that service, and connecting the knowledge gained to subsequent proposal activities. Of course, maintenance operations are performed in an extensive and thorough manner to provide the customer with stress-free use of a service, but in the off chance that a problem occurs, having that problem pointed out to us by the customer is not the best way of winning trust.

For current network services, we are developing and operating systems to monitor services for normal operation on a customer-by-customer basis. In the case of access premium services, these systems also monitor connection completion rate, band usage conditions, and other characteristics in addition to service normality. Analyzing operation data in this way enables us to provide customers with the support they need to use services in a comfortable and stress-free manner. From here on, our plan is to foster the further evolution of operations monitoring by developing advanced data analysis techniques using Artificial Intelligence (AI) while expanding target services.

(3) Application of advanced technologies

It is vitally important to create solutions using advanced technologies such as 5G, Virtual Reality (VR), IoT, Low Power Wide Area (LPWA)*4, AI and drones. Customers are also expressing interest and expectations in this regard, and one of our strengths is the capability of incorporating and providing advanced ICT technologies in solutions as early as possible.

One example of such advanced technologies is NTT DOCOMO's "curling VR" that was showcased at the 2017 Sapporo Asian Winter Games held in February 2017. This technology provides a new User eXperience (UX) such as a 360-degree view from the sliding "stone" in the winter sport of curling. More than 1,800 people had the opportunity of experiencing and enjoying this technology.

In addition, the practical use of low-power terminals using LPWA is progressing. This will drive the conversion of diverse type of equipment into IoT devices and lead to solutions that can contribute to a customer's business by improving productivity, etc.

Going forward, we will work closely with the R&D division to create templates of advanced technology solutions that are easy for system engineers throughout the country to sell. Our aim is to tie these efforts to industry creation and social problem solving as the driving forces behind NTT DOCOMO's "+d" (co-creation initiatives).

The true pleasure of corporate sales is the feeling of making a direct contribution to a customer's business through effective solutions. When working on a project together with a customer, hearing a comment like "We are glad to be working with NTT DOCOMO" is an absolute delight. Looking to the future, we will take up the challenge of solution evolution as a technology business department that can provide both "reliability" and "inspiration" through dependable service releases, safe and secure operations, and advanced solutions.

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[1] C. Koga et al: "Enhancing Quality of Upstream Processes in Corporate System Construction Contracts," NTT DOCOMO Technical Journal, Vol.23, No.1, pp.39–44, Apr. 2015 (in Japanese).

*1 Kitting: The work of installing applications in a terminal such as a mobile phone, configuring and registering the terminal, etc. so that the customer can begin using the product immediately.

*2 SaaS: A format that provides customers with software over the network as a service.

*3 PMBOK: A systematic grouping of know-how and techniques related to project management.

*4 LPWA: Wireless communications technology that can support a wide communications area on the kilometer level with low power consumption.

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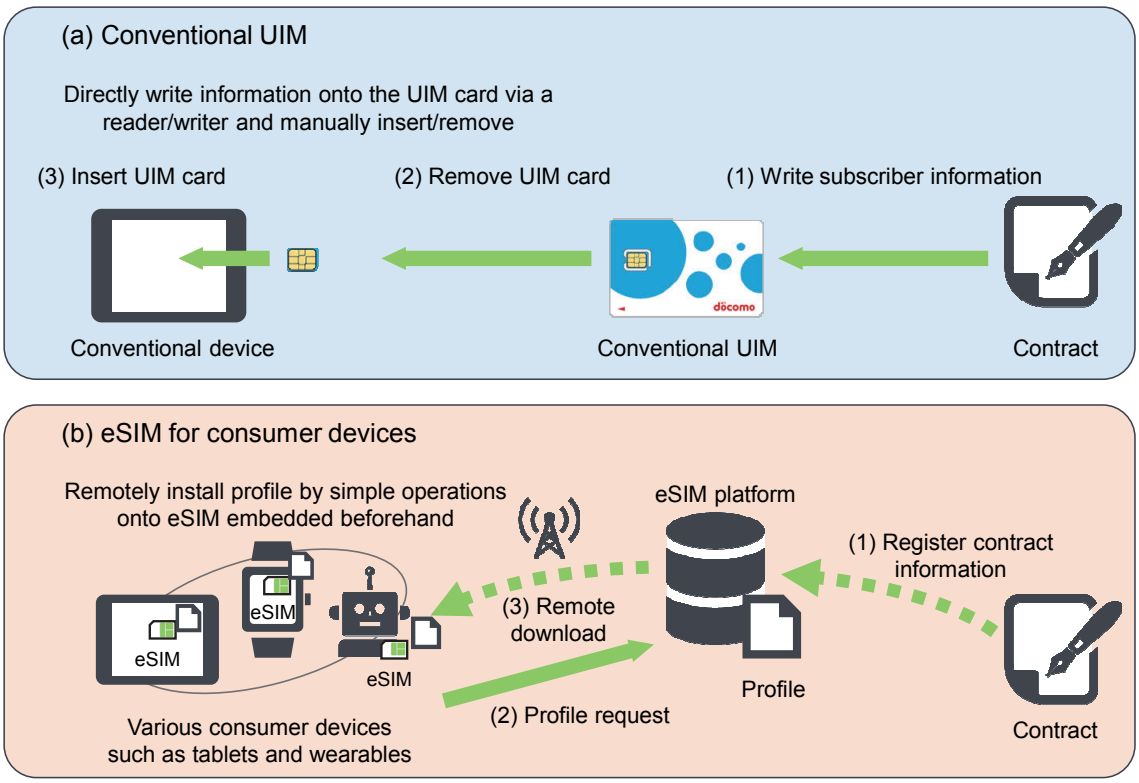

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Differences between conventional UIM and eSIM for consumer devices

Technology Reports

Consumer eSIM | LPA | SM

eSIM for Consumer Devices toward Expanded eSIM Usage —Secure Installation Conforming to GSMA—

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NTT DOCOMO has introduced Japan's first eSIM service for consumer devices conforming to GSMA. This has been achieved by adding an LPA function to consumer devices (terminals) for installing profiles triggered by user terminal operations and by constructing a platform consisting of a network and SM. This article describes the mechanism of the eSIM, LPA function, network, and SM developed for this service to achieve secure profile installation in consumer devices.

1. Introduction

Consumer devices (terminals) in all types of formats including wearable terminals have been increasing in recent years, and the need has been growing for a mechanism that makes it relatively easy to load and activate a cellular communications function on those terminals. NTT DOCOMO has developed terminals that incorporate a Local Profile Assistant (LPA)*1 function to remotely install a profile*2 for using communication services in an embedded Subscriber Identity Module (eSIM)*3 and has constructed a platform consisting of a network and Subscription Manager (SM)*4. At NTT DOCOMO, we call this new platform for providing eSIM services the "eSIM platform*5".

In this article, we describe eSIM for consumer devices and the mechanism behind the terminals and eSIM platform developed by NTT DOCOMO for the launch of eSIM services.

*1 LPA: Provides a relay function (LPD) for downloading profiles from SM to eSIM and a UI function enabling the user to perform profile-related functions such as downloading, deleting, and switching.

† Currently Product Department

2. What Is eSIM for Consumer Devices?

Here, eSIM for consumer devices refers to the capability of installing profiles securely from SM using terminal operations as a trigger. In terms of form factor, the original definition of "eSIM" is a SIM embedded in a device, but its definition in GSM Association (GSMA)*6 Remote SIM Provisioning (RSP)*7 Version 2.0 includes a card form in addition to a chip form. In the rest of this section, we describe the benefits of introducing eSIM for consumers, standardization trends, and differences with eSIM for Machine to Machine (M2M)*8 devices.

2.1 Benefits of Introducing eSIM for Consumers

The conventional method of enabling communication services in a consumer device has been to use reader/writer equipment to record a profile on a User Identity Module (UIM)*9 card and to then insert that card into the user's terminal (**Figure 1** (a)).

In contrast, eSIM for consumer devices provides the following benefits.

- The UIM function can be built into the terminal beforehand eliminating the need to insert or remove a UIM card (Fig. 1 (b)).
- The work of service provisioning can be performed without having to physically use special equipment (reader/writer) thereby

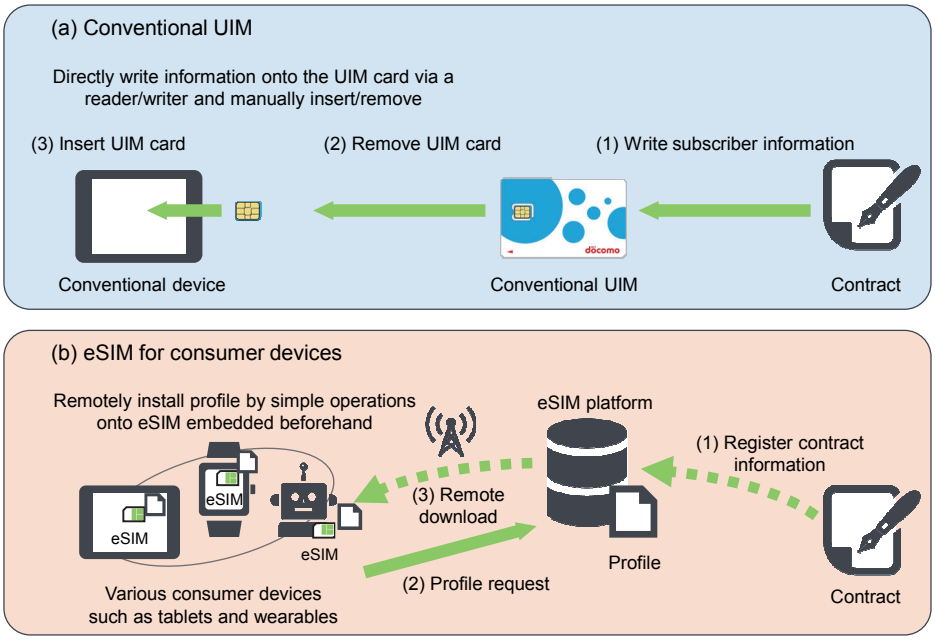


Figure 1 Differences between conventional UIM and eSIM for consumer devices

*2 Profile: UIM software running on eSIM OS consisting of various files containing telephone number, IMSI (see *12), and other data, applications such as network authentication, etc. There are OP and PP types of profiles.
*3 eSIM: Generic name for SIM that can install profiles remotely.
*4 SM: A server linking with the operator information management system. Provides a function for generating and saving profiles and a function for downloading and installing profiles in eSIM via LPA, etc.
*5 eSIM platform: A platform consisting of a network, SM, etc. for providing eSIM services. On this platform, a compatible user terminal can install a profile via the network into an eSIM built into the terminal through a terminal operation.

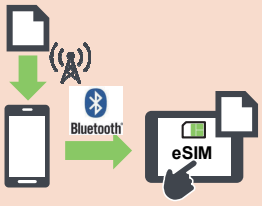
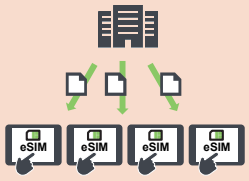
enabling prompt use of communication services simply through possession of the terminal.

- Conventionally, in the case that a UIM card had to be issued when purchasing a terminal from an online shop, the user was required to perform service-provisioning processing through a telephone-based procedure or Web-based procedure using, for example, a separate personal computer. With eSIM, the user need only perform simple and guided terminal operations to perform activation processing as part of initial terminal settings when starting up the purchased terminal for the first time.
- Since there is no need to insert or remove a UIM card, the card-slot portion of a terminal can be omitted thereby increasing the degree of freedom of terminal design. This makes it easy to support cellular communication services in even compact devices like wearable terminals.

In short, eSIM makes it much easier for a user to use communication services resulting in a higher level of convenience. On the other hand, conventional UIM enables simple switching of UIM information without the network as intermediary when changing models or exchanging handsets at the time of a terminal failure. Going forward, we can envision the use of both conventional UIM and eSIM depending on the application.

2.2 Standardization Activities

Standardization activities targeting eSIM for consumer devices have been taking place mainly at GSMA RSP meetings. As shown in **Figure 2**, Version 3 specifications are currently being discussed within GSMA RSP to add to existing specifications up to Version 2 released in October 2016.

Specifications version	Version 1	Version 2	Version 3
Release period	January 2016	October 2016	Under discussion
Use case	Download profile to 2nd device	Download profile to 1st device	Push delivery of profiles
			
Features	• Transfer profile to 2nd device such as a wearable or tablet via smartphone	• Download profile directly to a unit device such as a wearable or tablet • Supports installation of multiple profiles	• Supports kitting * for a large number of devices in corporate applications

* Kitting: The work of installing applications in a terminal such as a mobile phone, configuring and registering the terminal, etc. so that the user can begin using the product immediately.

Figure 2 Examples of GSMA RSP use cases

*6 GSMA: A global trade body of mobile operators that also includes terminal manufacturers, software companies, and other companies in the mobile industry. In addition to activities such as formulating roaming rules between operators, GSMA leads eSIM-related standardization.

*7 RSP: Generic name for remote profile writing technology for use with eSIM as defined by GSMA.

*8 M2M: Machine-to-machine communications between machines. Systems that enable machines to communicate with each other without any human mediation.

*9 UIM: Contains information such as telephone number and network authentication key and provides a user authentication function for registering terminal location in the communications network. Synonymous with SIM.

Version 3 aims to extend these specifications to consumer devices in enterprise applications.

Taking the features and characteristics of the Japanese mobile market into account, NTT DOCOMO has made a variety of proposals at these meetings in relation to a method of designating the destination SM, specifications of profiles to be downloaded, specifications of a function for assessing terminal capabilities, etc. Many of these proposals have been reflected in released specifications. The developments described here conform to GSMA RSP specifications Version 2 [1] [2]. NTT DOCOMO is achieving early development and commercialization through its deep involvement in standardization activities.

2.3 Comparison with eSIM for M2M Devices

The recent proliferation of M2M devices has been accompanied by increased use of embedded UIM (M2M Form Factor (MFF)*10) that cannot be removed for the sake of device durability. In addition, companies that are expanding their M2M business globally have a growing need for greater efficiency in production and management, which can be achieved by embedding one UIM at manufacturing time and storing the M2M devices as such and then writing the communications (service) operator information onto the UIM at shipping time. Against this background, NTT DOCOMO launched its "docomo M2M Platform*11" service for the corporate M2M market in June 2014 [3].

For consumer devices, on the other hand, the user is required to perform a terminal operation to download a profile (**Figure 3**). For this reason, we load the LPA function described below on the terminal side and provide a function for downloading a profile onto the eSIM.

3. Mechanism for Achieving eSIM for Consumer Devices

This section describes the eSIM for consumer devices (hereinafter referred to as "eSIM"), the terminal, and the eSIM platform and their constit-

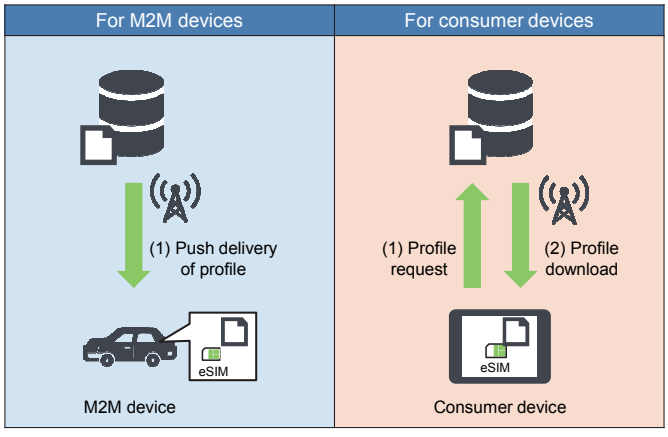


Figure 3 eSIM for M2M devices and eSIM for consumer devices

*10 MFF: Refers to the Universal Integrated Circuit Card (UICC) form factor for M2M devices as defined by the European Telecommunications Standards Institute (ETSI).

*11 docomo M2M Platform: An eSIM solution for corporate M2M devices launched by NTT DOCOMO in June 2014.

uent elements (**Figure 4**).

3.1 eSIM

As shown in **Figure 5** (a), conventional UIM consists of an Operational Profile (OP) lying above the UIM chip and UIM OS. The OP, in turn, consists of various files containing information such as telephone number and International Mobile Subscriber Identity (IMSI)*12 and various applications such as a network authentication function.

In addition, conventional UIM incorporates a Universal Subscriber identity module Application Toolkit (USAT)*13 function for rewriting UIM information [4]. The purpose of this function was to enable some of the files and applications within UIM to be updated.

In contrast, eSIM incorporates a function for remotely and securely installing an OP from SM, which makes it possible to update in units of OPs each of which includes confidential information such as a private key for network authentication, as shown in Fig. 5 (b).

Moreover, as many profiles as capacity allows may be stored within an eSIM, but only one profile can be used at one time for communications. Using LPA, the user can control which profile stored in eSIM is to be used for communications.

Another type of profile stored in eSIM is the Provisioning Profile (PP). While the OP type of profile provides the user with services the same

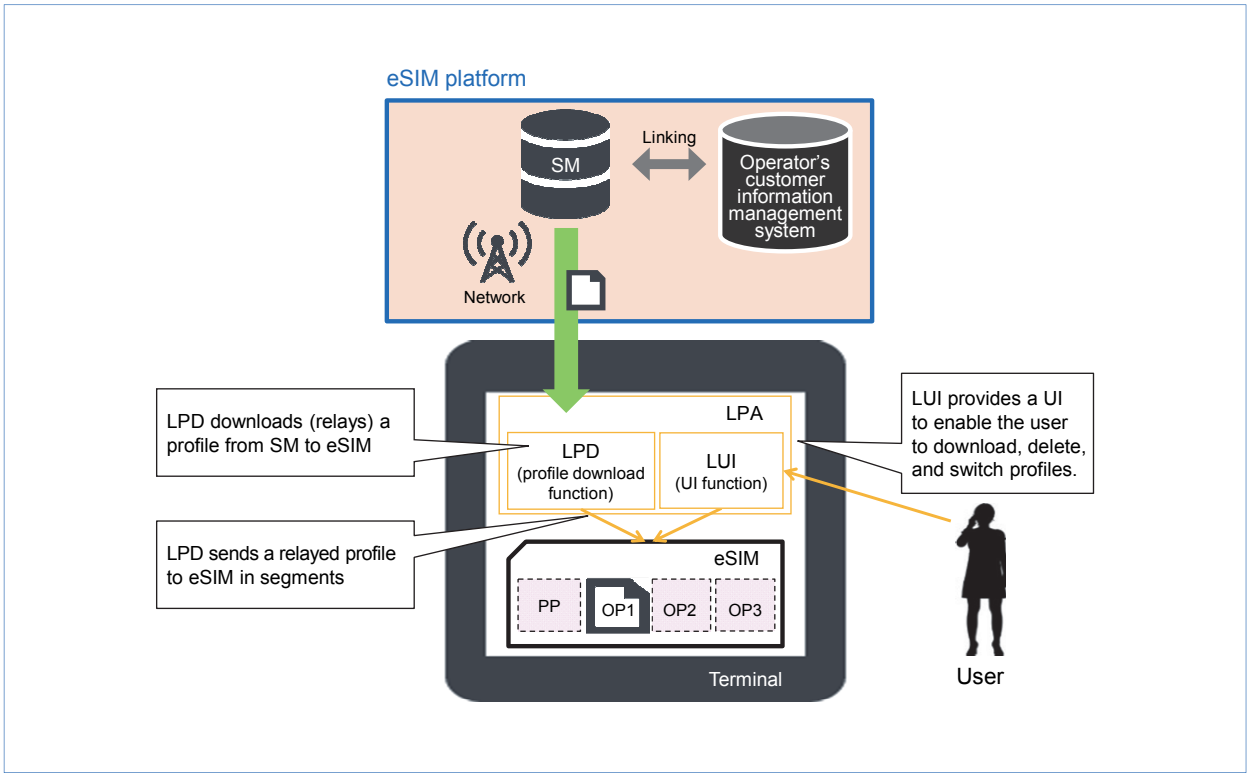


Figure 4 Constituent elements of eSIM, terminal, and eSIM platform

*12 IMSI: A number used in mobile communications that is unique to each user and stored on a UIM card.
*13 USAT: A standard specification specified by 3GPP TS31.111 for use in remotely updating information within a UIM.

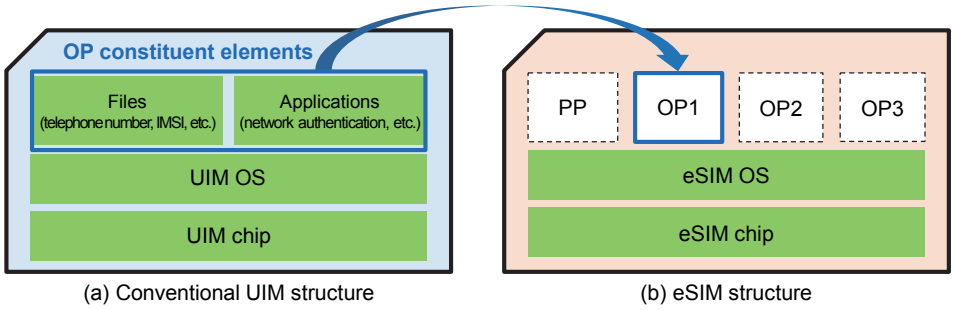


Figure 5 Typical structure of conventional UIM and eSIM

as conventional UIM software, the PP serves to download OPs. The use of PP for other than OP downloading is limited.

3.2 Terminal (LPA)

LPA consists of the following two functions (Fig. 4).

- Local Profile Download (LPD): This function performs a batch download of an encrypted profile from SM, sends that profile in segments to eSIM, and installs the profile. The Interface between the terminal and eSIM operates at low speed, so having LPD perform a batch download from SM first shortens communication time using the mobile network.
- Local User Interface (LUI): This function provides a UI for controlling the eSIM by user operations (as in downloading, deleting, and switching profiles).

Using LPA with these functions enables efficient profile downloading from SM and profile control in conjunction with user terminal operations.

3.3 Network

Using PP to perform communications with SM and download OPs enables the provision of voice services, packet communications, and other types of services.

While an in-area state can be achieved using PP, communications at this time are handled as "not yet under contract," so voice, SMS, and other services are restricted by the network.

Restricted communications such that only packet communications are allowed with SM are achieved by establishing an Access Point Name (APN)*14 for download communications and regulating access from that APN to points other than the SM's URL. However, it is unclear whether an APN for SM communications will be set in the user's terminal, and in this regard, it is also possible for the user to manually set an APN for SM communications, though this is an added burden.

This problem is resolved in the following way with reference to **Figure 6**. Once it is recognized at the Mobility Management Entity (MME)*15 and Serving General packet radio service Support Node (SGSN)*16 that packet communications is being

*14 APN: The name of a network connection point used by users to connect to the network when performing data communication.
*15 MME: A logical node accommodating a base station (eNodeB) and providing mobility management and other functions.
*16 SGSN: A logical node managing the mobility of mobile terminals that perform packet communications.

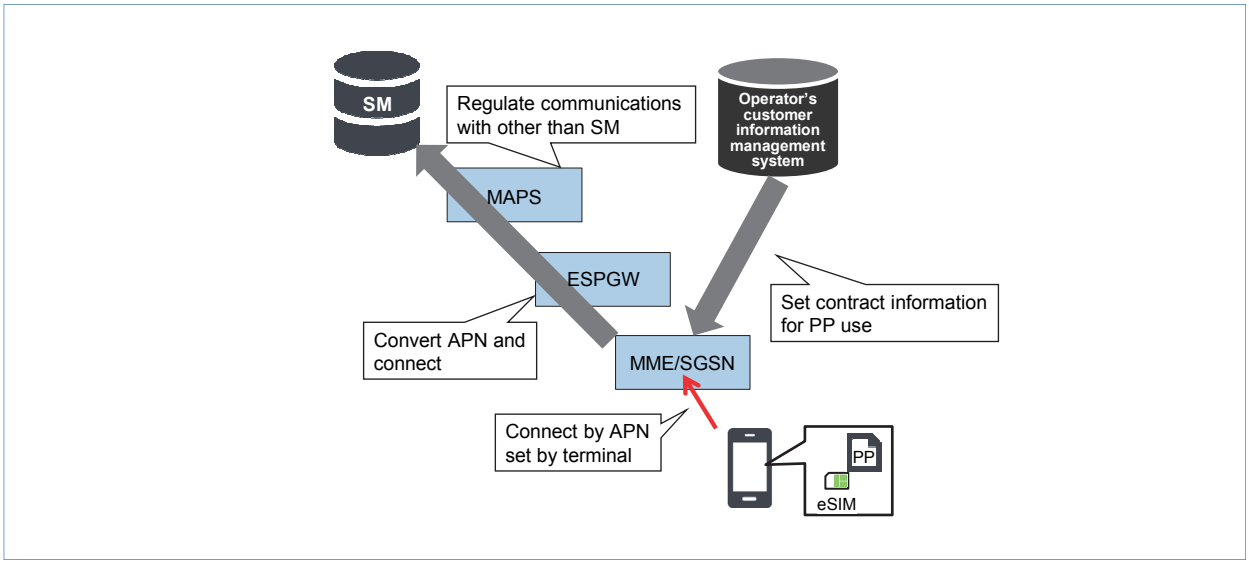


Figure 6 Control of communications from PP to SM

performed by PP, the EPC Serving and PDN Gate-Way (ESPGW)*17 will forcibly convert whatever APN has been set by the terminal to an APN for SM communications and connect to that APN. The Multi Access Platform System (MAPS)*18 will then regulate non-SM communications. In this way, the user connects only with the SM without having to consciously do so.

After establishing communications with SM and downloading an OP, services can be provided according to contract conditions the same as an ordinary user.

3.4 SM

The SM for eSIM mainly provides a function for generating and storing profiles and a function for securely installing profiles, as described below.

- Profile generation and storage

After a contract has been established between the user and operator, a profile needed for using communication services is prepared so that it can be downloaded to the target eSIM from the SM server introduced here.

The SM receives information such as telephone number, IMSI, and network authentication key from the operator's customer information management system, generates a profile according to specifications, and securely stores the profile after encryption.

- Profile installation

The profile is encrypted so that it can be decrypted only at the eSIM targeted for installation. This encrypted profile is installed in that eSIM via LPA. The eSIM platform system guarantees robust security based on the Public Key Infrastructure (PKI)*19. The eSIM, LPA, and SM each store a public key certificate issued by a trusted certificate authority. This certificate is used as a basis for authentication processing in inter-system communications.

*17 ESPGW: Equipment having the capabilities of S-GW and P-GW.
*18 MAPS: A platform that provides Internet connections and corporate system connections from various types of access circuits.
*19 PKI: A generic term for systems, etc. built for ensuring secure communications using public key encryption technology.

3.5 Example of a Profile Download Sequence

An example of a sequence using the above mechanisms to install a profile from SM to eSIM via the network and terminal (LPA) is shown in **Figure 7** and summarized below.

(1) The terminal storing eSIM is turned ON and a packet communications call is established using PP.

(2) SM is accessed by LPA in the terminal and HTTPS communications is established based on LPA and SM certificates. Only an LPA having a certificate that allows access to SM can do so.

(3) Once a communication channel is established between SM and LPA, eSIM and SM perform mutual authentication via LPA. A closed, secure communication channel between eSIM

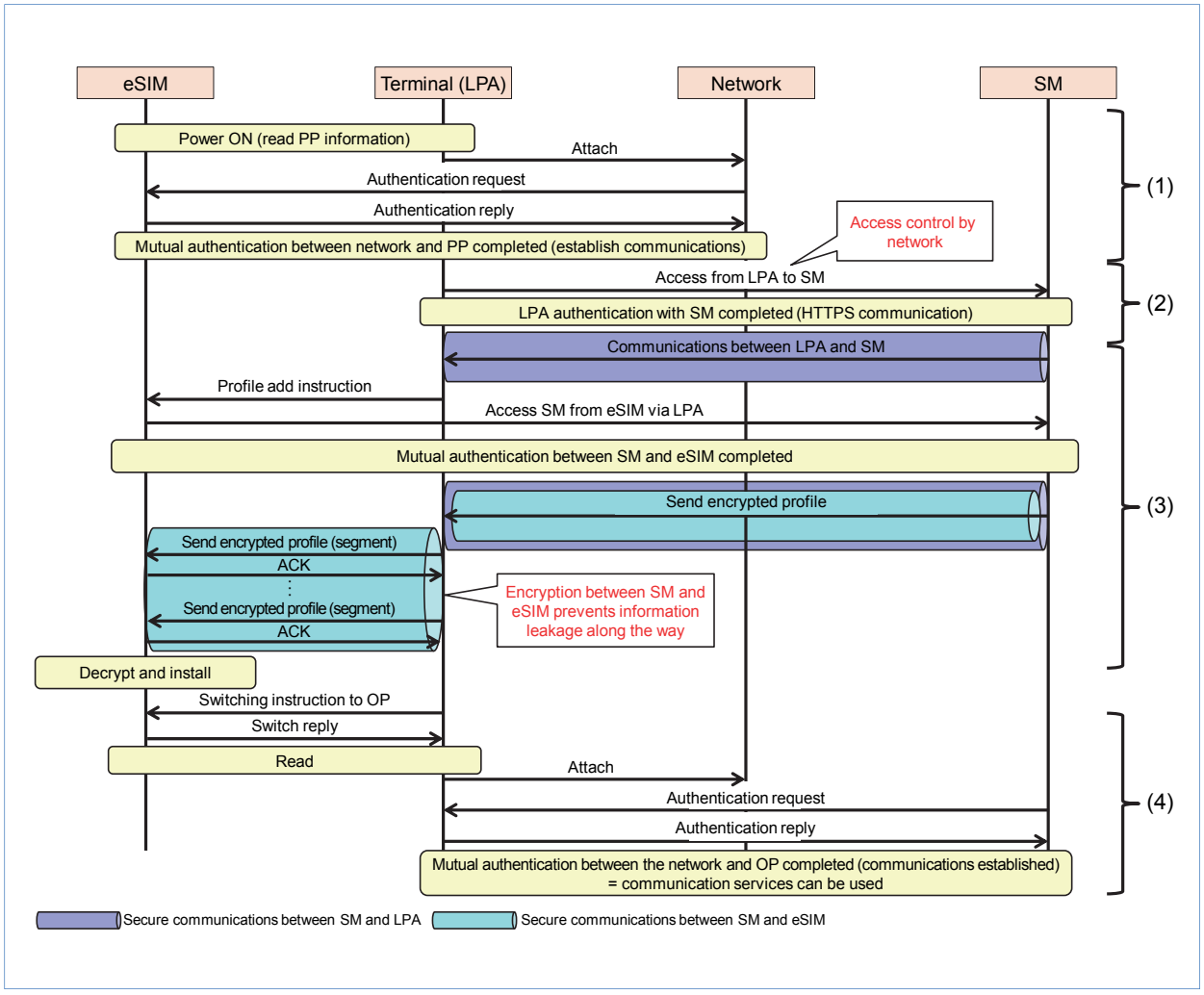


Figure 7 Example of a profile download sequence

and SM is established during this mutual authentication process, and a profile is then installed in eSIM without any leakage of profile information at the terminal or LPA. As described above, a batch download is first performed at LPD followed by segmented transmission to and installation on the eSIM to shorten communication time using the mobile network.

(4) After installing a profile, profile switching, deletion, etc. becomes possible through LPA operations. A variety of communication services are available using OPs.

4. Conclusion

NTT DOCOMO has developed an eSIM platform conforming to the GSMA global standard with an eye to a wide range of applications and low-cost provision.

It is envisioned that eSIM will be used in an embedded state within the terminal. However, while tests to check the terminal's network connection function, for example, can be performed by inserting/removing a test-type UIM given a terminal having a conventional UIM card slot, such a test-type UIM cannot be used if a UIM cannot be inserted/removed as in eSIM, which poses a new problem. For this reason, parts of the previously released GSMA RSP specifications Version 2 such as test environment setup are still under discussion. Taking the above standardization trends into account, we plan to apply this eSIM platform to a dramatically diverse range of terminals to make communication services even more convenient for users.

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Technology Reports
Chord Recognition | Performance Evaluation | Chroma Vector

Musical Chord Recognition Technique, and Applications Thereof

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Due to recent advances in artificial intelligence, a growing number of practical systems are employing technologies such as voice interaction. At NTT DOCOMO, by incorporating absolute pitch and musical intelligence into voice interaction systems of this sort, we have developed acoustic recognition technology that can evaluate musical performances with the aim of realizing an agent that can understand music. This technology can recognize musical chord progressions and evaluate ad-lib performances. In this article, we describe our chord recognition technology and an ad-lib performance evaluation function that uses it.

1. Introduction

The effects of music on living beings and their state of mind have been researched in a wide range of fields including physiology, psychology, medicine, nursing and music therapy, and some reports have even included scientific data on effects such as relaxation and stress relief [1] [2].

It has been shown that playing music stimulates the brain, and could play an important role in the treatment of conditions such as dementia in the aging society of the future.

At NTT DOCOMO, we have therefore developed acoustic recognition technology for the assessment of musical performances with the aim of developing an agent that helps people to enjoy giving musical performances even when alone. We focused our attention on a technique for recognizing chords in music, and used a Deep Neural Network (DNN)*1 to improve the chord recognition accuracy.

We also applied this chord recognition technique to the development of an ad-lib performance evaluation function. With this function, the user plays a favorite recording and ad-libs on a musical

*1 DNN: A machine learning method based on the use of a neural network with multiple intermediate layers.

instrument while listening to the recording. An intelligent agent determines whether or not the ad-lib performance matches the recorded music, and responds accordingly. This results in an agent that can understand the user's performance, and could help the user to enjoy playing music or become more motivated to practice.

This article presents an overview of chroma vectors as a means of understanding the pitch of musical instruments, and discusses our technique for extracting these chroma vectors. We also describe the recognition method used in our chord recognition technique, a recognition method that uses a DNN, and we report on the accuracy of these methods. We also describe an ad-lib evaluation function that uses this chord recognition technique.

2. Chroma Vectors

2.1 Overview

In the recognition of musical pitch, a single note can easily be recognized by using an f0 extraction*2 technique (e.g., autocorrelation*3). However, for a polyphonic instrument like a guitar or a piano, f0 extraction is difficult because it is sometimes only possible to recognize a single pitch, and sometimes the incorrect pitch is recognized. To analyze sounds and chords that include multiple pitches, feature values*4 called chroma vectors are often used [3].

A chroma vector is a vector that has feature quantities representing the amplitude of oscillations at the frequency of each of the 12 notes of a musical scale spanning multiple octaves. The amplitude intensity indicates how many signals of a specific frequency are contained in a certain audio segment. The frequencies of each musical scale are fixed. For example, the note A has a frequency of 440 Hz, and the note E has a frequency of 660 Hz. Doubling the frequency produces a note one octave higher, and halving the frequency produces a note one octave lower. Since musical pitch is determined by the ratios of frequencies in this way, the notes of the 12-tone musical scale increase in frequency by a ratio of $1\sqrt[12]{2}$ per semitone. A chroma vector is obtained by calculating the amplitude intensity of each frequency in each scale. This shows which notes of the scale are loudest, making it possible to estimate the chord that is playing based on the combination of strong notes.

2.2 Calculating Chroma Vectors

1) Using Fourier Transforms

To determine the amplitude intensity of a certain musical scale, we have to calculate the average value of the amplitude intensity in the vicinity of these frequencies of the musical scale. A Fourier transform*5 is often used to extract frequency components from sound (signals). Frequency analysis based on Fourier transforms is performed using orthogonal frequencies. If T is the time duration of one of the segments to be analyzed, then the intervals between these orthogonal frequencies is $1/T$ (Hz), so to increase the frequency resolution, the time duration of the segments to be analyzed has to be increased to some extent. In particular, in the low pitch region, the frequency difference between one note and the next is very small, so the Fourier transforms must have a finer frequency resolution than the frequency difference between neighboring pitches. This makes it difficult to analyze fast melodies.

*2 f0 extraction: The analysis of the lowest reference frequency in a waveform signal that includes overtones.

*3 Autocorrelation: A technique where a signal is correlated with itself after applying a varying temporal offset. The offset timing at which a strong correlation is obtained is inferred to be the signal's reference frequency.

*4 Feature values: Values extracted from data, and given to that data to give it features.

*5 Fourier transform: A process that extracts the frequency components making up a signal and their respective ratios.

Figure 1 (a) shows the results of frequency analysis by Fourier transform. If the duration of a time frame is T seconds and the number of samples per transform is n, then the Fourier transform has base frequencies*6 of $1/T$, $2/T$, $3/T$, ..., n/T. The number of samples is the number of discrete quantized parts that a single time segment is divided into. If we want to analyze frequencies down to a low A (55 Hz), the next highest pitch is B♭ (58 Hz), so we required a frequency resolution such that $1/T$ is less than 3 Hz. This means that T has to be at least 333 ms, making it impossible to analyze melodies where the pitch changes faster than 333 ms.

2) Using Our Technique

Fig. 1 (b) shows the results of frequency analysis using our technique. In this technique, the fundamental frequencies in the Fourier transform are set to musical pitch frequencies, and the amplitude intensities are calculated by the following formula in the same way as for a Fourier transform.

$$p(f) = \sum_{k=0}^{n} \cos\left(\frac{2\pi f k}{SF}\right) - i \sum_{k=0}^{n} \sin\left(\frac{2\pi f k}{SF}\right) \quad (1)$$

SF is the sampling frequency, $P(f)$ is the amplitude and phase information of frequency f of the musical scale, and the square of $P(f)$ is the amplitude intensity of frequency f. The sampling frequency indicates how many times the signal waveform is sampled per second. The cosine term obtains the correlation with a cosine wave, and the sine term obtains the correlation with a sine wave. Unlike an ordinary Fourier transform, not all pairs of frequencies satisfy the orthogonality condition, so there is the drawback that they can interfere with one another. However, it is still possible to analyze the frequency components of each musical scale, facilitating the extraction of musical scale features. This also makes it possible to analyze data

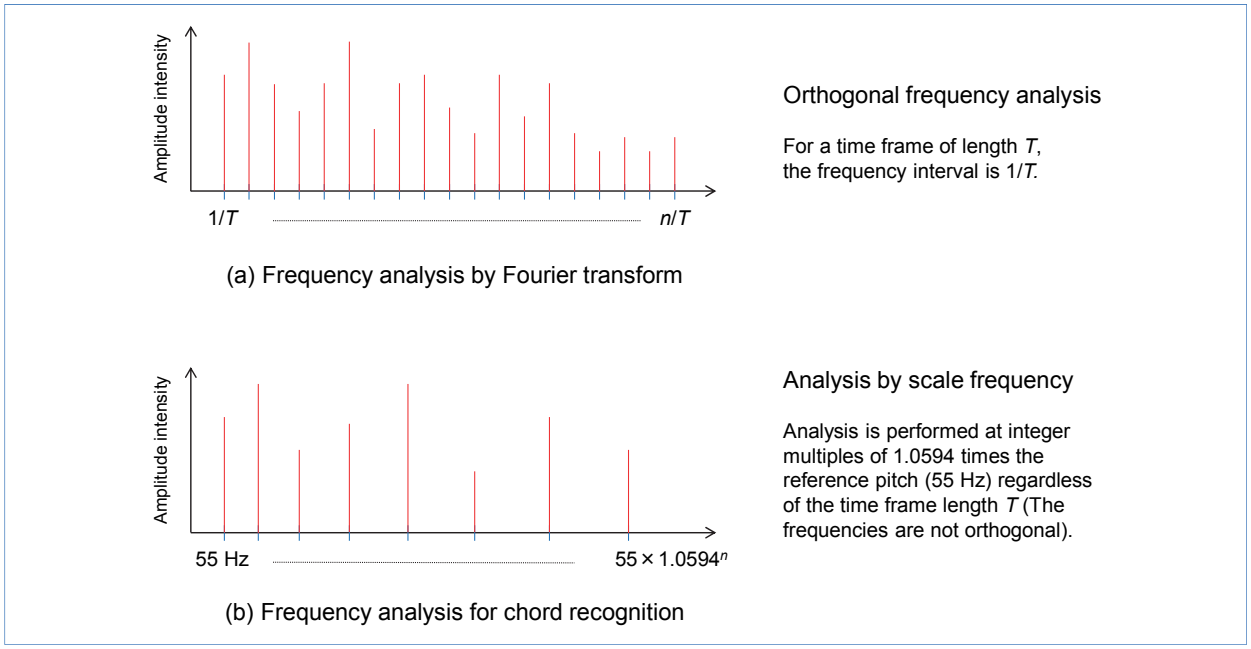

Figure 1 Frequency analysis method

*6 **Base frequency:** The discrete frequency unit used in frequency analysis.

with an arbitrary frame duration, so that fast melodies can be analyzed for a short period of time, and slow melodies for a longer period of time.

Since there are 12 musical scales if notes an octave apart are regarded as the same, it is also possible to reduce the computation time by using a 12-dimensional*7 chroma vector where the amplitude intensities of the same notes in different octaves are added together. To see the differences between octaves, it is possible to increase the number of dimensions of the chroma vector. If a four-octave musical scale is analyzed, then this results in a 48-dimensional chroma vector.

2.3 Using a Chroma Vector for Chord Recognition

Even with chroma vectors alone, it is possible to recognize chords in music. For simple triads (three-note chords), even considering just major and minor chords, there are two types of chord for each of the 12 musical scales, making a total of 24 types of chord. Since the constituent notes of each chord are fixed, we calculate the inner products of the chroma vector with binary vectors that contain 1 for notes that are included in a chord, and 0 for notes that are not included in the chord. Out of 24 different chords, the one that produces the largest value is output, thereby implementing a chord recognizer.

This method works well with notes produced by a single instrument. However, to recognize the chord progressions in tunes that combine multiple instruments with percussion and/or vocals, the recognition performance is not adequate. Therefore, in our technique, we apply a DNN to the chroma vectors so that musical chord progressions can be recognized more accurately.

3. Chord Recognition Technique

A chord recognition technique for music is able to analyze music data recorded on a CD or the like to produce sheet music showing the chords that are played. There are many different kinds of music, but in this article, we will concentrate on music played by bands that include drums, bass, guitar, keyboards, vocals and the like. In this technique, in order to accurately analyze the chords in this sort of music, we use a DNN to learn about the music data and chord progressions of existing music with the aim of improving accuracy. **Figure 2** shows the chord recognition procedure of this technique.

1) Input Music Data (Fig. 2 (1))

First, the music data is input into the chord recognizer. The music data is assumed to be in a format such as data recorded on a CD, and is input as a stereo sound source.

2) Beat*8 Detection (Fig. 2 (2))

To create the chord notation, the music must be divided into bars by detecting the beat based on the strength of the drums or instrument sounds. This is done by using the stereo music source directly, and estimating the beats from changes in the intensity of the music amplitude.

3) Vocal Cancellation (Fig. 2 (3))

With the aim of deleting vocals, percussion and the like to facilitate chord recognition, we cancel out the sound sources positioned at the center of the stereo sound source. The sound at the center can be canceled simply by adding the opposite phase of the right-channel signal to the left-channel signal. Since the sounds of instruments like guitars

*7 Dimension: The number of elements in the DNN input vector.

*8 Beat: A quarter-note period in music.

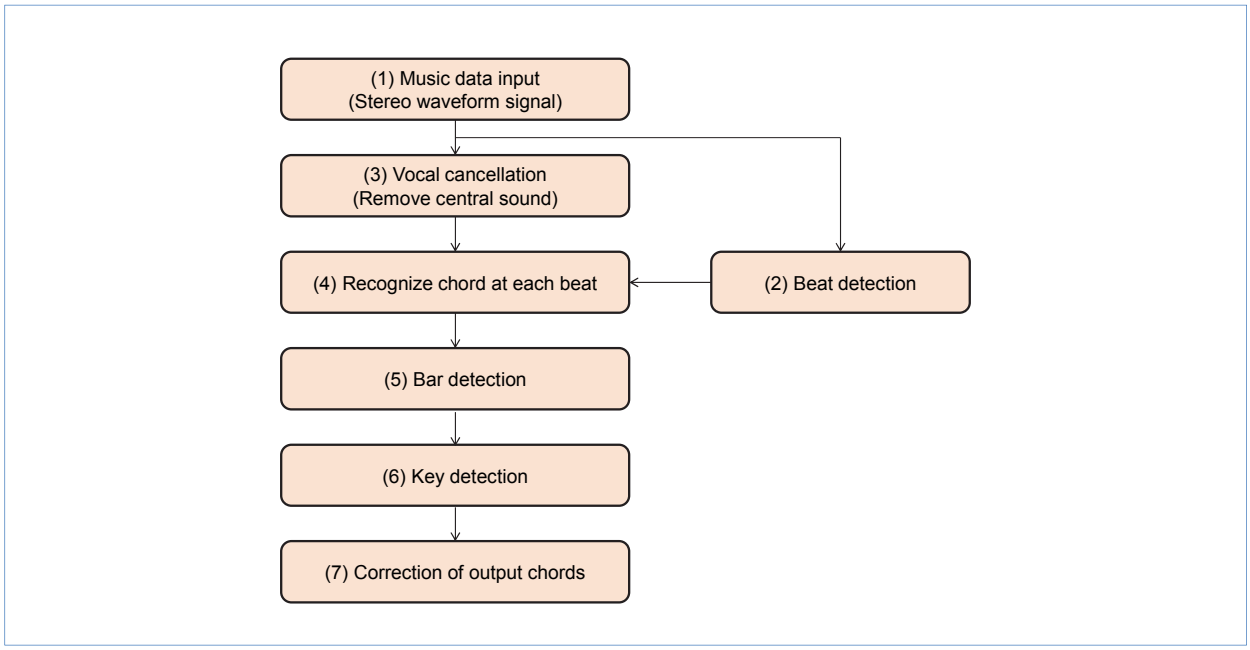

Figure 2 Procedure for analyzing chords in music

and keyboards are often positioned towards the left or right side, this operation leaves behind the accompanying music. Chord recognition is performed using sounds that are close to this accompaniment music.

4) Recognition of Chords for Each Beat (Fig. 2 (4))

In chord recognition, chord pattern recognition is performed from the chroma vectors as described above, but a DNN is used here. **Figure 3** shows the procedure for using a DNN to recognize chords from a song's waveform data.

(a) Generate a feature map for each beat

First, each detected beat is partitioned off as a time-domain*9 segment. Chord recognition is applied to the segment from the timing of one beat until the timing of the next beat. Suppose the calculation of chroma vectors is performed in 80 ms units. If the duration of a single beat is 500 ms, then the chroma vectors will be calculated for approximately six frames per beat. If the chroma vector for a single frame is a 48-dimensional vector as a result of analyzing four octaves, i.e., if there are n frame regions in a single beat interval, then $48 \times n$ feature value maps can be generated.

(b) Generate 24-dimensional input vectors

This feature value map can be used as the input to the DNN, but since the time intervals for each detected beat are different, and since the feature value sizes are not fixed and may be redundant, we reduce the feature value map as in a Convolutional Neural Network (CNN)*10 to produce a 24-dimensional fixed-length input vector. 24-dimensional vectors generated in this way are used as the input vectors of the DNN. This may be considered as a process corresponding to the convolutional layers*11 and pooling layers*12 of a CNN.

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

*10 CNN: A neural network that performs pre-processing such as filtering on feature values to be input to a neural network and forms an input vector.

*11 Convolutional layer: A layer that emphasizes key features by applying a filter to the input feature value map.

*12 Pooling layer: A layer that compresses feature values by averaging or selecting redundant feature values with respect to the input feature values.

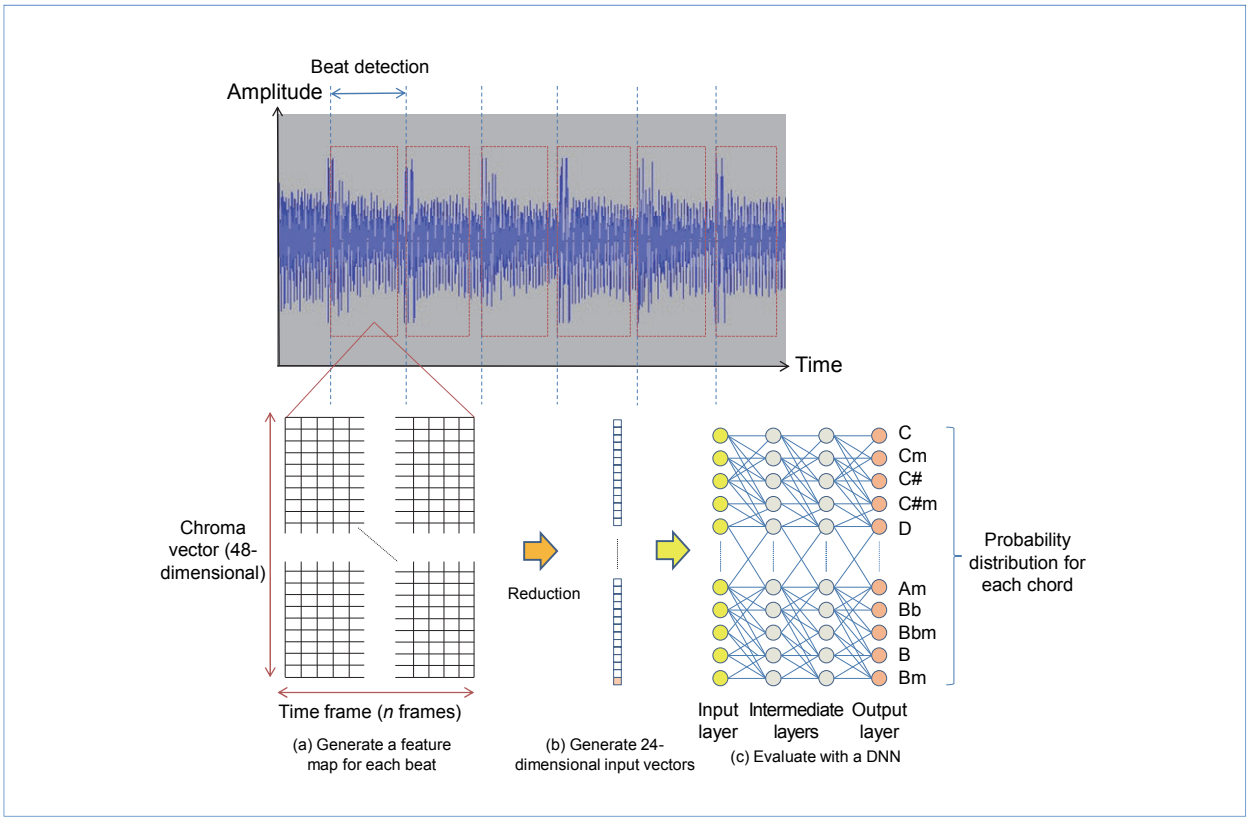

Figure 3 Chord recognition method

(c) Evaluate with a DNN

A DNN is formed with this input vector as the input layer values, and with two intermediate layers and an output layer that yields a probability distribution of 24 types with a softmax function[*13]. Although this technique can also be applied to tetrads (four-note chords) such as seventh[*14] and diminished chords[*15], we will concentrate on the evaluation of 24 different triads in this article in order to see the effect of the performance improvement.

For the learning data, we used CD music recordings saved as stereo WAVE files[*16] with 15 bits per sample at a sampling rate of 44,100 Hz, and we performed learning using meta-files[*17] recording the chords at each beat of the music.

Up to the point where we generated a feature value map for each beat and a reduced 24-dimensional input vector, the learning and evaluation processes are both the same. To train the DNN, we used music data consisting of 30 tunes played by a band. After training the network, we performed chord recognition using the music data of five tunes prepared separately from the training music data. For chord recognition, we compared the correct answer rates of recognition using the abovementioned method based on chroma vectors alone with that of the proposed method where a DNN is also used. The results of this comparison are shown in

*13 Softmax function: A function that normalizes a distribution function so that the sum total of all the output values becomes equal to 1.

*14 Seventh chord: A four-note chord obtained by adding the seventh note of the scale to the triad comprising the root, third and fifth notes.

*15 Diminished chord: A code obtained by adding the third and flattened fifth notes to the root note.

*16 WAVE file: A file format to store audio waveforms. The sampled audio data is stored without compression.

*17 Meta-file: In this article, a meta-file is a file containing data such as chord progressions and rhythm of musical content.

Figure 4. The correct answer rate depends on the tune data, but we found that the use of a DNN improves the correct answer rate by about 12% on average compared with chord recognition using only chroma vectors. We only used 30 tunes as learning data in this test, so it is possible that even greater correct answer rates could be achieved if a greater amount of learning data is used.

5) Bar[*18] Detection (Fig. 2 (5))

After recognizing the chords for each beat, the boundaries between bars are detected. This is done by using the fact that chord changes often take place between bars. Specifically, by lining up the chord recognition output results for each beat and assuming an ordinary rhythm of four beats to the bar, the first beat of the bar is recognized as the beat where there are the most chord changes.

6) Key Detection (Fig. 2 (6))

Next, the music's key is judged. This is needed in order to output the final chord recognition results correctly. The diatonic chords of the C major scale are shown at the top of **Figure 5**. Diatonic chords are chords that are often used in a particular key, so for example in the key of C major, these would be the set of triads formed by each note of the scale with the notes 3 and 5 steps further up (i.e., C-E-G, D-F-A, E-G-B, etc.). A tune in which this set of diatonic chords appears very frequently is highly likely to be in the key of C major. So if we calculate the rate of occurrence of diatonic chords for every scale (C major, C♯ major, D major, etc.), we can judge which key a tune is in by seeing which key's diatonic chords appear most often.

7) Correction of Output Chords (Fig. 2 (7))

Finally, the recognized chords are corrected. Even when chord recognition is performed using a DNN, only 70–80% of the chords are identified correctly. These incorrect chord recognition results can be somewhat improved by weighting the results based on the diatonic chord and secondary dominant chord to produce a final chord judgment.

The bottom part of Fig. 5 shows the diatonic chords for the key of D major. In the key signature of D major, the notes C and F are raised to

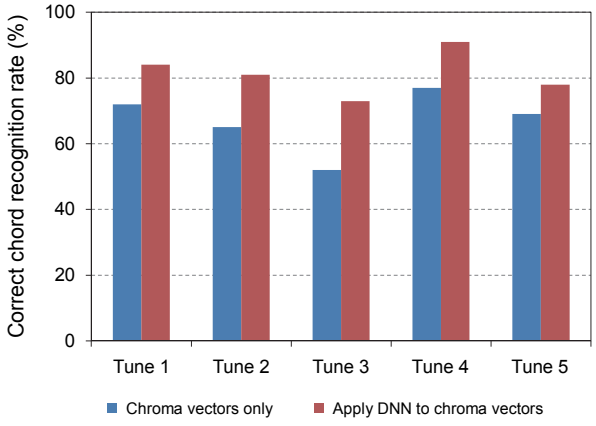

Figure 4 Correct chord recognition rate

*18 Bar: A unit time segment of a musical composition. In a composition written in common time, each bar consists of four beats.

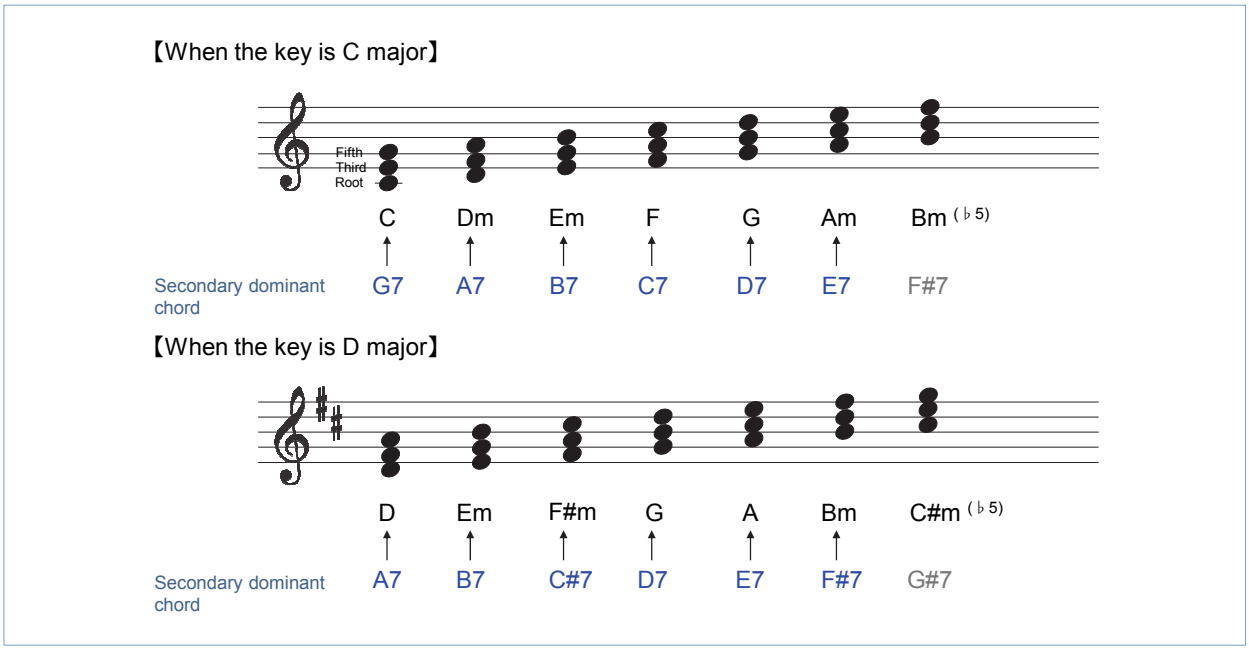

Figure 5 Diatonic chords and secondary dominant chords

C♯ and F♯, so this key uses a different set of chords than C major. There are many tunes that basically consist only of diatonic chords, but the next most frequently used chord is called the secondary dominant chord. This corresponds to a seventh chord based on the fifth note of each diatonic chord, as shown in blue in the figure. For the first chord on the left in Fig. 5, the chord on the fifth note is included in the normal diatonic seventh chord, so this is not regarded as a secondary dominant chord. Also, for the seventh diatonic chord (Bm), the root note[*19] (F♯7) of the seventh code on the fifth note cannot be used because it is outside the C major scale (C, D, E, F, G, A, B), so F♯7 is also excluded from the secondary dominant chords.

The chord recognition results are corrected by weighting these secondary dominant chords. The weighting calculations are performed by multiplying the probability distribution obtained from the DNN chord recognition results by the weightings of these chords, and taking the chords with the highest resulting values as the recognition results. This improves the chord recognition accuracy by about 5–10%. Based on the chord recognition results output by this process, it is possible to transcribe the music into chord notation. Although it is difficult to produce chord notation that matches the music exactly, it is possible to create chord notation that is useful for reference.

4. Ad-lib Performance Evaluation Function

In music, ad-lib refers to a playing style where the notes are played freely along with some accompaniment instead of playing notes exactly as they are written in a musical score. One way users can enjoy playing ad-lib is to play a free melody over

*19 Root note: The note at the base of the musical scale from which chords are formed. In most cases, it is the lowest note of the scale.

their favorite tune. Here, we will explain a performance evaluation function based on the above chord recognition technique that allows the user to perform ad-libs over a favorite tune.

First, when the user plays a favorite tune, the chords in this tune are recognized. At the same time, the bar boundaries and the key of the tune are also identified. While the music is playing, the performance evaluation system figures out which bar is currently being played, and which chords it contains. It then converts the user's performance into chroma vectors, and detects the pitch of the notes that the user is playing. If the pitch of the user's performance matches the constituent notes of the chords in the current bar, then the user's score is increased. If the user plays notes that are not included in these chords, a few points are still awarded if these notes are in the major scale of the tune's key. If the user plays a note that does not match either of these rules for more than one beat, then points are deducted. This scoring method provides a basic way of evaluating ad-lib performances.

In the ad-lib performance evaluation system implemented as an application of this technique, the user's ad-lib performance is analyzed while playing a tune, and the user is praised or cautioned if the score achieved in each bar is high or low. As a result, the user can experience the tension of being evaluated in real time while performing ad-lib.

5. Conclusion

In this article, we described a musical chord recognition technique that uses chroma vectors and a DNN. As an application example, we also introduced an ad-lib performance evaluation system. In the future, we hope to pursue more musical analysis functions and realize a musical agent.

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Technology Reports

Remote Control CDN File Distribution

CDN Application with Terminal Remote Control System File Distribution Function

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NTT DOCOMO is providing OS and software update services for Android™*1 terminals in our terminal remote control system, but it has recently become necessary to expand our download server due to security measures and increasing numbers of distribution files and users. We used an external solution called CDN to enable file distribution from external distribution servers. This has decreased the cost of equipment expansion and maintenance, and enabled flexible control of distribution performance according to need.

1. Introduction

Smartphones continue to spread and the share of smartphones in the mobile phone market increases yearly. Smartphone applications and OS are also advancing, and update files for them are increasing in size and frequency. To make these updates more convenient for users, NTT DOCOMO has been providing Android OS and software update services for some time and update files can be downloaded through the wireless network using NTT DOCOMO's remote control system.

However, with increasing demand in recent years it has become necessary to increase the performance of the remote control system, and the download server that distributes update files in particular. Security measures have also become more important, and systems that communicate directly with terminals are requiring stronger security levels. Thus, implementing additional security measures such as an Intrusion Prevention System (IPS)*2 has resulted in greater loads on the remote control system.

However, expansion of server equipment based on peak traffic would result in surplus equipment when file distribution is not taking place, inflating costs.

† Currently Human Resources Management Department

*1 Android™: A software platform for smartphones and tablets consisting of an operating system, middleware and major applications. A trademark of Google Inc., United States.

These factors and the potential to support Internet of Things (IoT)*3 devices in the future suggest a need to implement distribution of update files more efficiently, to more terminals and more quickly.

To this end, NTT DOCOMO has used a Content Delivery Network (CDN)*4 solution to implement stable, flexible file distribution that is not affected by traffic fluctuating according to the needs of users. In doing so, we have implemented a remote control system able to handle the various needs described above. This article describes the new remote control system implemented by linking NTT DOCOMO's remote control system to the CDN, including an overview of CDNs.

2. CDN Architecture Overview

A CDN is a network solution optimized for stable delivery of high-volume content to many users at high speed. **Figure 1** shows delivery of files before and after application of the CDN. With the network before applying the CDN, files were delivered directly from the "origin server*5" where the original files were stored (Fig. 1 (a)). After applying the CDN, files to be delivered to users are cached*6 on the CDN distribution servers, which can distribute large files to many users, accelerating file distribution and reducing the load on the origin server (Fig. 1 (b)).

Distribution of video is one example of using a CDN. With this type of service, when many users are viewing a video distribution speed often drops, distribution is unstable, or distribution stops before completion. If a CDN is used to distribute the video, the load on the origin server is decreased and viewing conditions for users are improved. Delivery is also faster and more stable when an event is held causing access to Web pages to become congested.

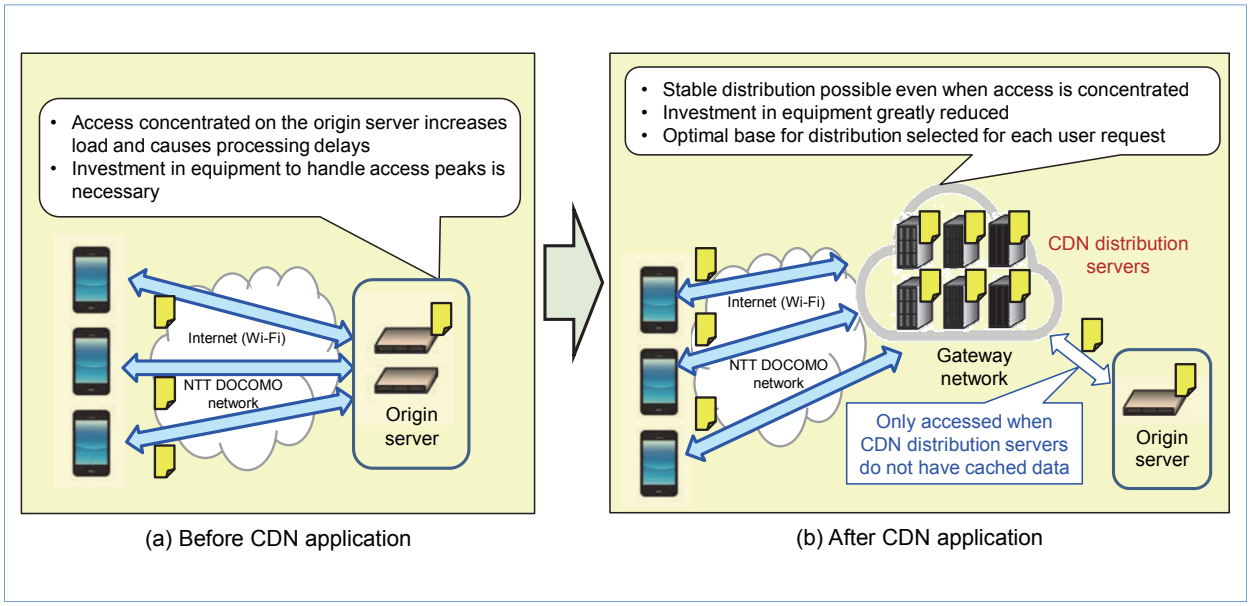


Figure 1 File distribution before and after CDN application

*2 IPS: An attack prevention system that detects unauthorized access by monitoring Internet communication on servers and networks.

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

*4 CDN: A network solution optimized for fast and stable distribution of large files such as images and video.

*5 Origin server: A company's own server holding the company's content.

*6 Cache: Temporarily stored data to be distributed.

In the past, when server capacity had to increase due to increased demand or larger distribution files, equipment to accommodate peak traffic on the origin server increased costs, but this equipment was idle when no file distribution was being done. A CDN provides services to various companies and users, so costs can be kept lower than if NTT DOCOMO maintained all of the equipment. The CDN is also flexible in accommodating user demand for file distribution, enabling it to provide low cost, optimal file distribution.

Thus, a CDN has various benefits compared to only operating our own origin server.

CDNs can be divided broadly into centralized and distributed architectures. Centralized architectures limit the locations of CDN distribution servers, which facilitates distribution of large files. In contrast, distributed architectures have distribution servers spread over many locations. Distribution is accomplished by selecting a distribution server for each user request, so transfer time can be reduced.

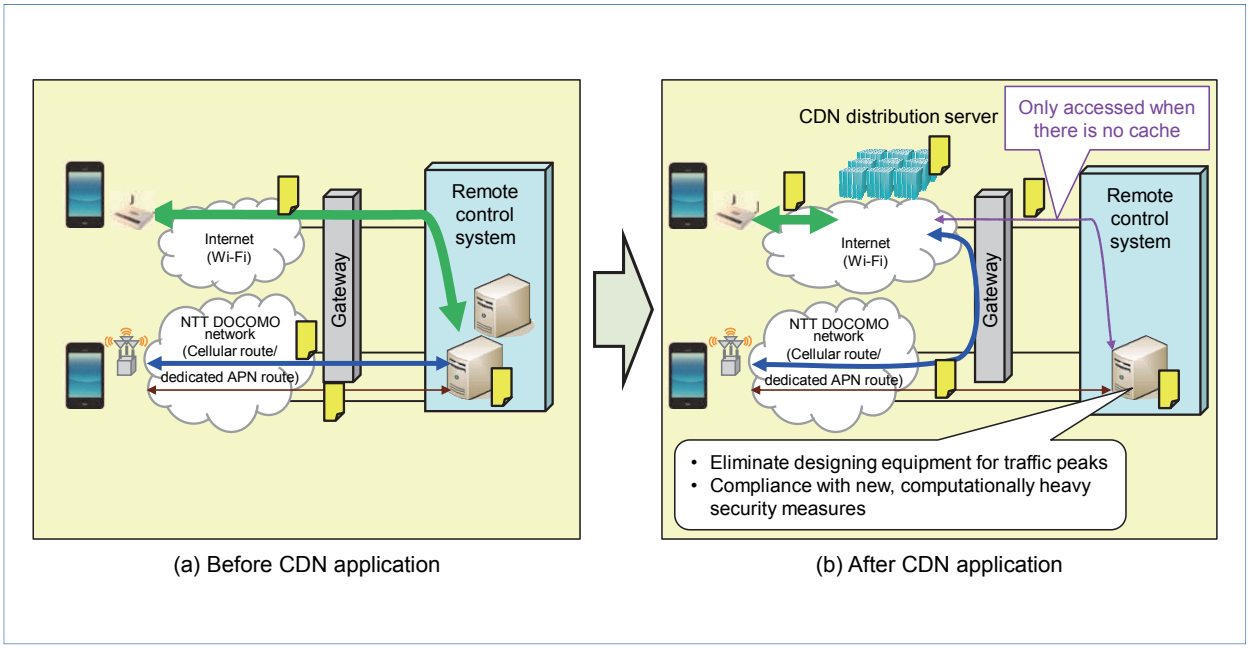
The main use of the system at NTT DOCOMO is for OS and software updates as mentioned earlier and in this case large files are distributed to many terminals at once, so we used a system with a centralized architecture.

3. Application of a CDN to the Remote Control System

The following sections describe features for switching to CDN application, for free-of-charge distribution, and for using general-purpose ports.

3.1 Implementation

The structure before and after CDN application is shown in **Figure 2**. On the network before CDN



(a) Before CDN application

(b) After CDN application

Figure 2 Remote control system structure before and after CDN application

application, terminals connected using Wi-Fi®*7 and 3G/LTE to obtain files directly from the remote control system where the files were stored (Fig. 2 (a)). After CDN application, terminals connected as they did before, but obtain the files from a cache on a CDN distribution server on the Internet (Fig. 2 (b)). Once the file cache is created, unless the cache is deleted, files are distributed to terminals from the CDN distribution server, greatly reducing the load on the remote control system server. At the same time, the CDN is able to handle any increase in number of users or traffic in the future with flexibility, avoiding any drop in service level, such as distribution speed. Previously, the remote control system was maintained to meet peak traffic, but with application of the CDN, the amount of equipment can be reduced, along with costs.

3.2 Switching Method

OS and software updates are performed by the remote control system in accordance with Open Mobile Alliance Device Management (OMA*8-DM*9) [1], and as shown in **Figure 3**, the service provider and maintainer perform update notifications, file distribution, version management and other tasks remotely on terminals.

File distribution can be divided mainly into a control phase and a distribution phase. When applying the CDN, the control phase specifies the server to connect to as with the existing system, and in the distribution phase, the terminal connects to a CDN distribution server or the origin server to get the files. In this way, the switch to using the CDN can be implemented without affecting existing terminals.

1) Process before CDN Application

The OS update process before applying the CDN is shown in **Figure 4**. Note that the process for software updates is almost the same.

When the remote control system receives a control

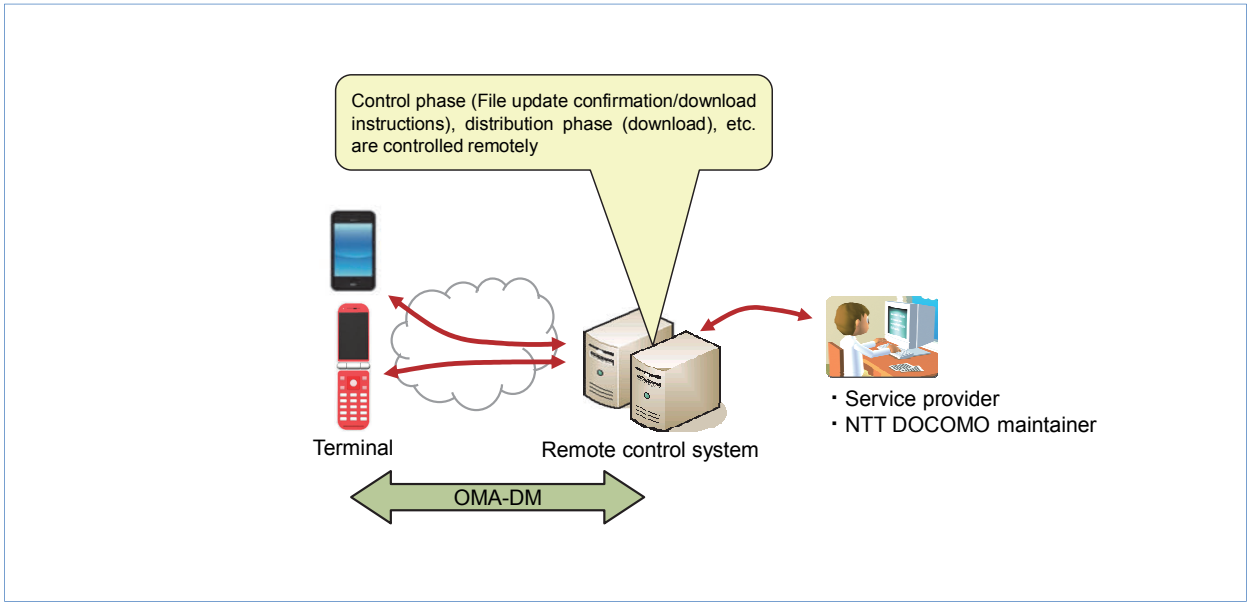


Figure 3 Remote control system overview

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

*8 OMA: An industry standardization organization that aims to standardize service and application technology and achieve interoperability in mobile communications.

*9 DM: Device management function.

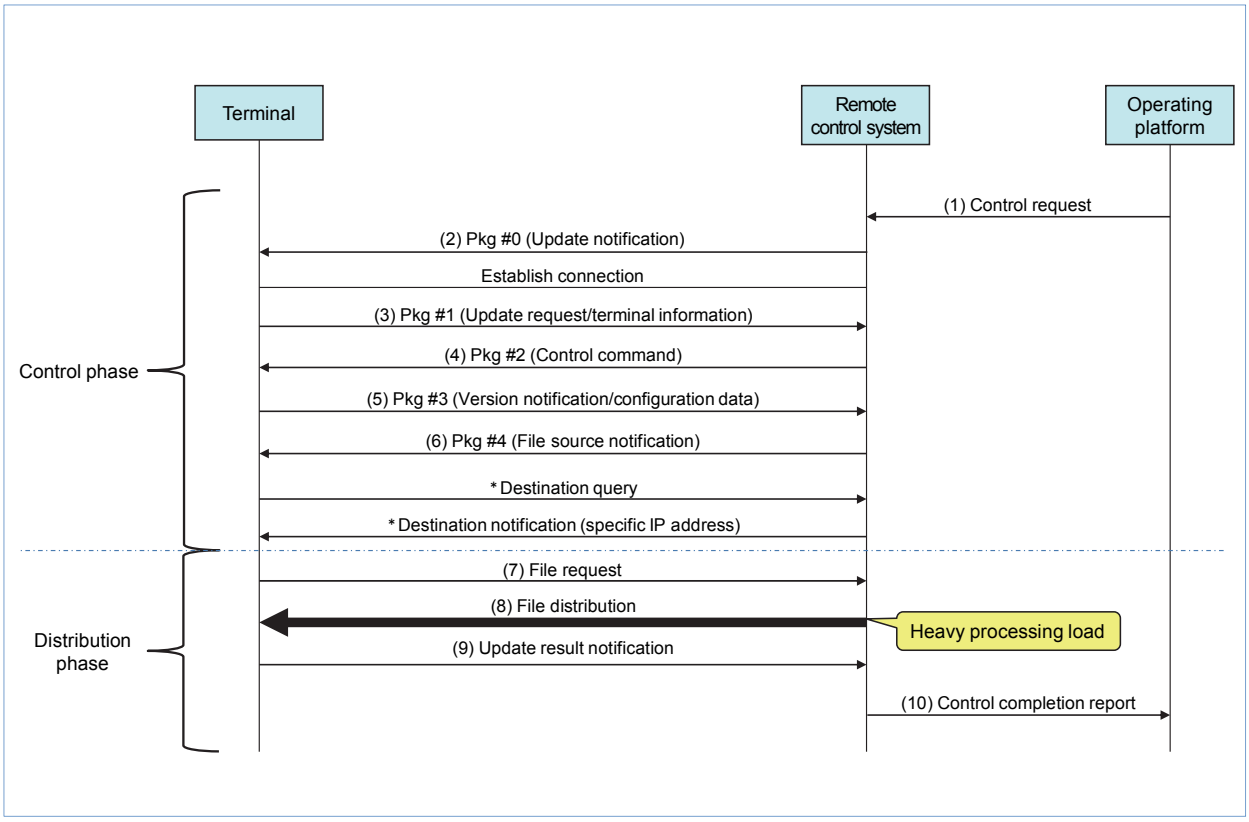


Figure 4 Process for OS update (before applying CDN)

request (Fig. 4 (1)) from the operating platform*10, it sends an update request in the form of a Pkg#0 to the terminal (Fig. 4 (2)). After receiving the Pkg#0, the terminal establishes a connection with the remote control system using packet communication. Then, it sends Pkg#1 with update request/terminal information to the remote control system (Fig. 4 (3)). The remote control system then sends Pkg#2 with a control command to the terminal (Fig. 4 (4)) and the terminal sends Pkg#3 to the remote control system based on Pkg#2 (Fig. 4 (5)). The remote control system then sends Pkg#4 to the terminal, based on OS version and other information needed for the OS update in Pkg#3, indicating where to get the applicable files (Fig. 4 (6)). After receiving Pkg#4, the terminal requests the necessary files from the specified location (Fig. 4 (7)), and downloads them (Fig. 4 (8)). After the update has completed, the terminal notifies the remote control system with the result (Fig. 4 (9)). After receiving this notification, the remote control system sends a control completion report to the operating platform, completing the control operation (Fig. 4 (10)).

2) Process Flow after CDN Application

The OS update process after applying the CDN is shown in **Figure 5**.

The process until Pkg#4 is the same as before applying the CDN, but then the terminal connects to a CDN distribution server to request the files (Fig. 5 (7)). This is implemented by indicating a CDN

*10 Operating platform: An operations system for service providers and operators to control terminals remotely through the remote control system.

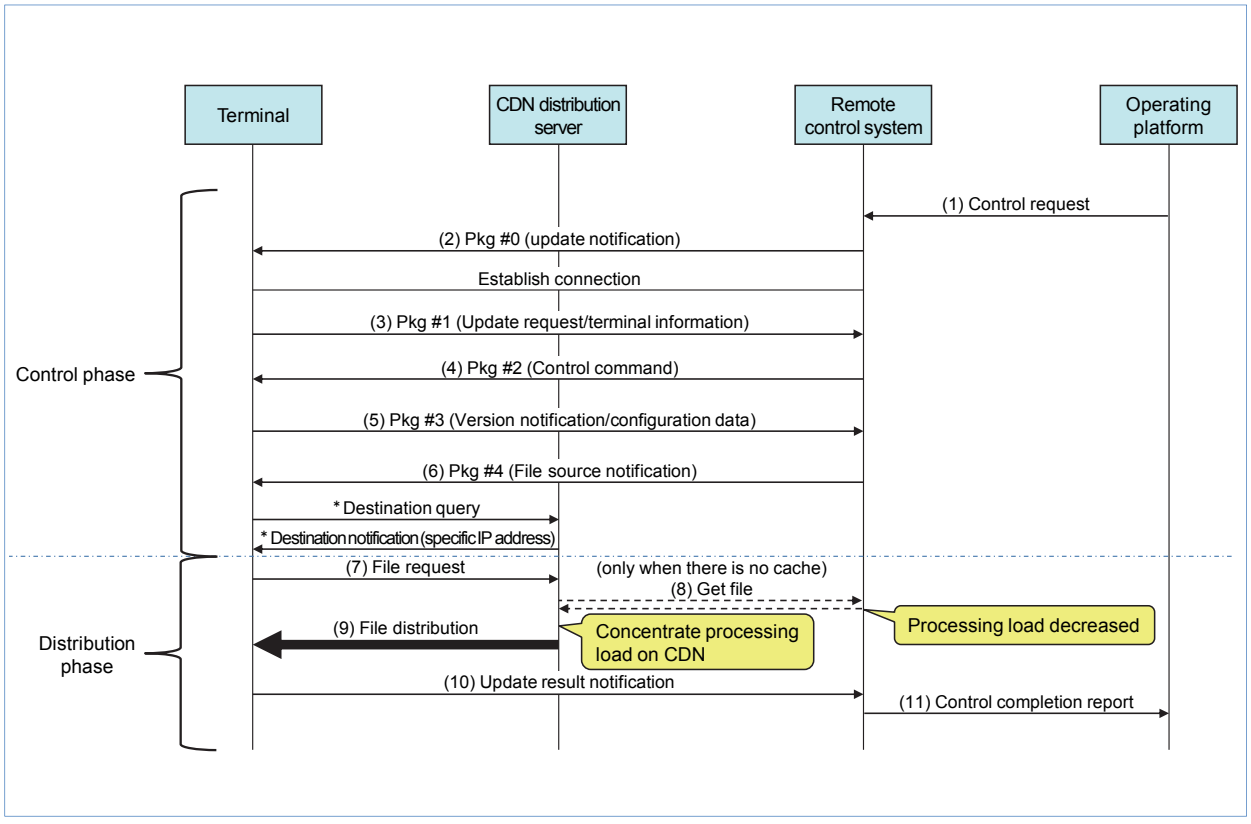


Figure 5 Process for OS update (after applying CDN)

distribution server instead of the remote control system, which was previously the source, when the remote control system notifies the terminal of the file source (Fig. 5 (6)). The control request sent from the operating platform can specify the file source that the remote control system indicates to the terminal on a per terminal basis (Fig. 5 (1)). This can be controlled for each terminal, including specifying that a terminal should request files from the remote control system in the conventional way, rather than from a CDN distribution server. This functionality makes it possible to control traffic.

When the CDN distribution server receives the file request, it checks whether it has the files in its cache and if it does, it sends the cached files to the terminal (Fig. 5 (9)). If the cache does not contain the requested files, it gets the files from the remote control system (Fig. 5 (8)), and distributes them to the terminal while keeping them in its cache (Fig. 5 (9)). The load on the remote control system can be greatly reduced by having the CDN distribution servers handle distribution of large files that incur a greater processing load. The length of time files are saved in the cache can be set by the service provider or maintainer, but unless there is some shortage of resources on the distribution server, normally they remain in the cache until they are explicitly deleted by the service provider or maintainer.

3.3 Free-of-charge Feature

NTT DOCOMO OS and software updates are provided free-of-charge, regardless of how the client connects. Normally, communication with specific IP addresses*11 can be provided free-of-charge (Fig. 4*), but with the CDN, distribution is provided using access to many cache servers, so it is not well suited to providing free-of-charge service on a specific IP address. To implement a free-of-charge service even after applying the CDN, the CDN was customized so that all CDN distribution servers use a fixed destination address.

The system is designed to recognize NTT DOCOMO OS or software updates from the file source notification and the content of the file request in Pkg#4 (Fig. 5*), and to route the request to a particular CDN distribution server IP address. This enables traffic to the relevant IP address to be provided free-of-charge. A particular CDN distribution server receives the file requests and forwards them to another CDN distribution server deployed in a later stage. This arrangement has similar distribution capabilities as when not routing to the IP address of a particular CDN distribution server, while also allowing the communication to be identified as free-of-charge.

3.4 Use of General-Purpose Ports

Till now, the NTT DOCOMO remote control system has used proprietary port*12 numbers, mainly to identify different services. General-purpose ports were also intentionally not used for security reasons. However, with the application of the CDN, the system was changed to use general-purpose ports for two main reasons, as follows.

(1) Changing perceptions of security. In the past, non-regular ports were used as a way to make cyber-attacks more difficult, but attack methods have become more sophisticated and machine processing capabilities have increased, so that changing ports now has little effect in avoiding attacks. Conversely, by using only general-purpose ports, measures to strengthen security can be focused at specific locations, making security measures and security management easier for the overall system.

(2) General-purpose ports are usually used with CDNs and are the same across CDN vendors. Thus, if for some reason there is a need to change vendors, it will be easier to switch vendors while keeping the same specifications. Also, by supporting ports common among vendors, it should also be possible in the future to implement a multi-CDN structure, using multiple CDN services at the same time. As our services diversify in the future, implementing a multi-CDN system would enable us to provide services according to various needs, using the different CDNs according to their respective merits. Note that when applying the CDN, we identify services by domain, so the service identification function is implemented the same as it was earlier, when services were identified by port.

4. Conclusion

This article has given an overview of CDN architectures and described features of their application to the NTT DOCOMO OS and software

*11 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.

*12 Port: In TCP/IP communication, a sub-address below an IP address used to specify different channels for communication on the same terminal.

update services. By applying a CDN to the remote control system, it is possible to distribute large files without expanding our download server equipment, and enabled us to deal with future increases in traffic demand. This will enable us to distribute update files more quickly to more users. We will also continue to implement service improvements to provide services more quickly and to more users in the future.

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Technology Reports | Operational and Maintenance Efficiency Improvement | OpenStack | TCO Reduction

Large-scale OSS Migration Using Private Cloud and Virtualization Technologies

DOCOMO Technology, Inc. Solution Service Division Yuki Kishikawa Kentaro Ishii

Regarding OSS responsible for service and equipment monitoring, NTT DOCOMO studied facility renewals accompanying the end of the HW support used with these systems, and introduced OpenStack private cloud and virtualization technologies. This article describes issues with the conventional OSS, requirements for their renewal, the results of studying renewal methods, issues and solutions with renewal methods, function development to improve operational efficiency, effects of deployment, and future issues.

1. Introduction

To continuously provide stable mobile services, NTT DOCOMO has developed an Operations Support System (OSS)*1 that is responsible for monitoring services and equipment, and has introduced this system commercially.

As the end of support (EOL: End Of Life*2) of HardWare (HW) used with OSS approaches, we have continued to study facility renewals with a view to making improvements into the future. With this endeavor, developing systems consisting of many pieces of HW and efficiently developing SoftWare (SW) when HW and OS are upgraded have been central themes. This article discusses the construction of an OpenStack*3 private cloud*4 environment, and discusses studies and outcomes on issues and solutions with the construction and operation of OSS SW in virtual environments.

2. Conventional OSS Configurations, Issues and Renewal Requirements

1) HW Issues

Conventional OSS consists of thousands of general-purpose blade-type IA servers*5, storages and

*1 OSS: Enterprise operations support system. For communications operators, this can include some or all of fault management, configuration management, charging management, performance management, and security management for the networks and systems providing the services.

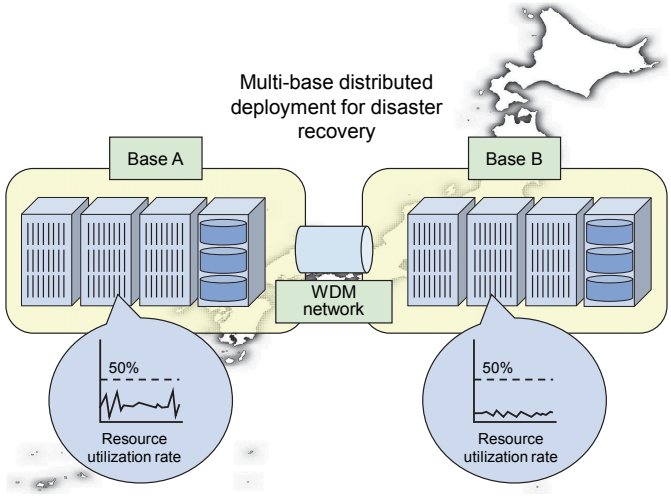
network equipment. Also, efficient disaster recovery*6 mechanisms for large-scale disasters [1] - [3] were introduced to ensure the continuity of OSS. **Figure 1** shows the conventional OSS configuration.

While it is important to ensure spare HW resources so that OSS can operate continually in emergencies such as disasters or network congestion*7, this lowers resource usage rate in times of normal operation, which in turn lowers the usage efficiency of facilities. Moreover, as an issue with conventional OSS facilities in terms of cost, these systems require facilities investment for initial deployment (CAPEX: CAPital EXpenditure*8) in addition to HW installation space rental, electricity, maintenance and other operating expenses (OPEX: OPerational EXpense*9).

2) SW Issues

In terms of SW, testing OSS OS when upgrading is problematic. For example, the CentOS*10 version currently used with OSS is not supported with the latest HW products, which means that when facilities are renewed with new HW, OS used by SW also have to be upgraded and tested to ensure proper operation. To date, we have periodically renewed facilities (including operations testing associated with OS upgrades). For this, it is also important to optimize development costs associated with OS upgrades by properly managing the SW level of degree of dependence on OS and localizing affected SW.

With the aim of solving the above issues, **Table 1** shows specific requirements for renewing facilities. We studied renewal methods that satisfy these



WDM (Wavelength Division Multiplexing) network: An information communications method that provides high speed and large capacity by multiplexing multiple signals using different optical wavelengths on a single optical fiber cable.

Figure 1 Conventional OSS configuration

*2 EOL: Refers to cessation of product manufacture and sales, cessation of support services for SW products, or cessation of provision of modification/upgrade programs for bug fixing and functional improvements.

*3 OpenStack: Cloud-infrastructure SW 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. OpenStack is open source SW.

*4 Private cloud: Refers to an in-house cloud system configured in a corporation or organization, and provided to various in-house divisions or group companies. In contrast, open cloud services that do not restrict their services to certain users are called "public cloud" services.

*5 IA server: A server equipped with an Intel microprocessor or an Intel compatible processor. Its internal structure is very similar to that of an ordinary PC, and it is less expensive than servers based on other types of microprocessor.

requirements.

3. Results of Study on Renewal Methods

To satisfy the requirements of facility renewal, it is necessary to improve the usage efficiency of facilities. Here, we made efforts to improve usage efficiency by implementing several applications with one HyperVisor (HV)*11.

1) Traditional Distributed Architectures

Conventionally, OSS applications have adopted distributed architecture which is made up of platform SW called Distributed Data Driven Architecture (D3A)*12 [4] and a group of distributed applications called multiple ELements (EL)*13 which operate on the platform. The D3A platform is responsible for transferring data between the distributed EL, and achieves simplification of EL functions. **Figure 2** shows the conventional OSS SW distributed configuration.

2) Adoption of HV-type Virtualization Technologies

Compared to conventional distributed architecture, more efficient use of facilities is enabled by using HV-type virtualization technologies and configuring and operating multiple Virtual Machines (VM)*14 on a single piece of HW.

Figure 3 shows the system configuration of the OSS SW using the HV-type virtualization technologies. With conventional D3A platform, it was not possible to implement more than two EL of the same type on one piece of HW, but because this

Table 1 Facility renewal requirements

Number	Requirements
Requirement 1	Efficiency with optimized HW resources usage
Requirement 2	Optimized SW development investments
Requirement 3	Efficient HW investments

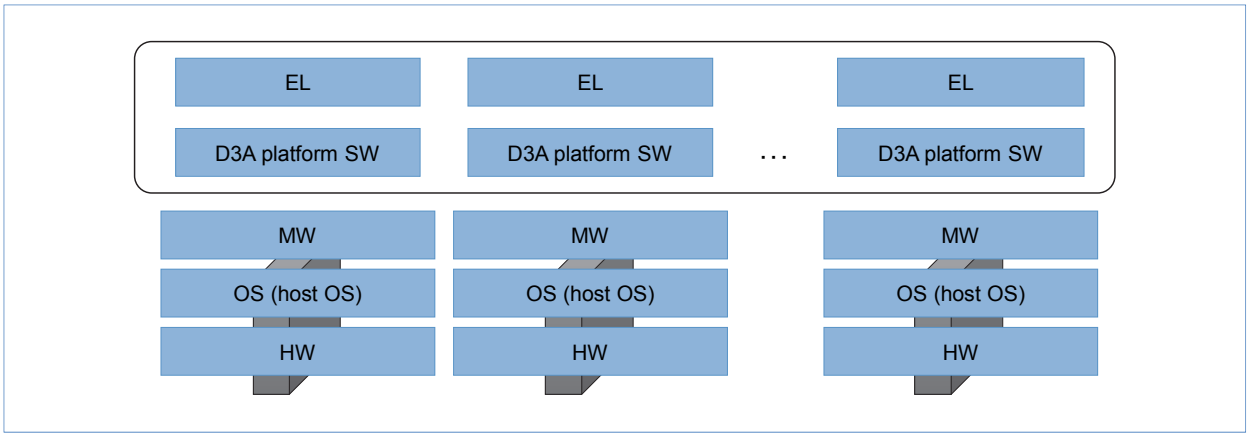


Figure 2 OSS application distributed configuration

*6 Disaster recovery: Repair and restoration of a system damaged by a natural disaster or other calamity. Also, preventive measures for minimizing damage.

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

*8 CAPEX: The amount of money expended on facility investments.

*9 OPEX: The amount of money expended for maintaining and operating facilities.

*10 CentOS: A free Linux distribution aiming for complete compatibility, based on the software source code included in Red Hat Enterprise Linux (see *16), but rebuilt without the Red Hat trademark and commercial packages.

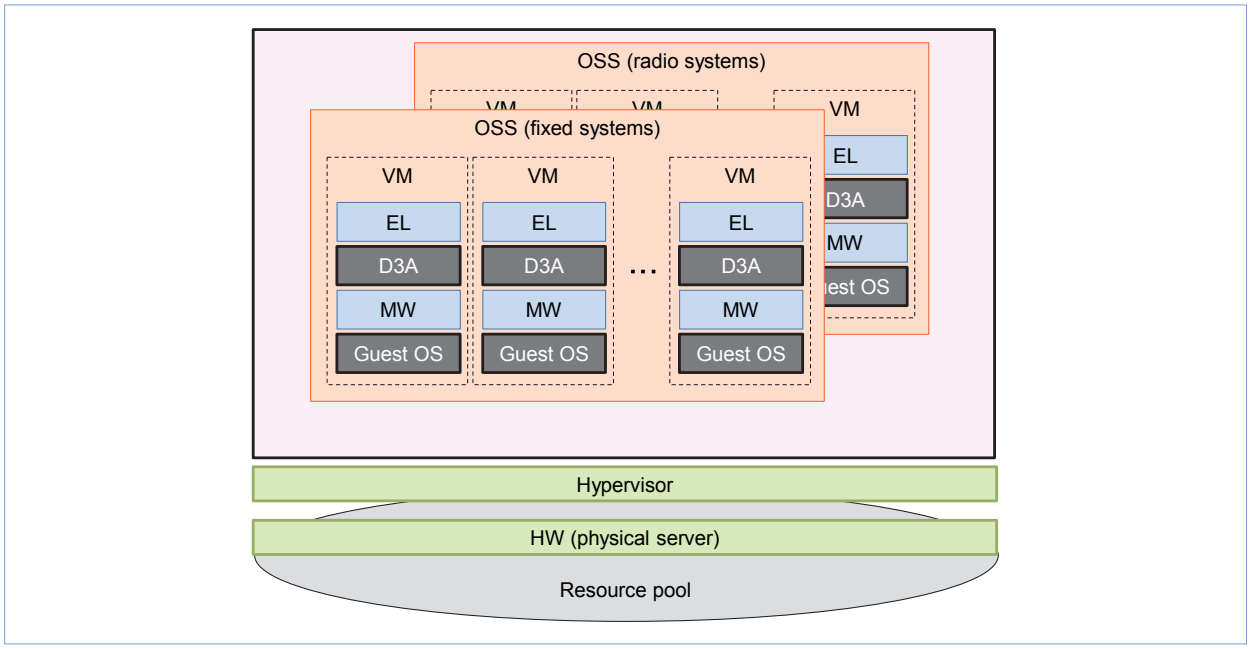


Figure 3 Configuration after implementation of HV-type virtualization

technology enables separate operating space with each VM, it's possible to implement several VMs with the same type of EL installed on the same piece of HW. Also, if there are changes to the OS or MiddleWare (MW)*15 due to HW upgrades, those changes are isolated and VMs are not affected as long as the OS is supported by HV. Basically, this means the effects of OS version upgrades can be avoided, and hence investment in SW development can be optimized for the long term. We adopted this method because the HV-type virtualization technologies can meet the full facility renewal requirements described in Table 1.

Furthermore, as HV, we adopted Linux®*16 standard free-to-use Kernel-based Virtual Machines (KVM)*17 for these facility renewals because we have a policy of building our OSS using royalty-free open source SW.

3) Adoption of the Private Cloud System

In terms of infrastructure, we have individually constructed our conventional OSS environment, but this time, we adopted a private cloud system using OpenStack to implement virtualization technologies for these renewals. In particular, to also use excess resources effectively, we can make company-wide operations more efficient by using the above system instead of building independent OSS environments or using external cloud services.

4. Challenges with Cloud Computing

1) Challenges with Using the Cloud

While conventional OSS SW was originally configured based on on-premises*18 physical server operations, we found new issues with virtualization

*11 HV: A virtual server technology that assigns and manages physical resources for SW to mount on virtual machines, and runs multiple virtual machines on physical resources.
*12 D3A: An architecture developed at NTT DOCOMO, which groups multiple IA servers to achieve high performance.
*13 EL: A basic structure of D3A, a mechanism that enables distributed operation on a number of servers by dividing SW into functional units. Because EL run on Java® VM, they are not dependent on particular HW vendors. Oracle and Java are registered trademarks of the Oracle Corporation and its subsidiaries and related companies in the United States and other countries.
*14 VM: A computer created in a virtual manner by SW.
*15 MW: Positioned between OS and SW, middleware is a collection of common basic functions and generic processing provided to all SW running on an OS.

and cloud systems with these renewals. For example, since EL with Active/Stand-by (ACT/SBY)*19 redundant configuration were separated in physical servers in the on-premises environment, it was extremely rare that both systems would go down due to HW failure, and hence the possibility that OSS services would be down was extremely low. However, in the virtual, cloud environment it's possible to implement the redundant ACT/SBY EL on the same HW, which means there is a risk of both systems failing if the HW fails. Also, with ACT/SBY switching, EL configured with a shared disk preserved data consistency with shared disk mount switching, but the current OpenStack does not always enable suitable unmount operations, which can lead to shared disk mount switching failures, thus requiring recovery time and lengthening the impact on business operations. In addition, appropriate control of VM placement is required for EL intended for the physical structure of conventional OSS, such as EL for multiple ACT configurations or EL implemented on the same HW to ensure performance. **Table 2** and **Figure 4** (a) describe specific issues.

2) Solutions

When using a cloud system, it is difficult to select HW or change cloud system settings. Therefore, solutions are required that entail changing SW specifications for virtualization. Fig. 4 (b) describes these solutions. As specific solutions to numbers 1 to 3 in Table 2, we adopted OpenStack's "availability zone*20" designation functions that enable placement of VM on specific HW and filter functions (Different Host Filter, Same Host Filter etc.) [5]. To preserve physical separation and redundancy, the Availability Zone function allows the user to specify the physical location of a VM such as a specific rack, floor or data center. Similarly, the filter functions enable VM launch rules to be set in detail. Normally these are specified manually, but with large-scale systems such as the DOCOMO OSS in which one system may contain 1,000 or more VMs, such settings would entail massive amounts of work and be prone to human error. For this reason, we implemented a virtualization controller for these technologies.

In number 4 in Table 2, we resolved the issue by changing storage configuration and revising the SW to implement data replication*21 between ACT/SBY.

Table 2 Challenges with cloud computing and solutions

Number	Issues to consider
1	EL for ACT/SBY configuration: To ensure redundancy, ACT-side EL and SBY-side EL (VM) are not implemented on the same HW
2	EL for multiple ACT configuration: To ensure redundancy, all ACT EL (VM) are not implemented on the same HW
3	Some EL correlated greatly with operations: To ensure processing performance, correlated EL (VM) are implemented on the same HW
4	EL on shared disks: Due to the OpenStack constraint that unmounts do not operate properly when a VM stops, shared disk systems are changed to individual disk systems

*16 Linux®: An open-source Unix-type OS that can be freely redistributed under GNU Public License (GPL). A registered trademark or trademark of Linus Torvalds in the United States and other countries.

*17 KVM: SW for achieving virtualization. KVM is open source SW.

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

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

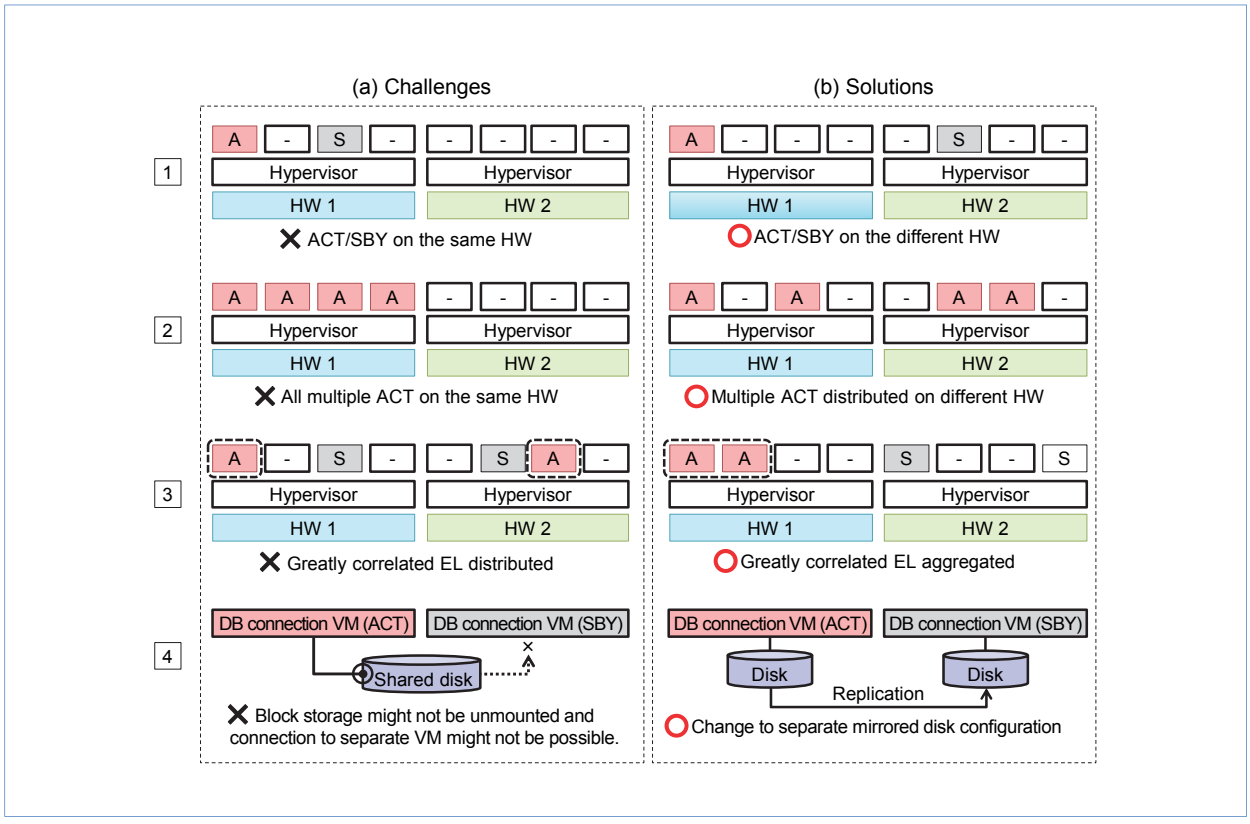


Figure 4 Challenges and solutions

This enabled migration to a virtualization and cloud environment while preserving the redundancy, performance and functions of conventional OSS SW.

5. Challenges with HV-type Virtualization Technologies and Their Solutions

Because HV-type virtualization technologies use SW to emulate HW, and because many VMs can share one HW resource, performance can degrade due to virtual layers (SW processing). For this reason, in particular, sufficient study and solutions on storage and network performance are required to solve the specific issue of performance degradation with HV-type virtualization technologies.

In these facility renewals, we confirmed that the I/O performance[*22] of external storage in the OpenStack private cloud environment was lower than the conventional method. Hence, we avoided using external storage HW in the cloud environment and used higher performance internal flash storage. Although this completed solutions in terms of performance, issues remained with data persistency.

In the OpenStack virtual environment, data saved in external storage is basically persistent, and remains on the disk even if a VM stops. Hence, on restarting the VM, and connecting the external

*20 Availability zone: In OpenStack, there are areas that are geographically separate such as data centers that are referred to as "regions." An "availability zone" refers to an independent location in a rack or power system within a region.

*21 Replication: A data-copy process between file systems performed on a one-to-one basis. Defines pairs of replication sets between file systems. Copies data sets not stored in the transfer destination and copies differences only if data sets have already been stored.

*22 I/O performance: Refers to the input/output performance of data and signal exchange between the CPU or memory and storage or disks.

storage to the VM, the stored data can be reused. However, data stored in one type of OpenStack storage, ephemeral storage*23, is not persistent, and is deleted if the VM is deleted. Hence, with OSS, because some data such as equipment monitoring and controlling logs and traffic data must be retained for a certain period, we upgraded SW data replication functions to ensure the persistency of such data. Specifically, we took measures to replicate ACT-side EL data in the SBY-side EL internal disk with ACT/SBY-related EL, as described in **Figure 5**.

6. Improving Operational and Maintenance Efficiency

When increasing equipment with operations in physical environments, it takes two to three months to procure and build HW, and install SW, depending on the scale. However, with virtualization technologies, HW required to build systems is abstracted, therefore virtual servers, networks and storage can be configured quickly with SW controls. Also, when testing requires changes to the system, the functions described in **Table 3** can be achieved by combining build and fault because virtual environments can also be stopped rapidly.

1) Developing Three Functions

The introduction of virtualization technologies enables not only improved operational efficiency due to improved HW usage efficiency and better use of excess resources, but also further improves business operational efficiency with improved maintenance efficiency and automation of operations. In view of this, we developed the following three functions with these facility renewals.

- Instantiation

  Instantiation means generating a VM. This refers to the operations from installing a VM on a physical machine, making virtual network settings, launching the VM and launching SW through other settings to achieve a usable state. We have accomplished this with a single touch.

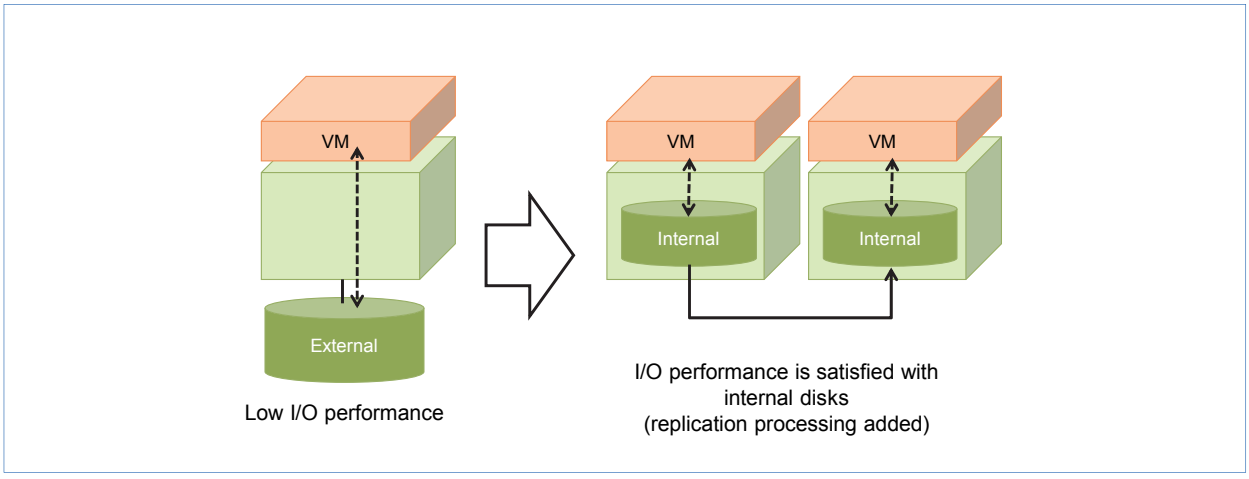


Figure 5 Persistent data handling with performance improvements

*23 Ephemeral storage: Volatile memory in OpenStack. When an instance is deleted, data in storage is also deleted.

Table 3 Developing functions for more efficiency

Number	Issues to consider
Function 1	One-touch VM creation (instantiation)
Function 2	One-touch redundancy recovery (healing)
Function 3	One-touch equipment expansion (scale out)

- Healing

  Healing means recovery of redundant VM and SW configurations. If one side of a VM with a redundant ACT/SBY configuration is lost, ACT/SBY switching takes place in the application layer and operations can continue, but the SW only runs on one side. In this situation, if a failure occurs and a VM stops leading to a system outage, recovery of redundancies becomes urgent. To counter this issue, we have achieved a one-touch redundant configuration recovery procedure.

- Scale out

  Scale out means expanding VMs. While it was possible to improve performance by increasing VMs with the same type of EL installed if the performance of operational VMs came under pressure, it was difficult to handle HW expansion for sudden performance concerns because this required HW expansion planning and works. Thus, with this development, we have achieved a one-touch facility expansion procedure.

2) Introduction of Virtualization Controllers

Figure 6 describes OSS architecture to further increase efficiency. A virtualization controller is responsible for executing and managing the functions described in Table 3, and achieves functionality interlocked with the OpenStack/D3A platform. The OpenStack and D3A functionality enables the achievement of instantiation, healing and scale out with manual work. However, with the introduction of virtualization and the private cloud, we have also implemented an automated system with execution and management functions to maximize simplicity and speed with maintenance.

This controller basically launches and stops SW and VMs. Conventional OSS consists of a combination of D3A platform SW and SW (EL), where the D3A platform launches and stops SW and manages system status. For this reason, it's not necessary to associate virtual controllers with each SW (EL), because SW and VM lifecycle management can be achieved with association to the D3A platform only. Thus, this architecture contributes to lower development costs because impacts are localized to existing SW.

In addition, it is also possible to entirely automate functions and eliminate the need for human intervention. While automation leads to a decrease in human errors, there are additional development costs associated with it. Hence, in this development, we estimated the cost of full automation and OPEX reduction effect, and chose one-touch automation operations. Generally, these developments comply with European Telecommunications Standards Institute (ETSI)*24 Network Functions Virtualisation

*24 ETSI: European Telecommunications Standards Institute. A European standardization body engaged in the standardization of telecommunications technologies. Headquartered in Sophia Antipolis, France.

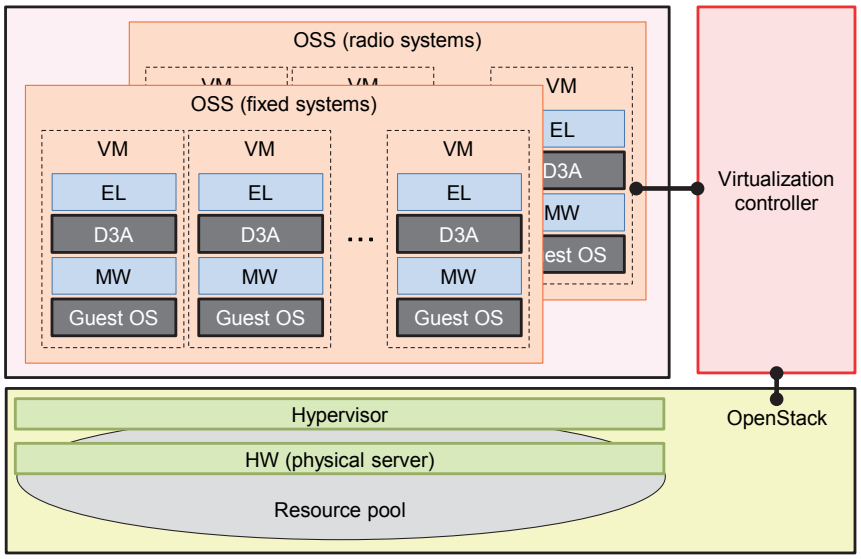


Figure 6 Architecture for achieving further efficiency

(NFV)*25 standards [6], and the virtualization controller is equivalent to Virtual Network Function Manager (VNF Manager)*26 included in Management and Orchestration (MANO)*27 in NFV standards.

7. Effects of Cloud Implementation and Future Challenges

Figure 7 describes the Total Cost of Ownership (TCO)*28 reductions calculated for the implementation of the OpenStack private cloud and virtualization technologies. This figure compares the TCO over seven years including operational costs of the current physical environment (Fig. 7 (a)) with the implementation of OpenStack private cloud and virtualization technologies (Fig. 7 (b)).

In terms of CAPEX, we achieved massive reductions in equipment investments. After renewing, optimized HW facility investments through improved HW performance and efficient uses of resources by virtualizing were largely responsible for reductions in TCO.

In terms of OPEX, both maintenance and electricity expenses were reduced by the above-mentioned optimization of HW facilities investments. Also, as combining the functions shown in Table 3 with the virtualization technologies enables planned execution of maintenance support, a future issue is the study of operational methods to maximize effectiveness with the aim of further increasing efficiency.

8. Conclusion

This article has presented studies on the im-

*25 NFV: A technology that uses virtualization technologies to implement processing for communications functionality in SW running on general-purpose HW.
*26 VNF Manager: The system that performs VNF control operations such as launching and termination as VNF lifecycle control.
*27 MANO: A mechanism that provides VNF management functions and orchestration functions for HW and SW resources in virtual environments.
*28 TCO: The total expenses incurred with initial deployment and operations management of a system.

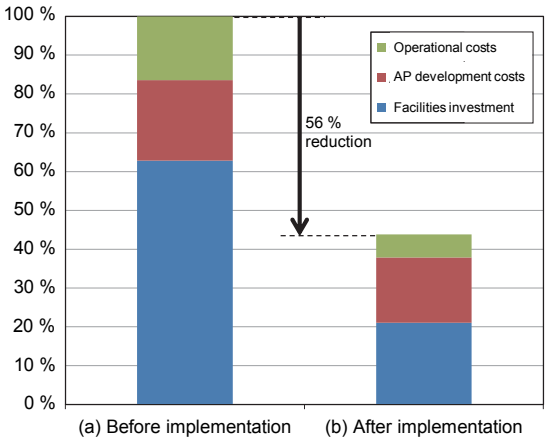


Figure 7 TCO cost reductions with cloud and virtualization technologies implementation

plementation of OpenStack private cloud and virtualization technologies in facility renewals of conventional OSS, and has shown the potential to reduce TCO and use excess resources effectively. This was NTT DOCOMO's first attempt to migrate large-scale OSS to a cloud system. As a result of various measures to achieve the desired performance and redundancy by moving non-cloud native*29 OSS SW to cloud systems, we achieved commercial implementation. While new operational processes are required with the implementation of virtualization technologies, these developments are highly advantageous because they can achieve efficient, agile and flexible operations. We intend to continue studying ways to further improve business efficiency by maximizing the effects of implementation of cloud computing and virtualization technologies.

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*29 Cloud native: Refers to systems and services designed for configuration and operation on the cloud, rather than on-premises.

“5G Trial Site” Opens

To generate new 5G services, NTT DOCOMO opened a “5G Trial Site” on Monday, May 22, 2017 as an initiative to give customers the opportunity to experience the characteristics of 5G [1].

Firstly, a 4K multi-stream live was fed from the TOKYO SKYTREE ®*1 Tembo Deck to the TOKYO Solamachi®*2 commercial center in the TOKYO SKYTREE TOWN®, and was open to the public on the first floor event space in TOKYO Solamachi as a “virtual observation deck” until Sunday, May 28, 2017. This system used an optical cable to send images from 4K cameras in six positions around the Tembo Deck to the first floor of TOKYO Solamachi. Then, using that feed through a 5G base station and terminal, three of the six images were displayed with three 4K LCD televisions to reproduce a live 180° image. The presence of this live feed achieved with 5G’s characteristic high-speed, high-capacity and low latency data transmission enabled customers to experience the sensation of being in a place even though they were actually in a separate location.

Also, an event was held for the opening of the 5G Trial Site at TOKYO SKYTREE on Monday, May 22, 2017, which provided a large number of reporters with a preview experience of the 5G Trial Site.

This event was held on TOKYO SKYTREE Tembo Deck Floor 350 (350 meters high), with CEO Yoshizumi Nezu of Tobu Railway, 5G Trial Site partner company, and NTT DOCOMO President and CEO Kazuhiro Yoshizawa taking the podium to talk about their enthusiasm for the 5G Trial Site. Mr. Nezu described how 5G Trial Site is contributing

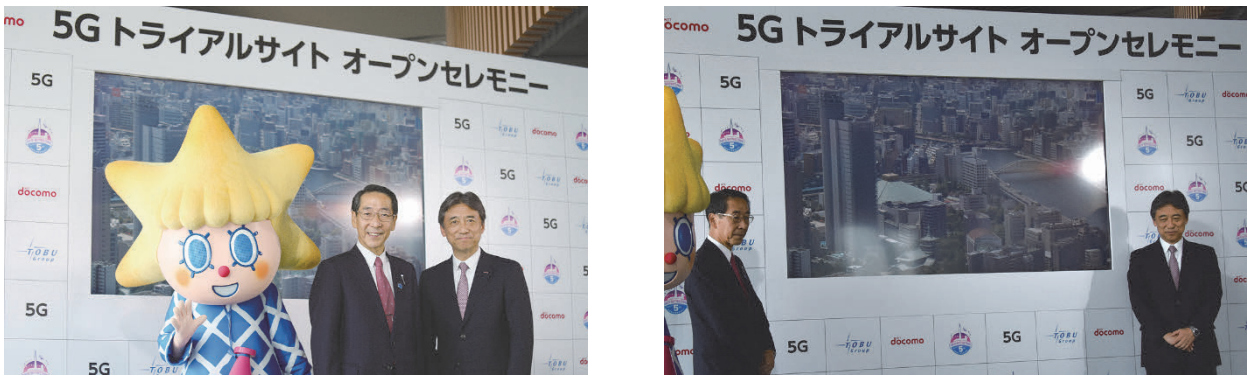
4K multi-stream live feed and 5G transmission equipment on the first floor of TOKYO Solamachi

*1 TOKYO SKYTREE®: “TOKYO SKYTREE” and “TOKYO SKYTREE TOWN” are registered trademarks of TOBU RAILWAY CO., LTD. and TOBU TOWER SKYTREE CO., LTD.

*2 TOKYO Solamachi: A registered trademark of TOBU RAILWAY CO., LTD.

to making TOKYO SKYTREE and Asakusa area as well as the Nikko and Kinugawa areas become showcases of cutting-edge technology. Mr. Yoshizawa stated that the 5G Trial Site is not only a venue to verify 5G's high-speed, high-capacity and low latency, but also an initiative to generate new services in the 5G era with potentials for new business launches by exploring and discovering the sorts of experiences and services that can be converged with 5G with partners companies. Then in the opening ceremony that followed, in a world first, 8K live, high-resolution images captured with an 8K Super Hi-Vision camera on the Tembo Deck and transferred with 5G were displayed on an 8K display to attendees.

Furthermore, as an example of a 5G usage case, a demonstration was held for reporters onboard the "Limited Express Revaty" Tobu Railway new express, which began services on Friday, April 21, 2017, to impress upon them the strength of simultaneous 5G connection in actual usage scenes, which entailed simultaneous display on eight tablets via 5G of 4K images captured in advance from the driver's seat.



5G Trial Site opening ceremony and 8K live feed images

4K video multiple simultaneous connection demonstration in the new "Revaty" express train, and 5G transmission equipment

Remote control system for construction equipment

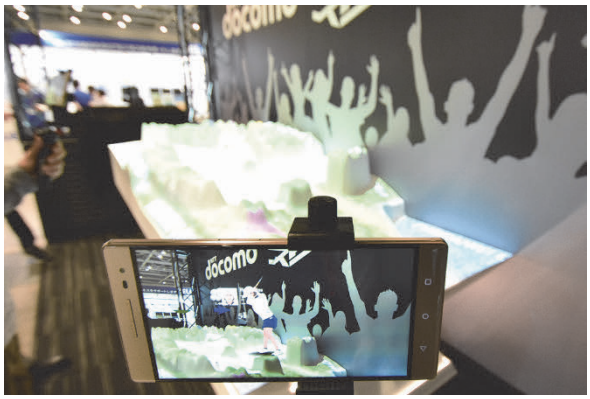
Remote control system for robotic hands

From Wednesday May 24 to Friday 26, 2017, an exhibition was held on initiatives with partner companies at the 5G Tokyo Bay Summit 2017®*3 pavilion in the Wireless Technology Park 2017 [2] held at Tokyo Big Site as a 5G Trial Site-related event. This pavilion holds the largest national event specializing in 5G, which has been scaled up, planned and operated by NTT DOCOMO since last year.

NTT DOCOMO, its existing and new partner corporations presented details of their initiatives for prototype demonstrations of services utilizing 5G in a range of industries such as demonstrations of 4K and 8K real-time video streaming, remote control systems for construction equipment and robotic hands, and new communications and sports viewing styles with Augmented Reality (AR) and Virtual Reality (VR) [3] - [7]. Also, we displayed the DOCOMO-developed "5G Real-time Radio waves Visualizer" [8], the world's first demonstration and experiment equipment for measuring, analyzing and visualizing radio waves arrival in real time, and also presented a demonstration vehicle used with the 5G Trial Site.

Furthermore, a seminar program was held on the 5G Tokyo Bay Summit on Wednesday May 24 and Thursday 25, 2017. On the 24th, lectures and a symposium were held on trends in the latest VR technologies for the 5G era as the "5G Tokyo Bay Summit Workshop." As the opening lecture, Takehiro Nakamura, General Manager of the 5G Laboratory of NTT DOCOMO delivered a lecture on "Open innovation combining 5G and VR" followed by theme lectures from Crescent, NS Solutions Corporation, Fuji Television Network and Japan Display. After that, a panel discussion was held as the "5G × VR Symposium." Enthusiastic discussions were held on the global potential for achievements combining 5G and VR. On the 25th, vendor companies also delivered lectures in the "5G Tokyo Bay Summit Technology Seminar."

The pavilion was constantly full of visitors, and a lot of people including standing attendees enjoyed the seminar program on the 5G Tokyo Bay Summit. With even greater interest in 5G compared to last year, the event ended successfully.



Sports viewing on a smartphone with athletes represented on an AR diorama

5G Real-time Radio waves Visualizer

5G demonstration vehicle

*3 5G Tokyo Bay Summit: A registered trademark of NTT DOCOMO, INC.

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