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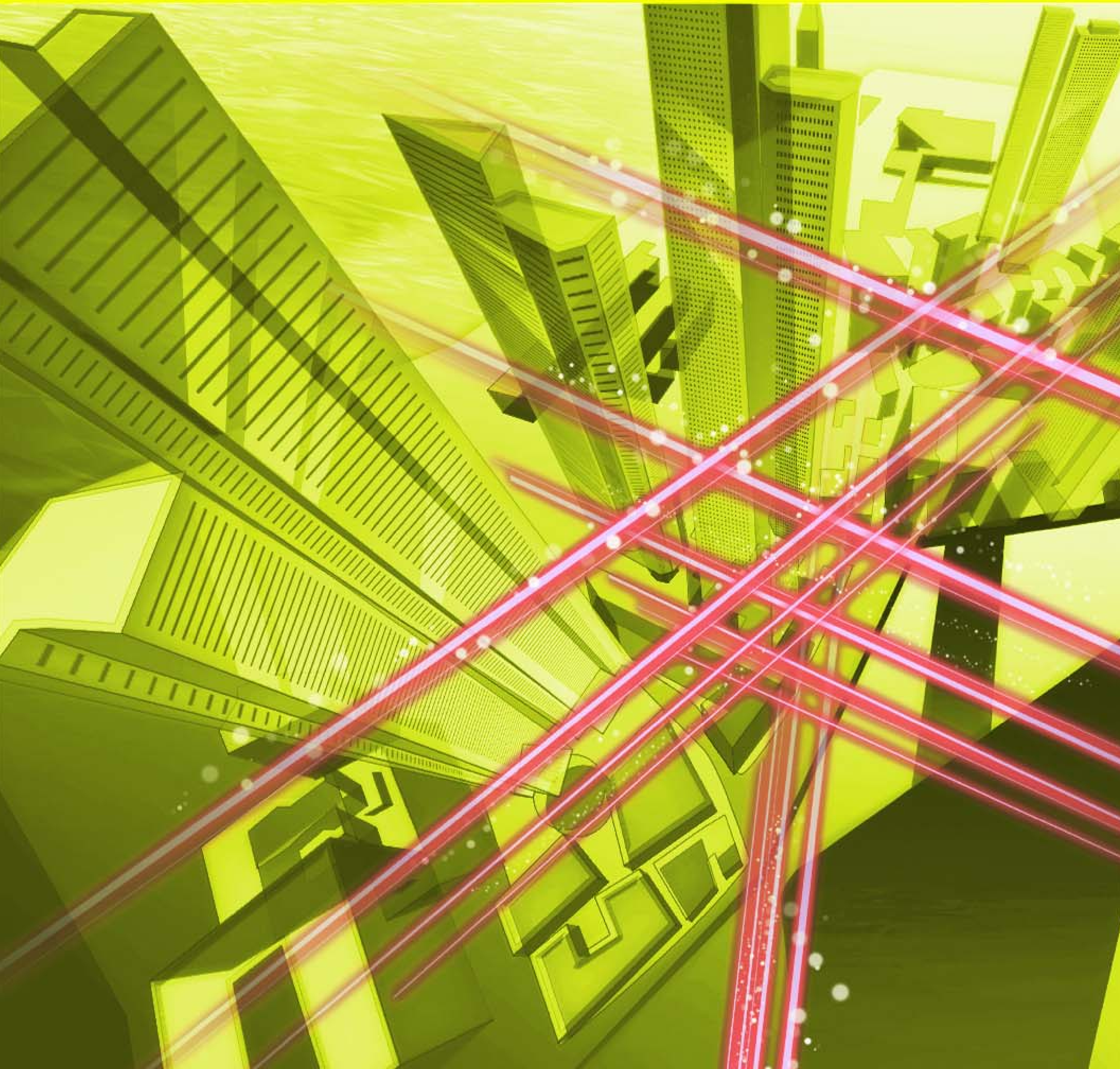

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Research and Development to Create Value with IoT

Shuichi Yoshino and Hiroyuki Tanaka

Abstract

Utilization of Internet of Things (IoT) technology is advancing as part of efforts to create new value in various fields, even those with little previous relation to information and communication technology. In view of this IoT era that will drive industry and society forward, NTT has defined four necessary roles in terms of requirements and technologies, and we are collaborating with our partners to build key technologies. In this article, we introduce technical development initiatives at the NTT laboratories to further advance IoT.

Keywords: IoT, sensing, edge computing

1. Introduction

With the Internet of Things (IoT), all manner of objects in society are being connected to networks, exchanging and processing information in cyberspace (the *cloud*), and producing value by visualizing objects and occurrences in the real world or by providing feedback for control. It is much anticipated that the IoT will facilitate the creation of new industries in various fields and will be a means of resolving issues faced by society as its use continues to spread.

At the NTT laboratories, we believe that a new era has arrived, in which IoT is used to visualize, optimize, and control physical objects and movement in society, and in this third-generation *driving* era, the role of information and communication networks is very different from what it was earlier. Consequently, we are conducting research and development (R&D) to meet the different requirements and develop new usage domains [1].

A study by the Ministry of Internal Affairs and Communications (MIC) of Japan [2] broadly categorized the use of IoT, based on collected data, into uses that increase the value of products by providing remote control, operation, or maintenance of robots and machinery, and uses that improve processes in companies and other organizations through visualization and optimization of business. An analysis revealed that as of 2015, IoT had been introduced into 20% of domestic products and services in a wide range of fields including agriculture, energy, manufacturing, distribution, services, and data communications, and this is expected to rise to 40% by 2020.

2. Topics for further development and initiatives in the NTT Group

However, the same study also reported many opinions indicating that scenarios for using products were not clear or that the effectiveness was questionable. Thus, to further develop IoT and expand the base of users in the future, it will be important to have environments and methods for creating value and realizing benefits, with low risk in terms of cost effectiveness, and allowing projects to start small and be verified easily. Thus, solutions to accelerate the spread of IoT must both create value with IoT, and provide methods for building IoT systems.

The NTT Group is working to create value with IoT by collaborating with partners from the earliest stages and building IoT technologies that realize value. For example, in manufacturing we are working with FANUC Corporation to develop an open platform called the FIELD system*. This system uses edge computing technology to collect and analyze the state of operations in a factory in real time, to add

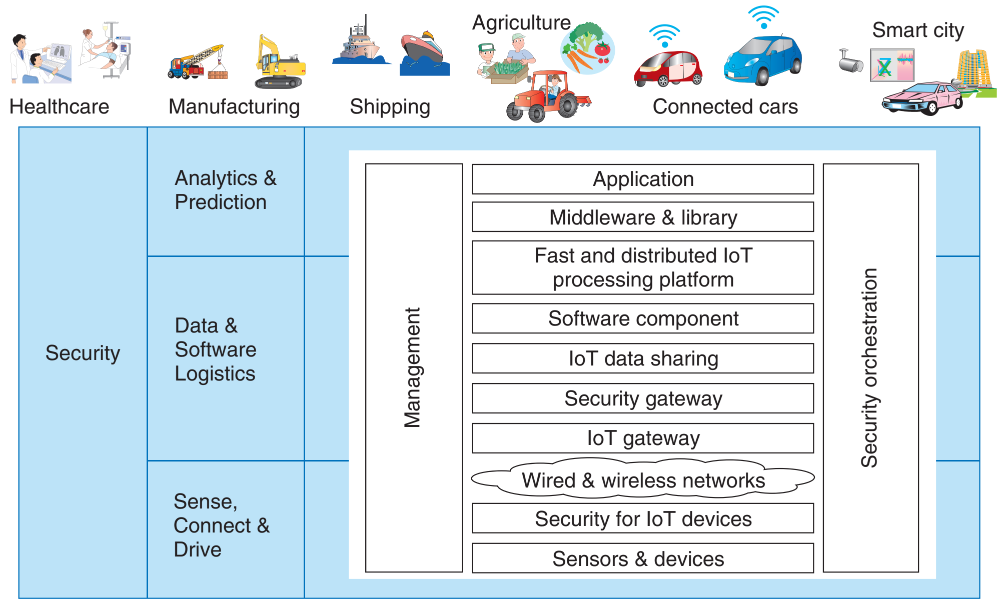

Fig. 1. Functional architecture.

efficiency and intelligence to manufacturing. By enabling applications to be downloaded to the edges, we are also working to realize *evolving factories*. This service has been offered within Japan since October 2017 [3].

To promote the use of IoT in the field of shipping, we are working with the NYK Group to develop technologies for advanced management of maintenance that take safety and the environment into consideration. This has included advanced vessel operations and fault prediction for machinery [4].

We have investigated methods for building IoT systems and have created a functional architecture for technology to meet various IoT requirements. This architecture is being used as a reference for R&D. The main functions as they relate to the real world are shown in **Fig. 1**.

The main functional elements of this architecture are sensors & devices, with functionality to digitize information from sensors and connect them to networks; IoT gateway, with functionality to convert to/from Internet protocols and connect to cyberspace; security gateway, which monitors the system in terms of communication flow and traffic behavior; IoT data sharing, which enables data to be exchanged among applications and devices with different specifications and protocols; software component, which optimizes data processing locations and software run-time environments; and middleware & library, which provides generic functionality to applications. A wide range of applications and services are expected with IoT, and not all of them will need to use all of these technical elements. The required functionalities can be combined and used with other technologies that may be on the market to suit particular applications.

The NTT laboratories are building these functions on a base of open-source and other general-purpose software to create systems that meet differing requirements in each field. We are ensuring that elements are highly generalized and meet common requirements to create a set of functional modules that can be reused. We continue to collaborate with partners in a wide range of fields to quickly realize new value with IoT, analyze and build universal functionality, and build environments in which these functions can be shared.

3. Directions for new technology and new value

We are developing technologies for each of the four roles and technologies needed to implement IoT, which are shown in **Fig. 2**. They are Sense, Connect & Drive, which digitizes data from *things* and is the interface between real society and cyberspace; Data

* FIELD (FANUC Intelligent Edge Link and Drive) system is an IoT system for manufacturers jointly developed by Cisco Systems, Rockwell Automation, Preferred Networks, and the NTT Group under a concept defined by FANUC.

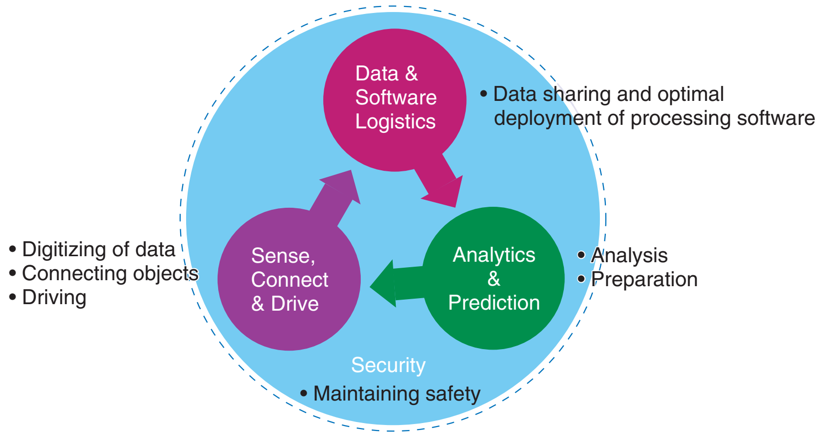

Fig. 2. Four roles and technologies in IoT.

& Software Logistics, which uses data and software and places them in the appropriate locations; Analytics & Prediction, which creates value from the data; and Security, which enables processes in society to be driven safely and securely using IoT.

3.1 Key to Sense, Connect & Drive: simple operation

Users are often quite conscious of the cost of building and operating IoT systems, so such systems need to be easy to build, maintain, and operate. It is important that sensors used to collect data can do so with simple and easy procedures. The NTT Group is conducting R&D on “hitoe” to achieve biological data sensors that can collect data simply by having the user wear a garment, and is developing scenarios for using it.

A recent example is a collaboration with Toray Industries, Inc. and Fujita Health University to visualize the state of patient rehabilitation. The data collected will be used to provide higher quality rehabilitation in hospitals and other facilities in hopes of resolving important issues in an aging society. This effort is introduced in the article, “Application for Rehabilitation Medicine Using Wearable Textile ‘hitoe,’” in the Feature Articles in this issue [5].

As the use of IoT expands, expectations are also increasing to use it in locations where networks that provide connectivity to cyberspace have not previously been available. For example, the NTT laboratories are conducting R&D on communication with devices that can inspect underground infrastructure to monitor deteriorating water pipes [6]. The goal in this example is to achieve highly reliable wireless communication from an underground water-pipe valve box, where radio propagation losses are 50 dB or more. Signal processing at the above-ground base station is used, and low-power consumption for maintenance-free operation over several years is needed. This effort is introduced in the article, “Wireless Relay Technologies for Monitoring Underground Infrastructures,” [7] in this issue.

3.2 Keys to Data & Software Logistics: shared data and structures, local data processing

There is much anticipation for new value created using big data with IoT, but according to an MIC study, industry and government perceive that there are issues with big-data utilization such as the cost of data collection and management and unclear cost-effectiveness of data utilization [2]. Most IoT initiatives are currently advancing separately, but to expand IoT more broadly in the future, standardization for data sharing will become more important, including standardization of data and common frameworks for handling it.

The NTT laboratories are conducting R&D and standardization work on oneM2M as a potential international standard for open data and use of data across industries. Specifications for oneM2M were created as a platform, with a set of common functions used in IoT systems.

Standards for interconnectivity with other existing standards are also being created. Systems built with the oneM2M architecture will be able to access collected data using the same application programming interfaces (APIs), and different applications and users will be able to use the same data more easily.

Applications in different fields can also access the data using the same APIs, making it easier to link with and introduce knowledge from other fields, which is important for the expansion of IoT.

The NTT laboratories are participating in R&D and standardization for oneM2M and driving the creation of standard specifications and testing, toward completion of the specifications so they will become widespread quickly [8].

Edge computing technology, which processes data locally, is also promising as a way to create new value with IoT. Compared with earlier information processing, mainly at either user terminals or in the cloud, edge computing is a technology that aims to create new effects by placing data resources and performing processing at points that are physically distributed between them.

The NTT laboratories began R&D in this area early and are testing ways to use this idea in various fields. One such joint research initiative we have with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is a hierarchical weather simulation system that uses a hierarchical network structure. This system is introduced in the article, “Utilization of Edge Computing and IoT Sensors in Hierarchical Weather Forecasting System,” [9] in this issue.

The continued development and expanding use of IoT means that in addition to many simple IoT devices, high-performance devices such as high-resolution cameras, with accompanying large volumes of data, are beginning to appear. To provide networks that support the use of such sophisticated and high-performance IoT devices, the NTT laboratories are conducting R&D on a data stream assist technology with a set of distributable functions that can achieve transmission for various data flow scenarios. This effort is introduced in the article, “Data Stream Assist Technology Supporting IoT Services,” [10] in this issue.

3.3 Keys to Analytics, Prediction, Security: scalability and ease of use

The potential to create new value using big data analysis and artificial intelligence technologies is promising, but specialized knowledge and optimized algorithms become more necessary as the amount of data handled increases. Security will also need to be strengthened in order to deal with larger and more sophisticated attacks than ever before as IoT development advances. To expand IoT broadly and make it available to everyone as a social infrastructure, it will be important to build environments in which such specialized and complex processing can be used easily and efficiently.

4. Future prospects

Going forward, we will continue to conduct advanced R&D and to collaborate with partners in various fields to create new value, further develop IoT, and expand its use.

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Application for Rehabilitation Medicine Using Wearable Textile "hitoe"

Takayuki Ogasawara, Kenichi Matsunaga, Hiroki Ito, and Masahiko Mukaino

Abstract

NTT, Toray Industries, Inc., Fujita Health University, and NTT DOCOMO have begun trials on patient rehabilitation support using the functional material called "hitoe," which can take continuous measurements of biological data simply by having patients wear it. As innovation progresses in medical and nursing care, it is necessary to improve the quality of rehabilitation, especially for elderly patients, in the recovery progress and return to daily life, and in preventing the recurrence of debilitation. This article introduces new initiatives to develop wearable technology in light of these social issues.

Keywords: wearables, rehabilitation, medicine, smart clothing

1. Rehabilitation during convalescence

Systems for providing medical and nursing care services are being reformed by the government in Japan [1, 2]. As part of this effort, there has been a strategy to reduce the number of hospital beds where advanced, acute medical care has been provided till now and to increase the number of beds that can more fully meet regional medical care needs (**Fig. 1**). Rehabilitation during convalescence plays an important role in these reforms. Patients who engage in focused rehabilitation after receiving acute medical treatment, when their condition first begins to stabilize, can accelerate the recovery of function and improve their activity in daily life. Such rehabilitation can also help prevent patients from becoming bedridden, return them to family and society, and limit recurrences of debilitation. Providing high-quality rehabilitation is therefore an important social issue in an aging society, going beyond the scope of private enterprise. As such, NTT, Toray Industries, Inc., Fujita Health University, and NTT DOCOMO began practical testing to improve the quality of rehabilitation services using "hitoe" wearable technology in February 2017 [3].

2. Smart clothing and "hitoe" functional material

NTT and Toray developed "hitoe," which is a functional material that can take continuous measurements of biological information when a person wears it [4]. The material is created by coating the surface of fibers with a conductive polymer (PEDOT-PSS: poly(3,4-ethylenedioxythiophene):poly(styrenesulfo nate)), resulting in a very flexible, hydrophilic, and durable material that is also electrically conductive [5]. Smart clothing incorporating this material can be used to measure changes in heart rate over long periods of time in a range of scenarios. It can also be combined with other sensors such as accelerometers, and new, higher-order feature values can be computed to expand the range of possible applications in various ways [6–8] (**Fig. 2**). This article describes an example of an application in the area of rehabilitation.

3. Clinical research with rehabilitation patients

The medical effects of rehabilitation can be broadly classified into general effects, in which exercise

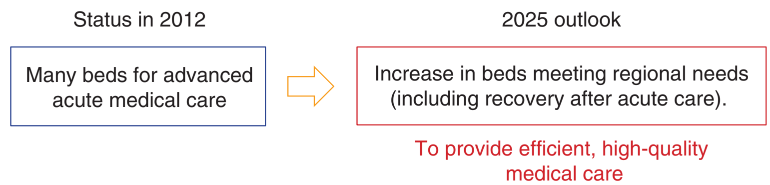


Fig. 1. Innovation in medical care system.

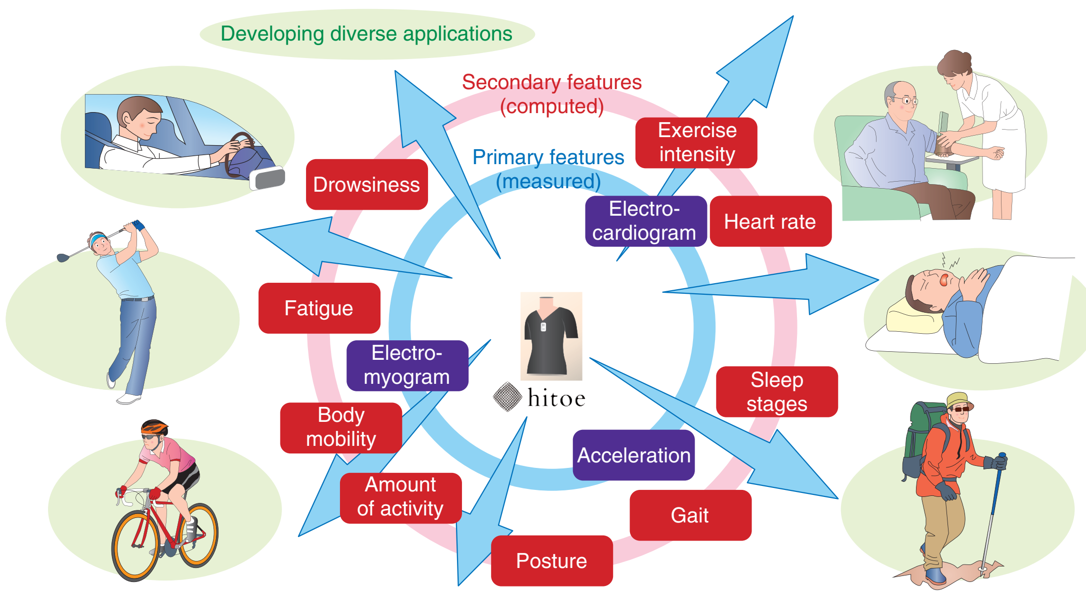


Fig. 2. Expanding applications of “hitoe.”

affects the entire body, and specific effects, which contribute to addressing particular motions or functions in the patient’s life. For general effects, the goal is to affect the whole body by ensuring that a safe and appropriate amount of exercise is achieved in the daily routine in the rehabilitation environment, but there have not been strong, clinical, and measurable indices for this. However, heart rate and activity data can be collected easily using “hitoe” 24 hours a day, and not just during the limited rehabilitation training period with therapists.

An overview of the system is shown in **Fig. 3**. Patients needing rehabilitation wear smart clothing incorporating “hitoe.” Biological data measured from the patient by the clothing are sent to a server through a smartphone or a relay device (an Internet of things (IoT) gateway) in the hospital and can be examined using a viewer. Doctors can use the collected data to evaluate the suitability of the activity in the treatment environment and can evaluate the general effects. The system also gives an understanding of patient lifestyle patterns, so it can help in giving safe and high-quality guidance and managing everyday risks more easily. It could also be useful for developing more comprehensive rehabilitation treatment systems. The components of the system are described below.

3.1 Smartphones

Most wearable devices on the market strive to reduce energy consumption by using simple displays with light emitting diodes and low-energy wireless communication such as Bluetooth so they can operate over long periods of time. Smartphones can be used to maximize the value of such devices. They can convey real-time feedback to patients on a high-quality display and send data to servers on the network using LTE (Long-Term Evolution) or Wi-Fi. Extensibility using applets is also a major benefit. NTT is studying

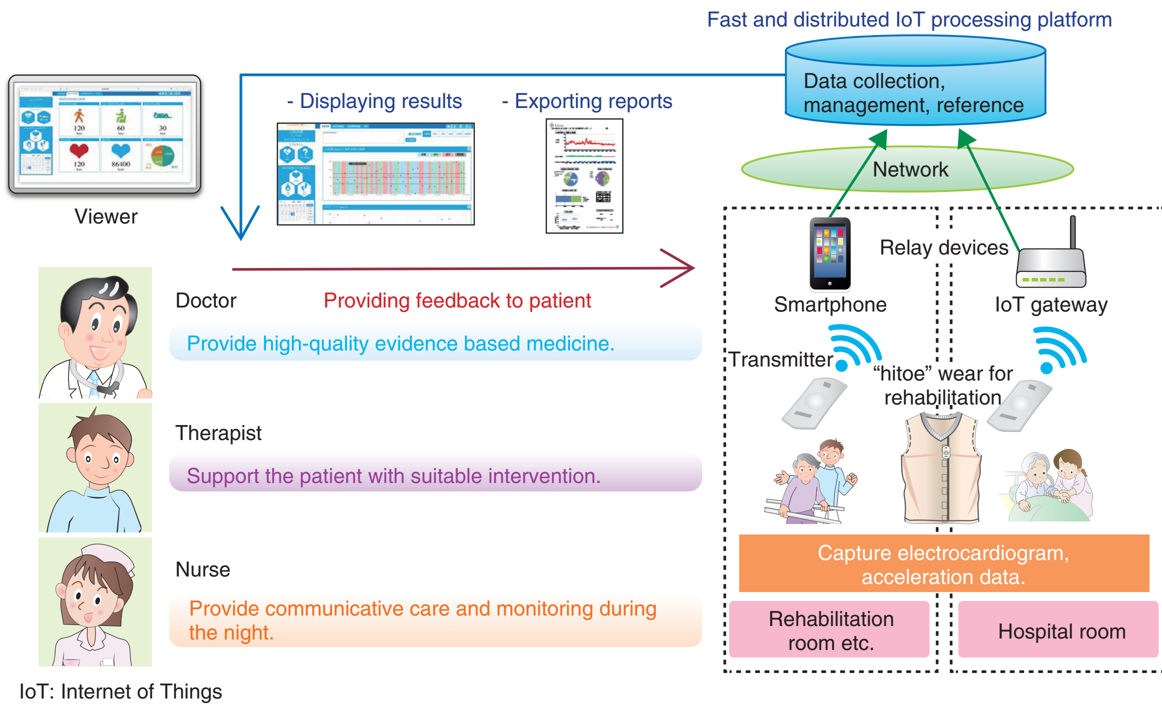


Fig. 3. Rehabilitation support system using "hitoe."

new ways to provide rehabilitation support using smartphones to increase patient motivation and actively encourage exercise.

3.2 IoT gateway

IoT gateways are installed in buildings and other environments. They enable free measurement of sensor data without patients having to hold their smartphones, and they transmit the collected data through the network to a storage device. The NTT laboratories developed an IoT gateway using compact, off-the-shelf hardware and our own time synchronization and protocol control software [9] (**Fig. 4**).

The time synchronization technology provides accurately synchronized timestamp data on the IoT gateway by estimating the time using the Network Time Protocol and correcting for effects including transmission delay on the wireless segments and packet retransmission times when bandwidth is congested, so that times can be recorded accurately for data from sensors that do not maintain time information.

The protocol control technology enables data transmission independent of the type of sensor by converting among transmission protocols with different communication standards and sensor data formats. In the future, these technologies will enable data collection and analysis to be coordinated among a wide range of sensors in addition to "hitoe" with video, location, and other data.

In these experiments, approximately 50 IoT gateways were installed in patient wards in hospitals—in rooms, corridors, rehabilitation facilities, and other areas—to maintain stress-free 24-hour data collection. The amount and frequency of data sent to the server was controlled by processing data signals collected on IoT gateways, which enabled collection of sensor data from approximately 100 patients.

3.3 Data collection, aggregation, referencing

The system handles data storage, aggregation, and referencing on the server. The server part of the system consists of two functions: one to store the biological data gathered from "hitoe" via the smartphones and IoT gateways, and another to process, aggregate, and display the stored biological data. Using both smartphones and IoT gateways to gather data enables the data to be collected continuously and with flexibility, no matter where the patients are. This is not only within the hospital but can include home care after leaving the hospital.

Commercial applications linked with "hitoe" for

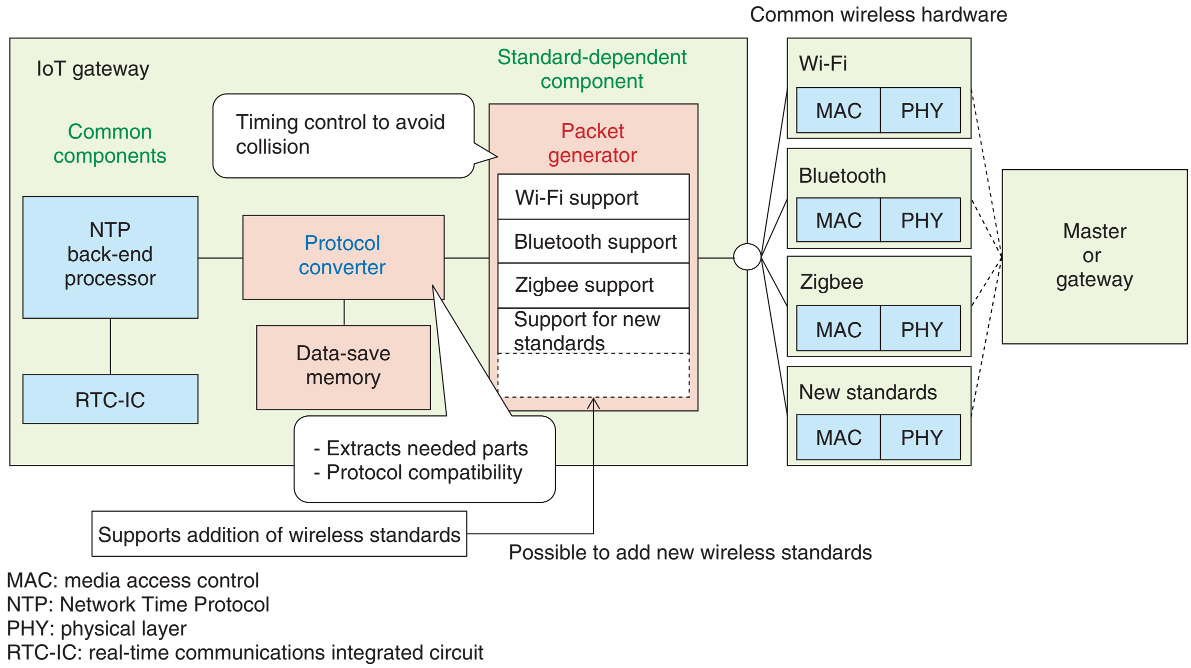


Fig. 4. IoT gateway architecture.

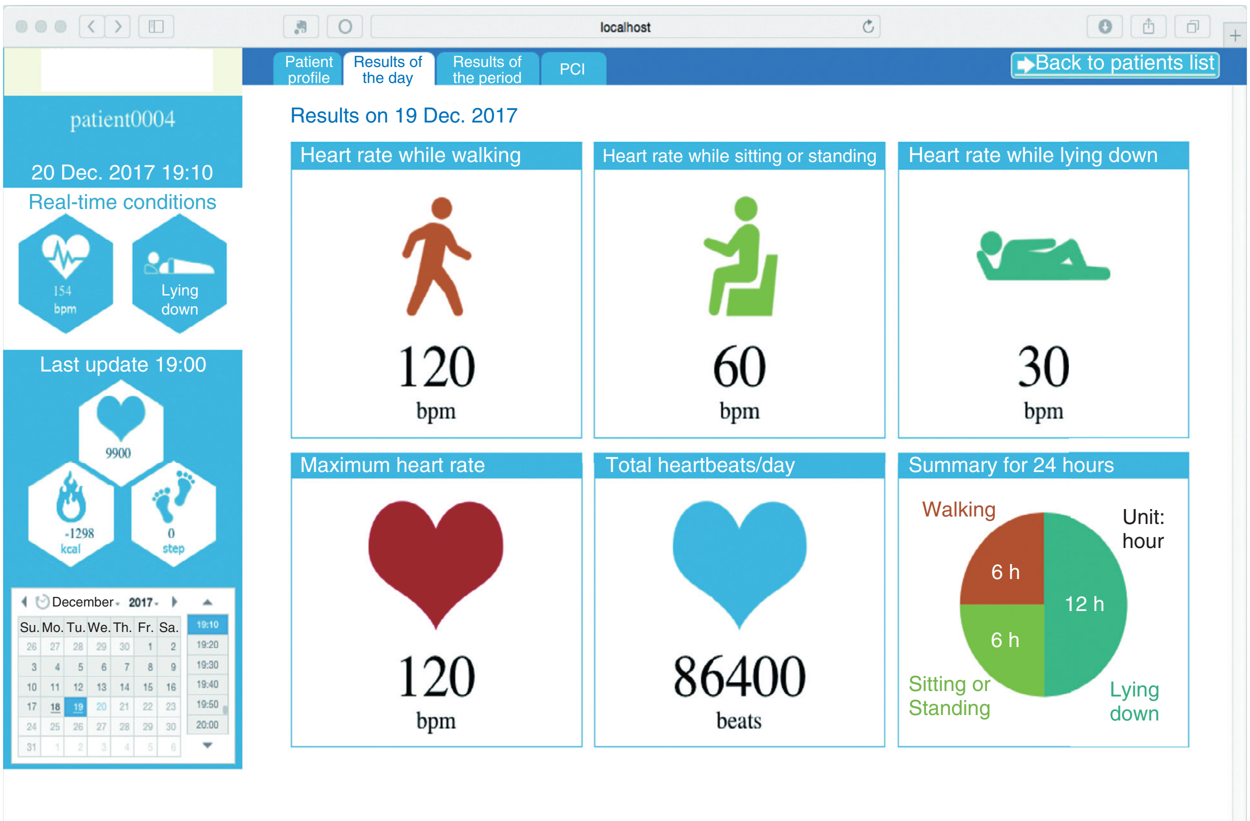
collecting biological data have already been developed, and customer needs can be met using a fast and distributed IoT processing platform [3] that is easy to scale out when the volume of data increases. For our experiments, we implemented an application using the fast and distributed IoT processing platform, with functionality to aggregate and display the collected data. Aggregating and displaying the data enables the data to be used for medical research and makes it possible to provide practical feedback to patients in the actual rehabilitation environment.

To ensure that the biological data collected on the IoT processing platform are suitable for applications in medical research, the system maintains relatively frequently sampled data. For this reason it can be difficult, for example, for a doctor to give feedback to a patient using a real-time graph of trends over longer periods of time. Therefore, for these experiments, we also prepared an application to aggregate and display results, compensating for such difficulties. The aggregation function aggregates biological data stored on the fast and distributed IoT processing platform over set periods of time, calculates statistics such as overall heart rate and total calorie consumptions, and stores the results in a database. The display function then provides access to the biological and statistical data from personal computers connected to the hospital network using a web-based user interface (**Fig. 5**). In addition to providing access to the biological data, the web-based user interface supports entry of comments and downloading of detailed data by doctors.

This system also supports measurement and monitoring of a physiological cost index, which is a typical physiological indicator of performance while walking that is used for patients in physiotherapy. It can be used together with long-term patient monitoring to improve the quality of daily rehabilitation guidance from doctors and therapists and to support the use of data for academic activities.

3.4 Features

The heart rate and state of activity are extracted from sensor data as features for visualizing patient condition. The patient's state of activity can be categorized as lying down, standing/sitting upright, or walking based on computations from data acquired from a three-axis accelerometer in the transmitter attached to the garment (**Fig. 6**). The length of time that patients stayed upright and the number of steps walked are objective indicators to evaluate the patient's condition. An elevation of the heart rate indicates a physiological burden, and this will be used as a personal or subjective indicator.



PCI: physiological cost index

Fig. 5. Example of web user interface.

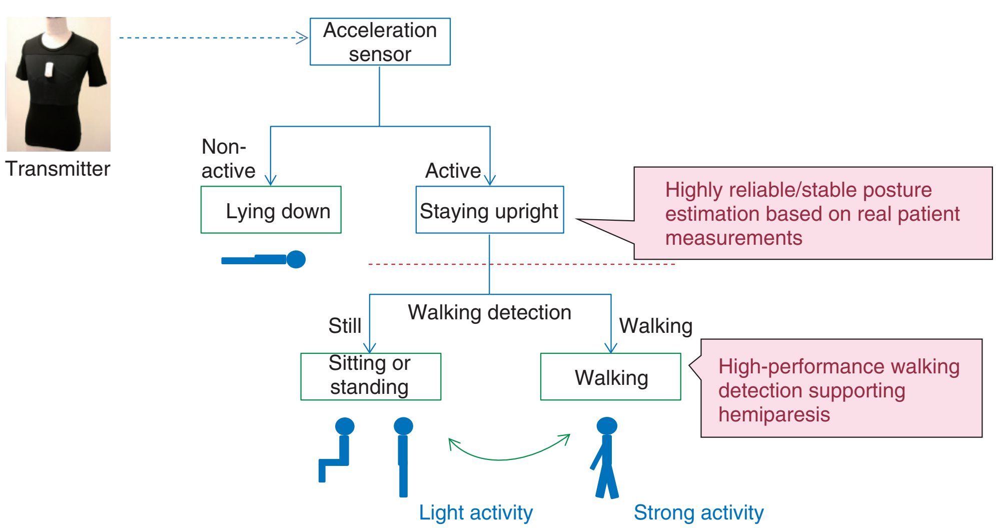


Fig. 6. Activity state estimation using acceleration data.

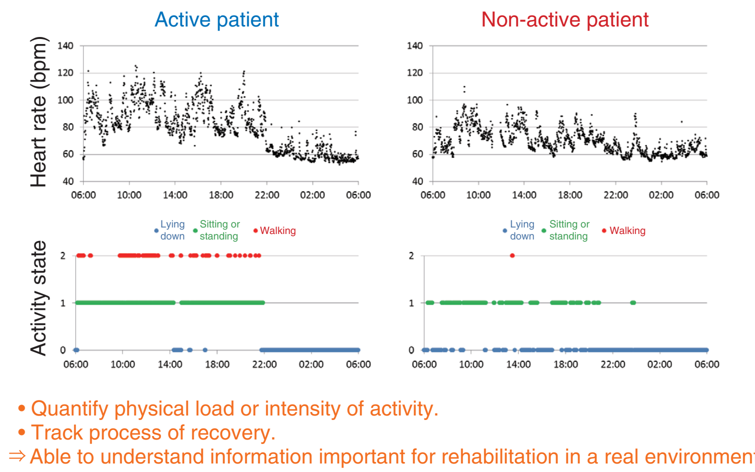


Fig. 7. Example of actual results.

These feature extractions were achieved by using a highly reliable algorithm based on real experimental measurements from various patients. By correlating these types of features, we can obtain detailed information that is important for rehabilitation in real environments, for example, the length of time patients are able to stay upright due to recovery of functionality, and the intensity of exercise patients can tolerate as time passes after their conditions occur. This sort of information is expected to help in improving the quality and efficiency of rehabilitation.

4. Experimental results

In one experiment conducted with this system, measurements were taken for two stroke inpatients with hemiparesis. The results are shown in **Fig. 7**. One of the subjects needed assistance for most daily activities, while the other did not. The differences between the two are clear in the measurement results. The subject not needing assistance was much more active, and there was a strong tendency toward having a higher heart rate while active.

This difference is understandable if we surmise that the subject not needing assistance can use his/her body more easily, making it easier to return to active daily life. However, the system can do more than compare cases of needing or not needing assistance. For cases involving patients who need assistance, when we compare those who are active during hospitalization and those who are more cautious with their activity, it is important to focus on which of these tends to have a better recovery, and why. This is because it could suggest that the general effects we discussed earlier are an important mechanism.

The system also shows the patient's physical condition, so interventions can be optimized for individual patients, and it can provide clues as to the cause if there is a change in condition. We have already conducted measurements with more than 70 patients and have encountered some very interesting cases. We are accumulating studies with this sort of evidence and participating in discussions at medical conferences, and through these activities we hope to develop monitoring methods to improve the quality of rehabilitation.

5. Future prospects

These efforts are aimed at developing systems that provide high-value services to patients and medical treatment providers by proposing monitoring methods using wearable technology and providing medical evidence. In addition to contributing to the development of rehabilitation, we will go beyond rehabilitation in the future, advancing development to reduce the burden on patients and medical providers, including areas such as remote rehabilitation and home support.

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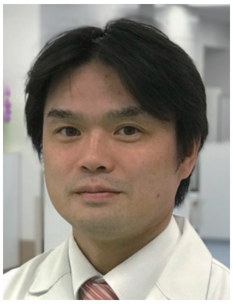

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Wireless Relay Technologies for Monitoring Underground Infrastructures

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Abstract

With the progress made in Internet of Things (IoT) technology, expectations have been raised for IoT services in areas outside the bounds of network coverage such as underground, underwater, and sky environments. We have been developing wireless communications systems aimed at achieving monitoring capabilities of aging underground infrastructures. Our systems make use of wireless relay terminals installed on vehicles or utility poles to efficiently collect data from sensors installed in underground infrastructures. In this article, we introduce two recently developed technologies for radio relay systems that are designed to reduce the costs of installation and operation of the system. One extends the coverage area, and the other reduces power consumption.

Keywords: underground infrastructures, radio relay system, transmitter diversity

1. Introduction

The growth of the Internet of Things (IoT) has been progressing rapidly, and expectations have been raised for IoT services to be provided in areas outside the bounds of network coverage. These include environments underground, under water, and in the sky. Monitoring of aging underground infrastructures such as water pipes is one potential use case. Most water pipes in Japan laid in the era of high economic growth are aging rapidly, and the proportion of deteriorated water pipes is expected to exceed 40% in 2020 [1].

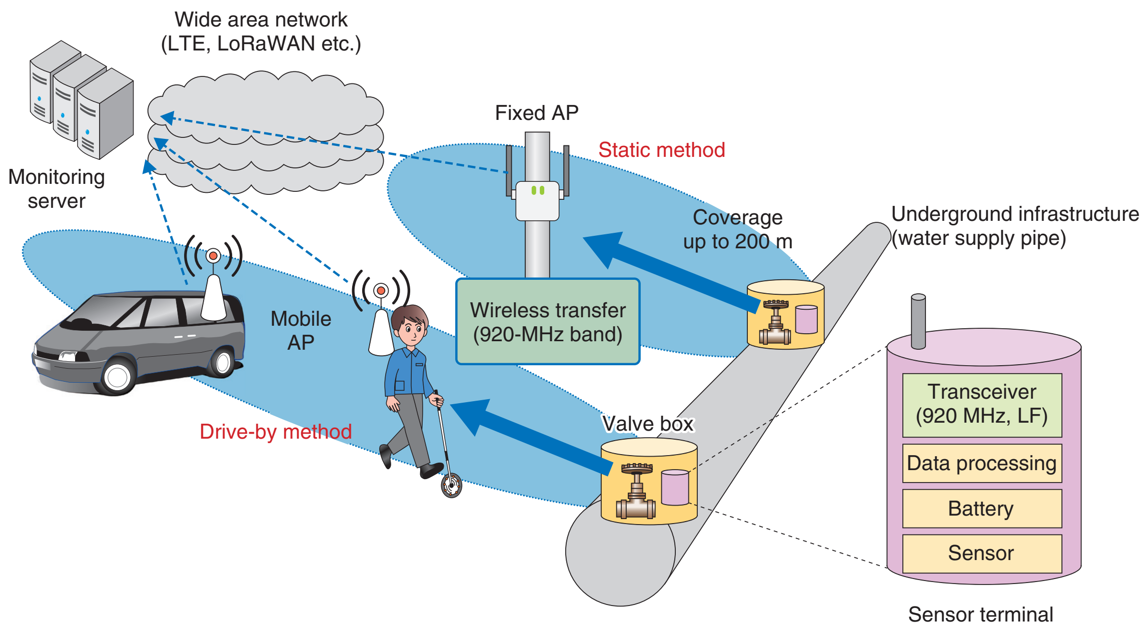
Investigations of water leakage from water pipes as well as maintenance of these pipes currently require skilled engineers, who conduct inspections manually. However, such inspections relying on skilled personnel will become harder to carry out in the future because of a manpower shortage due to the declining birthrate and the aging population. Therefore, the inspection of underground infrastructure making use of IoT combined with various kinds of sensors and wireless communications technologies have been strongly expected for efficient operations.

2. Wireless relay systems for monitoring underground infrastructures

An underground environment such as a water pipe is an enclosed space where the radio propagation path is extremely limited. Thus, radio waves do not travel very far even when compared with indoor environments such as inside buildings. Penetration loss from outdoors to indoors is known to be about 10–30 dB at frequency bands around 1 GHz, which are frequently used in IoT systems [2].

In contrast, the penetration loss from the ground to the valve box of water pipes installed underground is about 50 dB [3]. Hence, it is difficult to accommodate all sensors installed underground by using 4G (fourth-generation wireless systems) and LTE (Long-Term Evolution), which is assumed to be used in outdoor and indoor environments.

Therefore, we have been developing novel radio



AP: access point
LF: low frequency
LoRaWAN: Long Range wide area network, developed by the LoRa Alliance.

Fig. 1. Concept of wireless relay system for monitoring underground infrastructure.

relay systems that efficiently collect data from sensors under ground-level structures by using relay stations installed on cars and on utility poles [4]. A schematic drawing of our proposed system is shown in **Fig. 1**. In radio relay systems, efficient installation and operation of repeaters is important. Hence, we have developed two techniques to achieve this. One technique extends the coverage area of the relay system, which enables the repeaters to accommodate a large number of sensors over a wide area. Consequently, we can reduce the number of relay units installed. The other technique saves power. It enables relay terminals to operate on batteries, which makes it possible to install them anywhere, even in locations without a power supply.

3. Technique for extending coverage area

In wireless communications, the strength of radio waves gradually weakens as the communication distance increases. There are two simple methods to extend coverage areas. One is to improve receiver sensitivity by sacrificing transmission speed. In recently introduced wide area communication systems such as LoRa [5] and Sigfox [6], an ultrahigh sensitivity of –130 dBm or more has been achieved by limiting the speed by up to several hundred bits per second. However, since the required air time, or the running time of a transceiver, becomes longer as the transmission speed becomes slower, the power consumption increases.

The other method is to increase the transmission power. However, this also leads to an increase in power consumption at the transmitter. Therefore, other technologies for extending coverage areas are necessary for battery-powered long-life communication systems such as monitoring systems for underground infrastructures.

We are working to extend the coverage area by focusing on a phenomenon referred to as multi-path fading, which has a peculiar effect on radio communications. Radio waves in general propagate through multiple paths due to diffraction and reflection. Hence, the received signal is the sum of multiple waves, each of which traveled along a different path. With multi-path fading, the reception power level varies drastically depending on the receiving position due to differences in the phase relationship between each path (**Fig. 2(a)**). For example, at receiving positions where two waves with the same phase are combined, the strength of the received signal is 3 dB higher than the signal of a single path. On the other

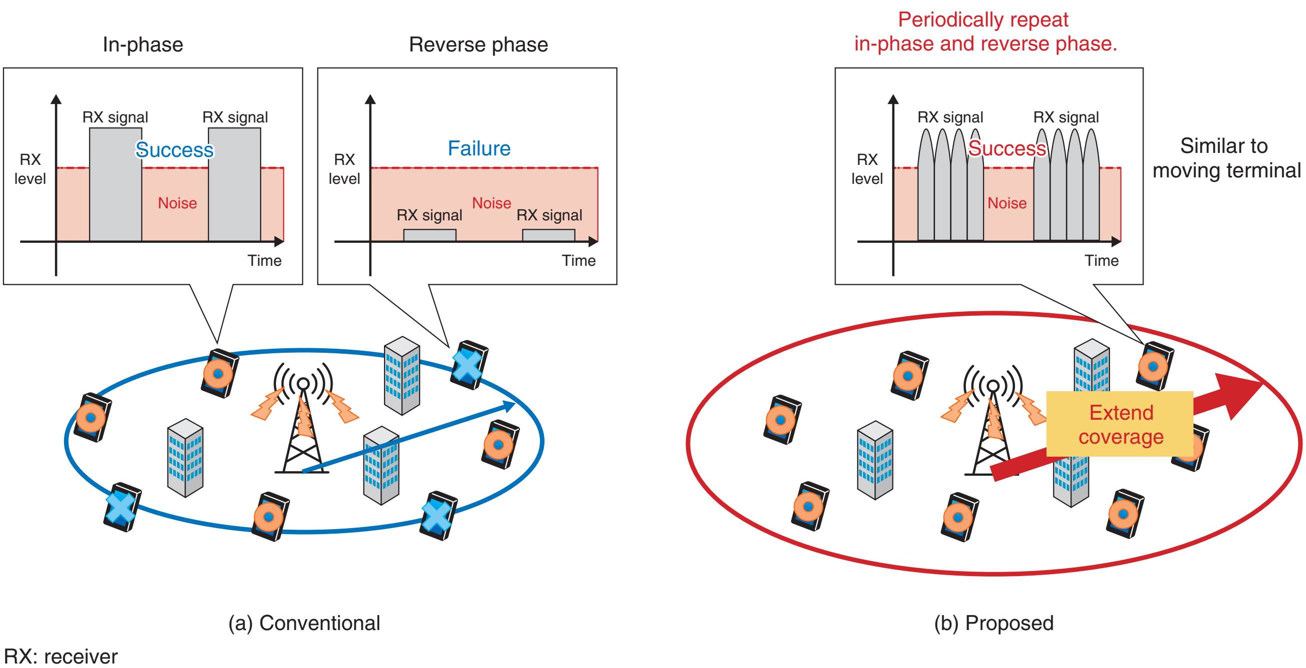


Fig. 2. Technology to extend coverage.

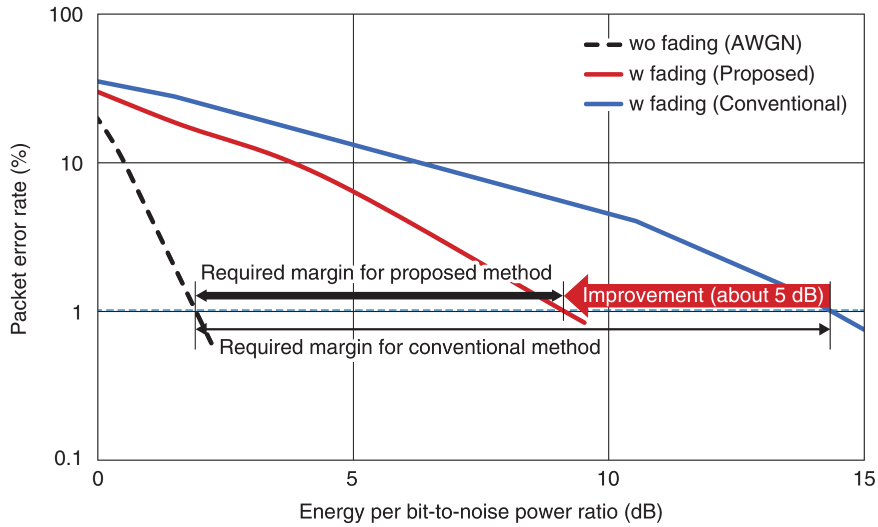
hand, the strength of the received signal significantly weakens at positions where two waves with reverse phase, or a 180-degree difference from one another, are combined. To cope with such fluctuations in strength, wireless communications systems are generally designed with a level margin according to the required quality.

Multi-path fading can cause a level fluctuation at a cycle of one wavelength or less. For instance, in a 1-GHz frequency band, it occurs at a cycle of 15 cm or less. In mobile communication systems where users typically use cell phones holding them in their hand, the terminal moves around naturally by about several centimeters. Moreover, it is possible for a person to autonomously move the terminal when it is not connected with a base station. Therefore, the link level margin that takes into account the effect of multi-path fading can be reduced more than in other communication systems.

In contrast, when the terminal is installed in a fixed position and does not autonomously move, as in a sensing system for underground infrastructures, a large level margin is required since the phase relationship of arrival waves is unchanged. This margin is a factor that limits the communication distance for IoT wireless systems.

To address this problem, we have developed a technology that suppresses the fluctuation of the reception level by transmitting radio waves from multiple antennas simultaneously with slightly different frequencies [7]. This makes it possible to forcibly change the phase relationship of arrival waves at the fixed reception point. This is analogous to generating a slight movement of the terminal. As a result, the arrival waves are not combined in reverse phases. Hence, the required level margin can be reduced, and the coverage area can be extended, as shown in **Fig. 2(b)**. Although the reception level fluctuates greatly within a packet by applying this technique, such distortion can be recovered by a receiver equipped with compensation functions for movement if an appropriate frequency offset is set.

This technology can be applied to various wireless systems. As an example, we experimentally evaluated the effectiveness of this technology when applied to a LoRa system. The relationship between Eb/No (signal energy versus noise power density ratio per bit) and packet error rate (PER) under the multi-path fading environment is shown in **Fig. 3**. The graph shows that the proposed method reduces the required Eb/No at the 1% point of PER by about 5 dB compared to the conventional method. This means that the level margin can be reduced by about 5 dB when designing a coverage area with a 1% dead zone (the ratio of



AWGN: additive white Gaussian noise

Fig. 3. Performance of packet error rate.

terminals that cannot communicate) allowed. In non-line-of-sight communications, the signal strength is mostly inversely proportional to the third power of the distance. Hence, the proposed method can extend the reachable distance by about 1.5 times longer than the conventional method by reducing the level margin of 5 dB.

4. Technology for reducing power consumption

IoT radio devices have achieved a battery life of several years by saving power consumption using the sleep state. However, power saving using sleep modes cannot easily be applied with relay stations since they are always waiting for data to arrive from sensor terminals and must remain in a receive mode. Therefore, another means of reducing power consumption is necessary to extend the battery life of relay terminals.

A method referred to as preamble sampling has been proposed to achieve a way for receivers to wait for data reception with low power consumption [8]. In preamble sampling, the receiver performs preamble detection at regular intervals as it waits for the arrival of data. Meanwhile, before the transmitter sends data, it transmits preambles with longer lengths than the period of receiver detection intervals. This makes it possible for the receiver to receive signals without fail, as shown in **Fig. 4(a)**. With preamble detection, reliable signal detection can be achieved in a short time even in environments where large environmental noise exists, or when the noise power is greater than the signal power. CSL (coordinated sampled listening), which is a kind of preamble sampling, is adopted as the power saving technology in IEEE* 802.15.4e.

However, in an unlicensed band shared by various wireless systems, it is impossible to send a long preamble with a length that is longer than a certain length because the air time of a radio signal at one time is limited by the radio laws of each country. For example, in Japan's 920-MHz band, the continuous transmission time at one instance is limited to 400 ms (4 s). For this reason, an intermittent standby with intervals longer than a certain length cannot be achieved. Hence, reducing the power consumption of repeaters is difficult.

To address this issue, we have developed a technique to activate a relay terminal using multiple transmission of divided preambles. This involves appropriately controlling the transmission length and the transmission interval of divided preambles, making it possible to reliably activate the relay terminals with the shortest time and minimum power while waiting for the arrival of data at an arbitrary reception interval, as shown in **Fig. 4(b)**. The method enables relay terminals to set a long intermittent reception interval that does not depend on the continuous transmission

* IEEE: Institute of Electrical and Electronics Engineers

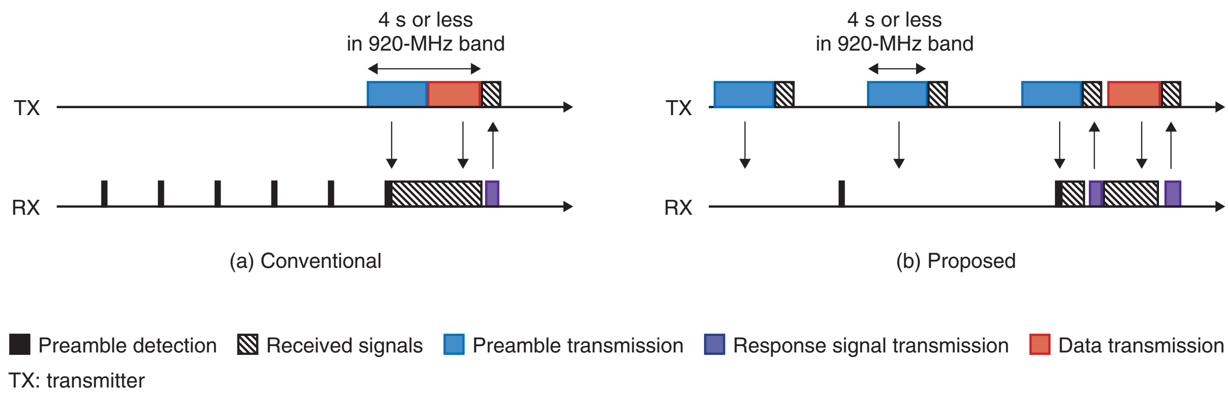


Fig. 4. Power saving standby operations.

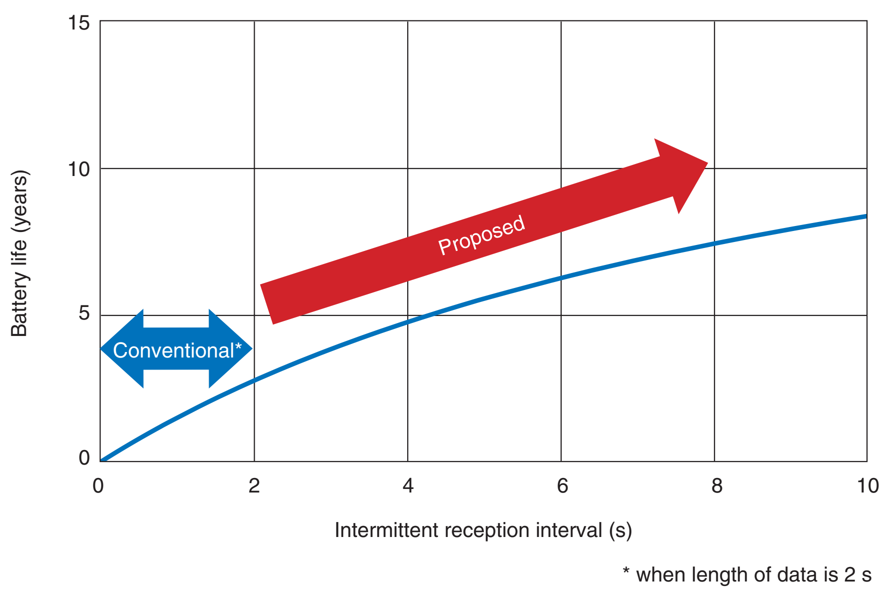


Fig. 5. Performance of power saving technology.

time that is restricted by radio laws. Hence, the repeater can be driven by the battery for several years.

As an example, we conducted an experiment to evaluate the effectiveness of our proposed method for wireless systems using Japan's 920-MHz band. The relationship between an intermittent reception interval and battery life is shown in **Fig. 5**. In the experiment, the battery capacity was 3000 mAh, the current consumption for data transmission and measurement was 0.5 mAh per day, and the current consumption at reception was 20 mA. The period of intermittent reception time was 10 ms. This technique enables repeaters to set a long intermittent reception interval regardless of the transmission time limit. Moreover, a battery life of five years or more can be achieved by setting the intermittent reception interval to 5 s or more.

5. Future work

We will continue to carry out research and development while working in cooperation with water enterprises and leakage research organizations to further advance the technology described here. In addition, because the extension technology and power saving technology introduced in this article are general-purpose technologies independent of the radio system, we plan to promote horizontal deployment to various uses other than underground infrastructure monitoring.

Acknowledgment

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Data Stream Assist Technology Supporting IoT Services

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Abstract

NTT Network Technology Laboratories has been researching and developing data stream assist technology that can be deployed lightly and flexibly to provide a network that supports complex services using Internet of Things (IoT) devices with high functionality and performance. In this article, we introduce technologies that improve the utilization efficiency of the network and the convenience of IoT services by changing the communication protocol, communication timing, and traffic volume according to various multipurpose versions of 4K surveillance camera images.

Keywords: edge computing, IoT services, video surveillance

1. Introduction

Research and development (R&D) of the Internet of Things (IoT) has been accelerating in recent years, and it is becoming more and more common for various devices with communication modules to be connected to a communication network. With the expansion and progress of IoT, progress is being made in techniques that enable visualization of the surrounding environment such as the movement of workers in a warehouse, and remote operation and automation of work tasks, and this progress is expected to improve productivity.

Relatively simple devices such as temperature sensors and power switches are used in many IoT services that are now being provided, but other devices such as monitoring cameras, drones, robots, and VR (virtual reality) equipment with high functionality and performance are also included in the concept of IoT. Such high-functionality and high-performance devices can transmit and receive raw data relating to the state and control of recording media and raw data containing large amounts of information such as video data from devices, and it is therefore expected that services using large-volume data streams will emerge.

At NTT Network Technology Laboratories, we aim to create a network that supports IoT services and to create and provide network technologies that support large-volume data streams and that enable an ICT (information and communication technology)-based society as a whole.

2. Characteristics and approach of IoT data streams

In this article, we define large-volume data streams transmitted from high-functionality and high-performance devices as IoT data streams. There are two key characteristics of these IoT data streams: (1) the large capacity communication occurs intermittently, and (2) different services (purposes) and qualities are required depending on the service provider or end user (**Fig. 1**).

Feature (1) means that centralizing the function that processes the IoT data stream results in extremely biased traffic. For this reason, we believe that an architecture that can minutely expand the minimum necessary functions to distribute the functions is required. In addition, because of feature (2), we believe that it is important to consider not only the sophistication and diversification of devices but also network capabilities in order to meet different services and required qualities.

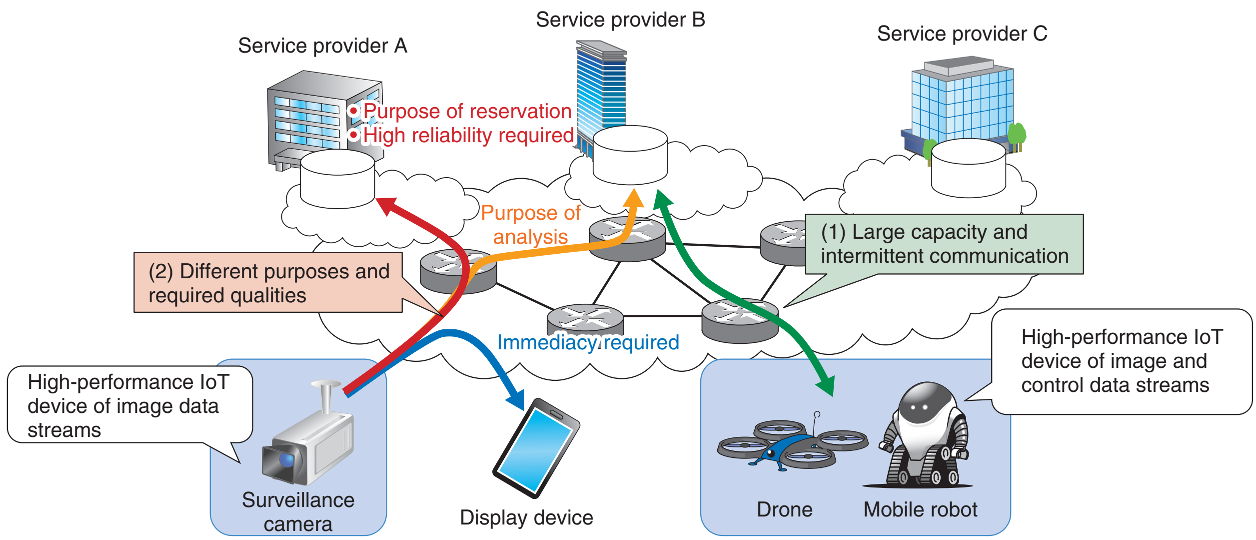

Fig. 1. Features of IoT data streams.

3. Overview of data stream assist technology

NTT Network Technology Laboratories has been studying data stream assist (DSA) technology to improve the convenience of IoT services by enabling the network to assist applications and devices according to the characteristics of IoT data streams.

DSA technology flexibly distributes and arranges the network function modules that operate in lightweight software without preparing dedicated hardware, which intervenes in the processing of communication protocols in the transport and application layers. With this technology, we achieve a simple construction and improve the added value of new services by responding to various applications and required qualities for each service provider that provides IoT services and each end user who uses IoT services.

In addition, to create useful functions and use cases realized with the DSA technology, we have been striving to clarify not only the needs of communication carriers but also the cooperation between a specific service provider and our software/network functions (see section 4). For that reason, we are not only looking at creating innovative elemental technologies but also integrating existing communication protocols and data formats with commercial technology.

4. Study of specific use case (video data stream)

We have been conducting joint research and experiments with the security service provider SECOM Co., Ltd. since 2016 as part of efforts to study technologies for future IoT services. The introduction of various IoT services is anticipated in the future, and it is therefore expected that social value will be created with new IoT services that use images captured by surveillance cameras, which will have higher resolution than existing devices. However, it is also necessary to study technology related to the network that supports such new IoT services.

Currently, much of the video data of surveillance cameras is written to the recording medium inside the surveillance cameras and extracted from the cameras as necessary for analysis and/or storage purposes. Furthermore, when acquiring video via a network, it is necessary to extract multiple videos for different purposes from surveillance cameras; therefore, congestion can occur in the end users' LAN (local area network) and the communication carrier's network.

We investigated how to use images from surveillance cameras more efficiently and developed an architecture that has a function to assist video distribution such as in the edge servers of communication carriers, so that a video data stream can be duplicated on a network and used for various purposes such as analysis, monitoring, and/or storage. To effectively deliver video data to be used in different applications, it is necessary to meet three functional requirements:

(1) a change in the communication protocol, (2) a change in communication timing, and (3) a change in communication volume.

4.1 Functional requirement: communication protocol change

There are two reasons for changing the communication protocol. The first is to adapt to cases where the required quality differs among multiple destinations that want to distribute videos. For destinations where videos will be recorded, real-time access is not required, so we send video data streams using protocols with high data reachability. In contrast, for destinations where videos will be viewed in real time, we send video data streams using a protocol that emphasizes real-time functionality.

The second reason is to adapt to cases where different protocols can be used for the destination and for the sender that delivers the video. There are situations in which the types of protocols that can be used by the receiver are limited due to the fact that there are few protocols supported by certain kinds of software such as the media player operating on a device, and also because users often prefer to use widely popular protocols such as the Hypertext Transfer Protocol (HTTP). With surveillance cameras, it is difficult to adapt to new protocols because the replacement frequency of such cameras is very low. The protocol used also depends on the compatibility between the protocol and the hardware.

4.2 Functional requirement: communication timing change

There are two reasons for changing the communication timing. The first is the need to send video data streams according to the state of the network to the destination where the video data stream will be distributed. When the network is congested, video data streams that are not required for real-time capabilities can be temporarily held back, making it possible to reduce network congestion and avoid retransmission requests due to video streaming/buffering problems.

The second reason is to use the latest video at a high frame rate backwards in time. It is assumed that videos stored in the destination intended for recording are stored at a lower frame rate in order to reduce the storage capacity. However, to quickly confirm the content in videos when accidents or incidents occur, it is desirable to have high frame rate videos. Therefore, the communication carrier temporarily stores video data streams at a high frame rate and delivers the latest video to the destination as necessary, so that the high frame rate video delivery can be performed without increasing the end user's storage capacity.

4.3 Functional requirement: communication volume change

A change in the communication volume may be required depending on the bandwidth of the network to the destination and/or the image processing capacity at the destination. When radio transmission capabilities are included in the network, the bandwidth is often narrowed, and congestion occurs when the sender tries to flow traffic at a higher bandwidth. Also, under the assumption that image analysis is performed by artificial intelligence, which has advanced remarkably in recent years, the number of video frames that can be analyzed per unit time varies depending on the analysis time. For example, if it takes more than 100 ms to process one video frame, image analysis cannot be done at more than 10 frames per second (fps); therefore, no more video frames are needed. Furthermore, even when people watch video in monitoring applications, image delivery exceeding 30 fps is unnecessary.

These three functional requirements must be achieved without transcoding video data at the network side. Many in-market devices or software that enable changes in communication protocols, communication timing, and communication volume have high capacity that enables connection of many surveillance cameras and/or viewing devices, as well as various functions such as object recognition in videos. However, such equipment is expensive, as it requires dedicated hardware or many computational resources. In addition, there are cases where transcoding is done, and changes are made to the image quality and the captured content. Furthermore, as the conventional system architecture is not designed considering dispersed and/or divided functions, the system needs to be deployed on a physical or virtual machine. For these reasons, the computational resources required to operate unnecessary functions, and the scalability of handling an increasing number of IoT devices such as surveillance cameras are issues that need to be addressed.

In contrast to the existing technology as described above, the proposed technology enables us to change the communication protocol, communication timing, and communication volume without decoding the information, by replicating a video data stream and appropriately distributing it to multiple destinations through implementation of a finely decentralized network function.

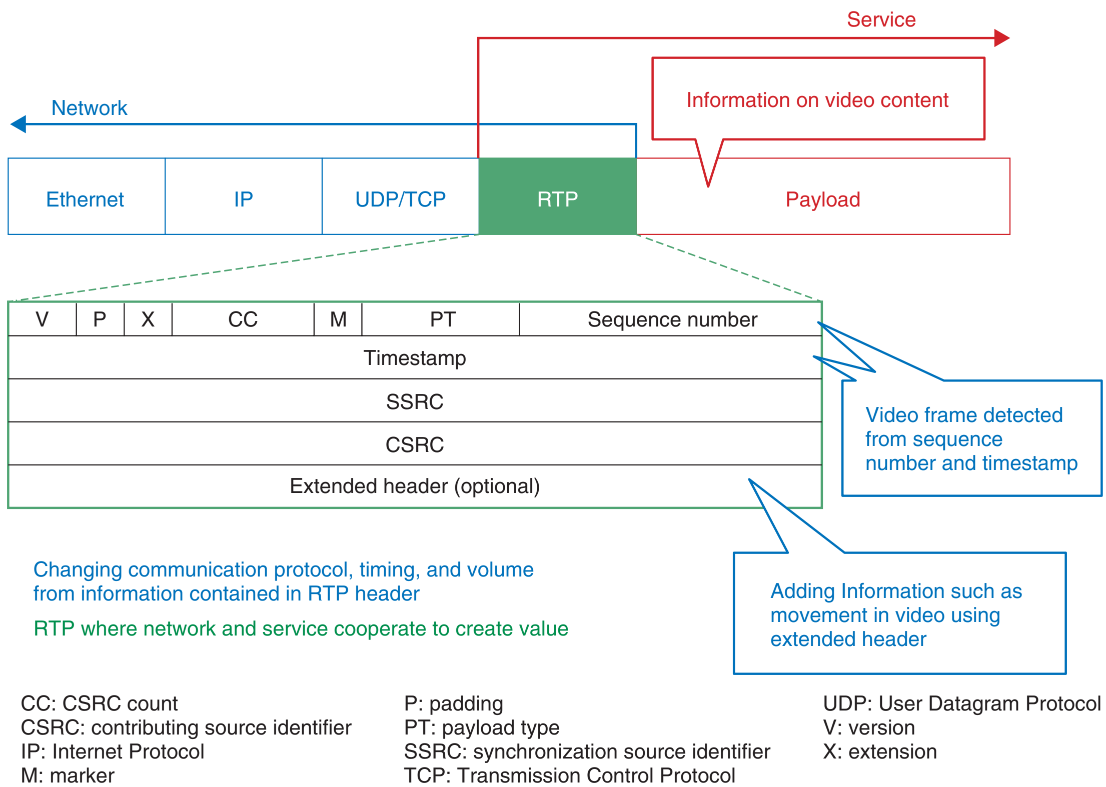

Fig. 2. Application example of network and service cooperatively using RTP.

5. Video DSA technology

This section explains the functions used to satisfy the above requirements and the system that manages these functions.

We have assumed the use of the Real-time Transport Protocol (RTP) as an appropriate layer to construct the functions for the three functional requirements without video transcoding. Most cameras support RTP, which is suitable for transmitting a real-time stream, and the Real-time Streaming Protocol (RTSP), which controls the stream.

A usage example of an RTP header used cooperatively between a network and a service is shown in **Fig. 2**. The RTP header contains information on the timestamp, sequence number, media codec, and other details, but it does not have information on the video content. However, we can detect or obtain the end of the video frame and the time the video frame was generated by using the information in the header. Furthermore, an RTP extension header enables us to add more specific information such as a flag indicating the motion of some objects in the video. Such information can be used to judge whether or not to stream the video, thereby reducing the amount of traffic.

RTP is designed as the protocol above UDP (User Datagram Protocol), but RTSP interleave enables us to utilize TCP (Transmission Control Protocol) as the protocol under RTP. Therefore, we can make the most use of the features of RTP and change the under-layer protocols, the timing of communication, and the amount of traffic without decoding the video. Thus, RTP can be said to be the layer where the network and the service cooperate and create value for each other.

The difference between the conventional approach and our proposed approach in the situation where a video stream is conveyed with changes in the communication protocol, communication timing, and communication volume corresponding to the destination is shown in **Fig. 3**.

In the conventional approach, video streams transmitted from surveillance cameras are decoded and re-encoded at the intermediary entity and then conveyed to each device (Fig. 3(a)). While the existing technology needs to transcode video in the intermediary

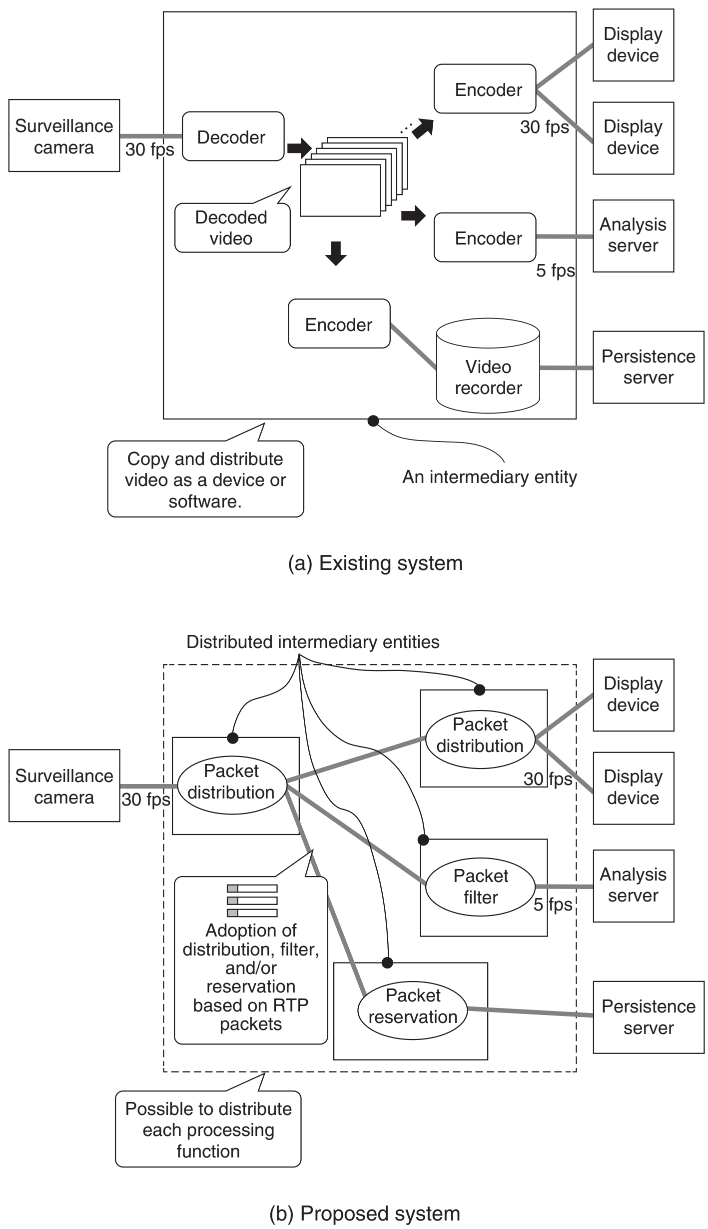

Fig. 3. Comparison of existing and proposed system architectures.

entity, our technology does not do so. Instead of transcoding, our technology changes the communication protocol, communication timing, and communication volume corresponding to the destination by handling RTP packets of one video stream; ensuring *distribution* of flow, which duplicates RTP packets and changes their under-layer protocols [1], applying a *filter*, which drops some RTP packets to adjust the frame rate, and implementing *reservation* of packets to store the video stream as RTP packets, but not as video containers (Fig. 3(b)).

An example of the operation flow of the DSA technology is shown in **Fig. 4**. These functional modules are designed to rapidly process RTP packets. In addition, because this technology handles each RTP packet, if packets are encrypted as SRTP (Secure RTP), the distribution function and the filter function in Fig. 4 do not need to have encrypted keys. These functional modules are constructed to enable pluggability, and they connect to each other like a pipeline.

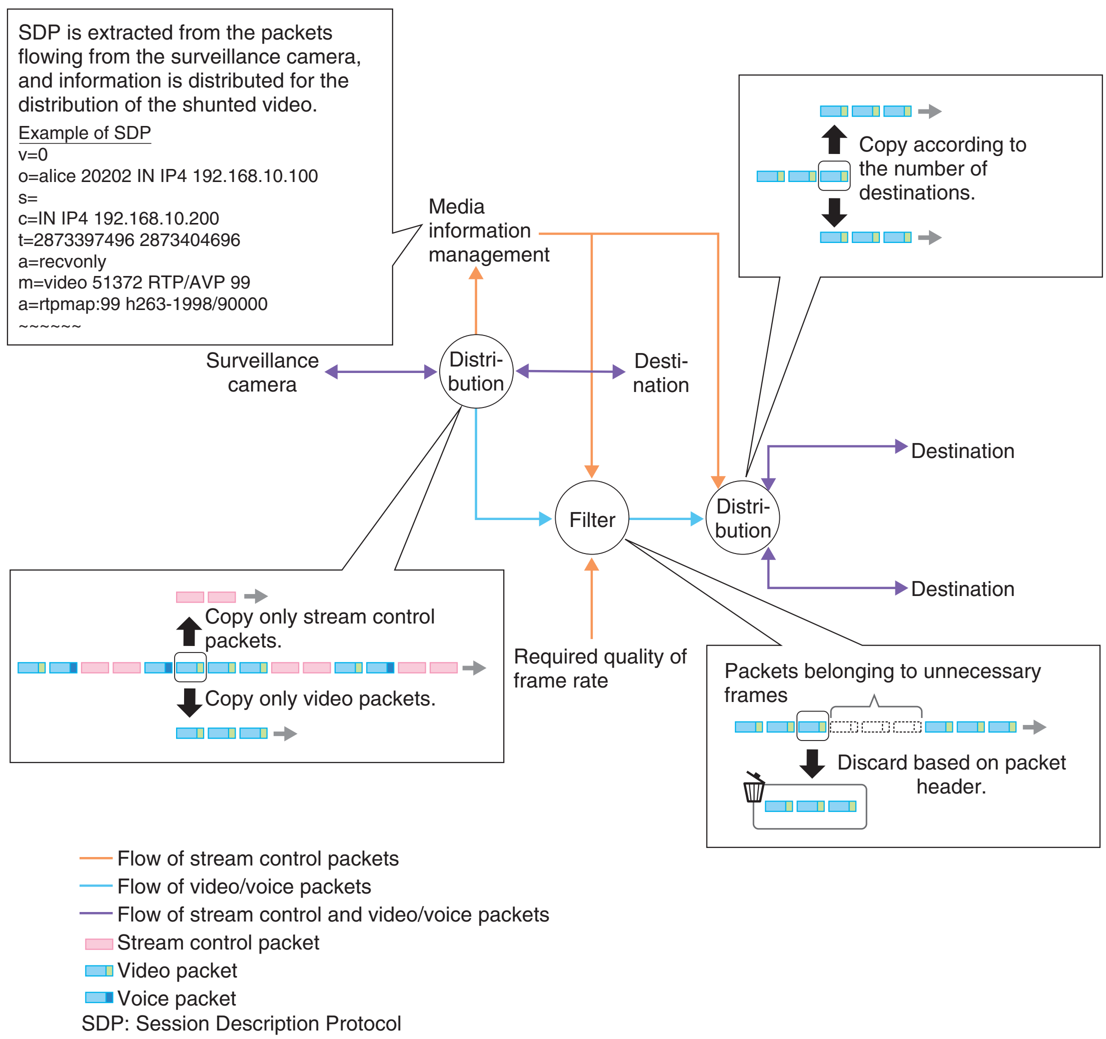

Fig. 4. Workflow of data stream assist.

This enables us to add new functions and to scale out with ease.

There are some advantages in processing packet-by-packet if we can use the semantics of the data format loaded on the RTP packet payload, for example, protocol conversion of JPEG over RTP from RTSP to HTTP or ROS (Robot Operating System), and clipping a specific area from an image.

6. Field trial

To provide our modules dynamically, we have adopted Docker [2] as the environment in which the processes run and Kubernetes [3] as the orchestrator of containers in the current prototype system. In the field trial that began in December 2017 [4, 5], we clustered the physical machines at some central offices (COs) by using Kubernetes and deployed containers dynamically. An overview of the trial is depicted in **Fig. 5**. We confirmed through the trial using 4K quality surveillance cameras that sufficient availability of our proposed approach was achieved by deploying functional modules based on containers, and that utilizing COs (or edge-computing platforms) was effective in terms of low latency and distributed processing.

When the target video data stream is registered by the user of the camera on our system, containers are deployed based on declarations about physical machines and regions, and a process that manages media information regarding the data stream takes place. Then, in correspondence to requests from

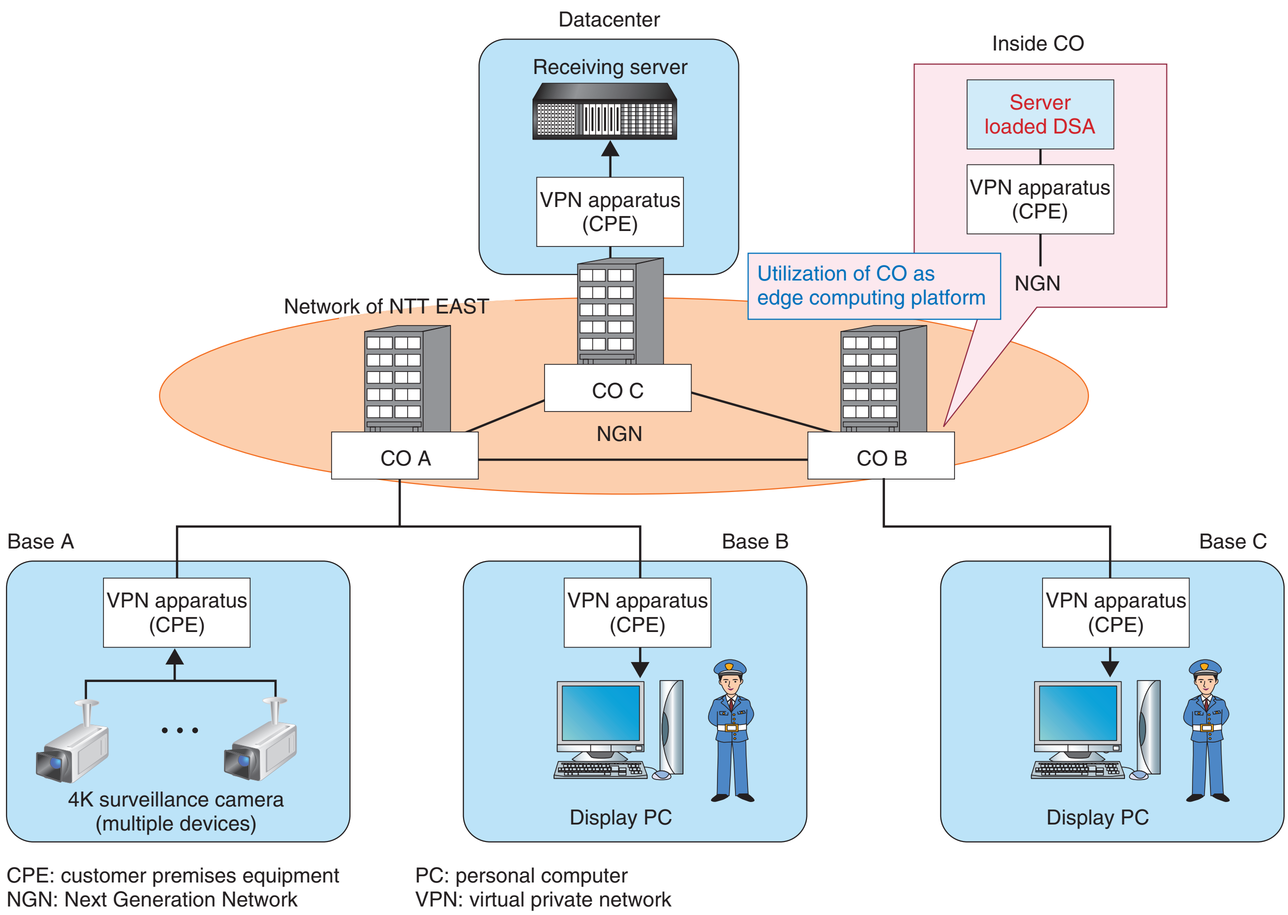

Fig. 5. Network configuration of demonstration experiment.

devices such as a viewing terminal, a function process in a related container boots up and duplicates the data stream. The duplicated data streams are transmitted to other functions, and the communication protocol, communication timing, and communication volume are changed. The cooperative operation of these functions is achieved with the Advanced Message Queuing Protocol (AMQP)*1.

A series of actions, registration of the video data stream, container deployment, and the booting process in response to requests are shown in **Fig. 6**. The location of functions is provisioned by a stream management function.

We demonstrated the prototype system and discussed new use cases for this technology in a project of ATII (APAC Telecom Innovation Initiative)*2 [6]. We also confirmed that it was possible to achieve smart buildings by integrating the technology with existing systems.

7. Future prospects

IoT data streams do not only contain video. A stream of raw data used for actuation and sensing can be used to control robots and drones. At the NTT R&D Forum held in February 2018, the concept of maintaining low latency by utilizing multiple routes for raw data obtained from actuation and sensing of haptic devices enabling *touching* of objects in virtual space was exhibited. In the future, when high-performance devices become more widely available, it is expected that services accompanying new IoT data streams will emerge.

In our R&D, we aim to realize new IoT services in collaboration with service providers by creating new

*1 AMQP: An application layer protocol of message-oriented middleware.

*2 ATII: An R&D initiative to realize virtual infrastructure technology by improving communication services in the APAC (Asia-Pacific) region and creating new network services after 2020.

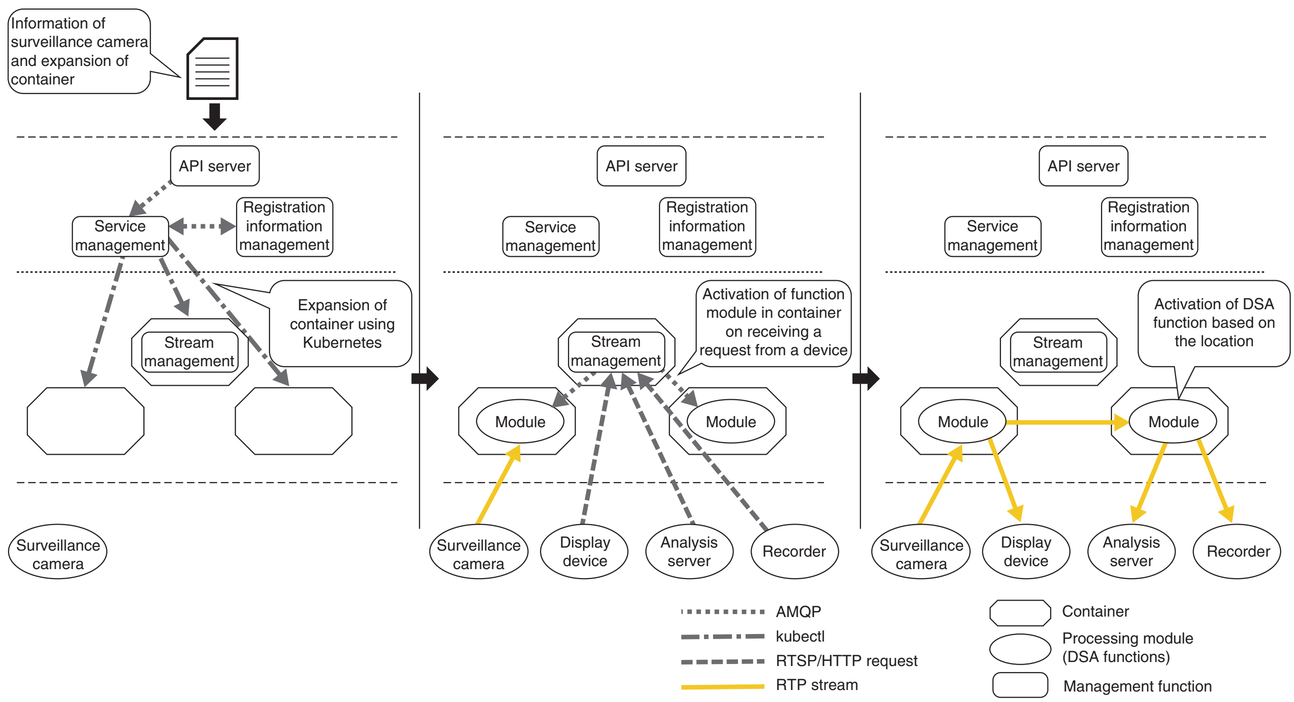

Fig. 6. Container deployment and process activation.

technologies, improving existing technologies and infrastructures, and integrating them.

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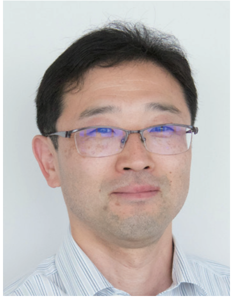

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Utilization of Edge Computing and IoT Sensors in Hierarchical Weather Forecasting System

Ryota Nakada, Koya Mori, and Noriyuki Takahashi

Abstract

NTT and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) began collaborative research on a hierarchical weather simulation system using the Earth Simulator and edge computing in 2016. This project promotes the creation of new technology for the interworking of geographically distributed Internet of Things (IoT) sensors, regionally located edge computing, and the Earth Simulator that is capable of large-scale weather simulation. The project also promotes the development of fundamental technology for supporting various IoT services.

Keywords: edge computing, IoT sensors, hierarchical weather simulation

1. Introduction

The Internet of Things (IoT) has been attracting attention because it connects all kinds of things to the Internet and makes various kinds of sensing possible. The future IoT society is expected to bring innovation in various industries by enabling the collection and analysis of a variety of sensor data via a network independently of time, place, or environment. While some IoT sensors such as thermometers transmit low-volume data, others produce large-volume data such as still-image or video data from infrared cameras. The sensing frequency and the number of sensors installed also vary with the service provided.

From the viewpoint of using sensor data in services, some data are used only regionally, and other data are aggregated for analysis on a national scale in the cloud. One use case that requires such aggregation of data that has different regional dispersion requirements is weather forecasting.

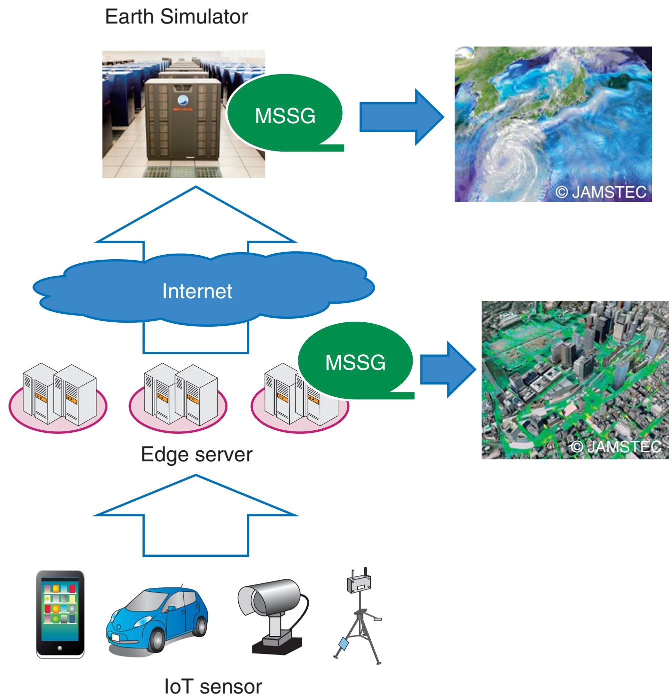
2. Weather forecasting simulation using IoT data

Weather forecasting is an important key in the construction of the IoT society. Highly accurate real-time weather forecast data are expected to be useful in many fields. In addition to obvious applications in the primary industries of agriculture and fishing, applications in the areas of automobile and rail transportation and sports stadium industries are also expected.

A simple way to increase the accuracy of weather forecasting is to increase the resolution of the model. In simulations such as weather forecasting models, the target spatial region is divided into a constant-interval grid, and calculations for each unit of the grid are done according to relationships with the neighboring units. A grid that has smaller units enables a higher-resolution simulation that closely models the behavior of the actual environment, but there is a trade-off between grid resolution and computational load.

For example, for a simulation in three-dimensional space, reducing the length of a grid unit by one-half increases the amount of grid calculation by a factor of eight (two to the third power). It is also necessary to reduce the time interval for the calculations by half, so the total computational cost increases by a factor of 16 (two to the fourth power).

Therefore, highly accurate prediction for all locations in the space requires a huge amount of calculation. However, it is not necessary to make highly



MSSG: Multi-Scale Simulator for the Geoenvironment (MSSG) weather forecasting software.

Fig. 1. Hierarchical weather simulation system.

accurate predictions in all locations. For predictions relevant to the agricultural industry, for example, it is sufficient to cover agricultural land areas, and for automotive transportation, it is sufficient to cover expressways and national highways. If it were possible to achieve highly accurate local weather forecasting simulations in addition to the conventional large-area simulations, it would be possible to provide sufficient weather forecasting at low cost.

Conventional large-area weather forecasting simulations are based on data for large regions; such data may consist of atmospheric pressure distributions and weather satellite images. For local weather forecasting, local on-site data are input to the simulation in real time. It is possible to provide highly accurate local weather forecasts by using IoT sensor data such as local sky images and data from local temperature sensors. Furthermore, the highly accurate local weather forecasting data can be used to improve the accuracy of regional simulations.

NTT and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) [1] began collaborative research on a hierarchical weather simulation system using the supercomputer Earth Simulator*1 and edge computing*2 in 2016 [2].

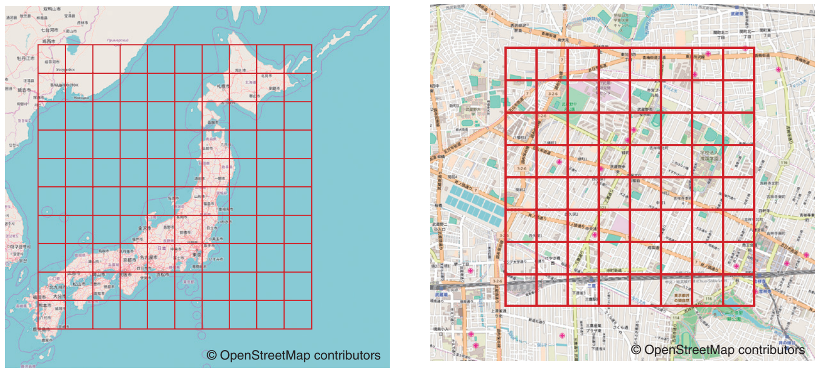
The collaborative research reported here involves construction of a hierarchical weather simulation system that looks toward a future IoT platform by combining IoT sensors, edge servers that serve as specialized regional computing resources, and a large-scale Earth Simulator computing system. We are using that system to test the effect of IoT sensor data in local weather simulations and will continue to work on identifying and solving problems of the system as an IoT platform [3].

3. Hierarchical weather simulation system

The hierarchical weather simulation system (**Fig. 1**) combines IoT sensors, edge servers that aggregate the data from the sensors, and the Earth Simulator supercomputer—all types of equipment that have different

*1 Earth Simulator: A large-scale computing system operated by JAMSTEC that is used for research in various fields of maritime and earth sciences, including predictive global warming models and geological changes.

*2 Edge computing: A distributed computing scheme that places servers between users and the cloud at locations that are physically near the users to enable execution of applications and some of the processing by cooperation between terminals and the cloud.



Calculation range: national scale
Grid size: 100 km scale

Calculation range: city scale
Grid size: 100–300 m scale

Fig. 2. Weather forecasting simulations on various geographical scales by MSSG.

specifications and functions—in a multilevel configuration. The hierarchical weather simulation system is run on the Multi-Scale Simulator for the Geoenvironment (MSSG) weather forecasting software developed by JAMSTEC. MSSG is capable of running weather forecasting simulations on various geographical scales (**Fig. 2**). The specified calculation range is divided into a grid, and the units of the grid serve as units for simulation of temperature, humidity, atmospheric pressure, wind direction, wind speed, sunshine, and precipitation. The grid unit can be set according to the computational resources that are available. If the grid is made smaller for the same amount of computational resources, the simulation is performed on a local scale, and if a larger unit is used, the simulation is run on a regional scale.

Another major feature of MSSG is the data assimilation function, which makes it possible to integrate observation data into the simulation results. The accuracy of prediction by simulation can be improved by inputting observation data within the range of the simulation. Specifically, temperature, wind direction, and other weather data can be assimilated, and in addition, sky image data can also currently be used by MSSG. In the future, it will also be possible to use the assimilation function for a wide variety of data acquired by IoT sensors in weather forecasting.

Next, we consider the role of the hardware in each level of the hierarchical weather simulation system. The top-level Earth Simulator is a supercomputer operated by JAMSTEC and is used for large-scale computations that are required for marine and Earth science research in areas such as global warming and geological changes. MSSG runs on the Earth Simulator and divides the entire globe into a grid that has units of about 10 km for weather forecasting simulations.

The edge servers that constitute the hardware for the middle level of the system are distributed over each region. It is assumed that the edge servers will be located near users within NTT's wired network and mobile network base stations in the future. In our joint research, the edge servers run MSSG in the same way as does the Earth Simulator. For the MSSG on the edge servers, the calculation range is narrowed to a grid unit size of several hundred meters to effectively use the computational resources in performing a local weather simulation.

The IoT sensors used for the bottom level are weather observation sensors, which measure basic weather data including temperature, humidity, precipitation, sunshine, wind direction, and wind speed at fixed time intervals and send the data to the edge servers (**Fig. 3**).

In the hierarchical weather simulation, data are assimilated and exchanged between adjacent levels in the hierarchy. The IoT sensors send data to the edge servers, which assimilate the data and run highly accurate local weather forecasting simulations. The edge servers exchange simulation results with the Earth Simulator. The local weather simulations can obtain boundary conditions for the margins of their calculation ranges by obtaining weather information outside their computation range from the regional weather simulations. The wide-area weather simulations can obtain the highly accurate weather simulation information from particular regions.

After the accuracy of wide-area simulations is

Fig. 3. Weather observation sensor.

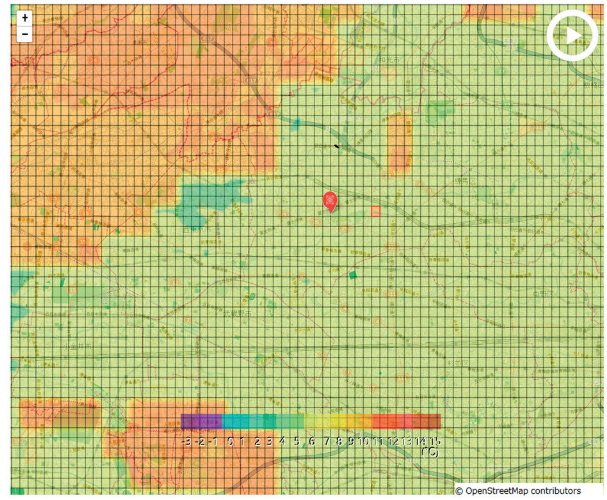


Fig. 4. Result of 300-m grid units of local simulation.

improved by assimilating data from the results of local simulations, data from the improved wide-area forecast results can be assimilated back into the local simulations. The middle latitudes in which Japan is located are known for weather that changes from west to east due to westerly winds. Wide-area simulations can use data assimilated from local simulations to good effect with respect to such temporal changes.

A nationwide distribution of IoT sensors and edge servers would make it possible to provide weather forecast data to locations of high business value such as dense population centers, areas in which primary industries are concentrated, riverine areas, national highways, and stadiums.

4. Effectiveness of hierarchical weather simulation

We used the hierarchical weather simulation system to conduct actual local weather forecasting simulations. The data from weather sensors and the results of wide-area simulation by the Earth Simulator were assimilated by edge servers. An example of the simulation results is shown in **Fig. 4**, which is a heatmap that shows the differences in temperature for the 300-m grid units of a local simulation for a sunny winter day, where we can see that there are temperature changes in each grid unit.

The temperature changes over time for the grid unit indicated by the red pin in Fig. 4 are plotted in the graph shown in **Fig. 5**, where dark blue data points are the forecast results for this hierarchical weather simulation, the light blue data points are the forecast results for a conventional simulation that does not use assimilation data from the sensors or from the Earth Simulator, and the red data points are actual data measurements (ground truth values) obtained by the Automated Meteorological Data Acquisition System (AMeDAS) operated by the Japan Meteorological Agency. We can see from the figure that using assimilation of the sensor data and data from the wide-area simulations results in forecast values that are close to the actual measured values.

5. Future prospect

We have described the principle of a hierarchical weather forecasting system that combines the Earth Simulator and edge computing. One problem for practical application of IoT in weather forecasting is installation of IoT sensors in non-ideal situations. Although the sensors used in the experiment reported

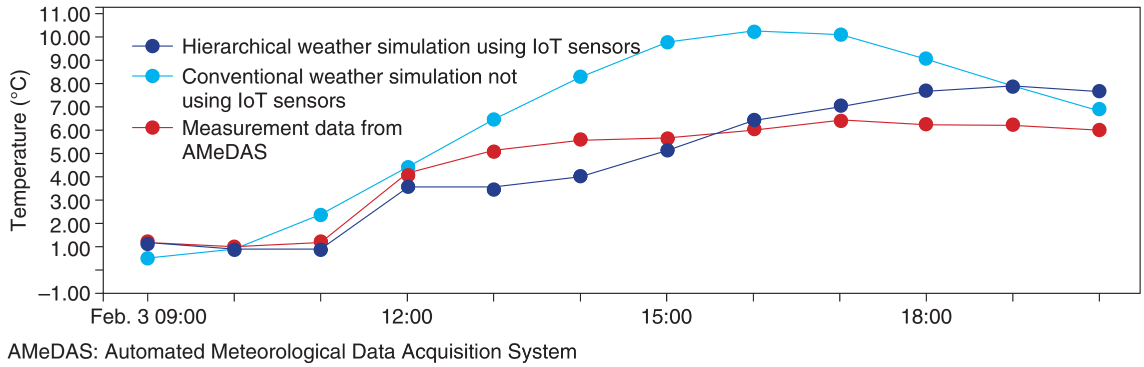


Fig. 5. Comparison of measurement data and simulation.

here were installed in ideal environments, we cannot expect that all of the many IoT sensors used will be properly installed and maintained.

To address this problem, we are investigating methods of determining sensor data reliability through a learning process based on past data to increase the value of IoT sensor data. We will also continue to explore generalized quantitative measures of the true value of an IoT platform for business by testing the effect of increasing the amount of measured data on the amount of sensor data and simulation results to determine how much value is generated with respect to the cost of installing edge computing resources.

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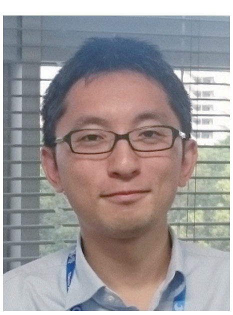

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New Transport QoE-control Technology Enabling High-definition/ High-presence Content Distribution

Takafumi Okuyama, Ken-ichi Endo, Takuto Kimura, Arifumi Matsumoto, Toshihito Fujiwara, and Yasunobu Kasahara

Abstract

NTT is striving to support the growing demand for high-definition video delivery services and is therefore developing technologies for optimizing the deployment of servers for content providers and telecom operators and their communication networks and for providing a new means of delivery control. This article introduces content delivery network technology for achieving economical and high-quality delivery of high-definition, high-presence video content.

Keywords: CDN, QoE control, multicast conversion

1. Introduction

The development of 4K/8K video coding schemes and high-definition user terminals has led to the introduction of services for delivering various types of high-capacity video content over the network. In the existing video content delivery services, content providers cope with the volume of traffic by increasing the number of servers and the network bandwidth in proportion to the product of content volume and number of users. The amount of content and the number of users is expected to increase dramatically in the future market, but the potential expansion in facility resources is limited. It will therefore be difficult to maintain or improve the user's quality of experience (QoE) when viewing video content and to provide enjoyable services at low cost with this conventional approach (**Fig. 1**).

This situation calls for a new mechanism that can improve the efficiency of using and operating facilities, by using more appropriate delivery information. For example, this might necessitate changing the delivery settings according to the type of terminal or circuit and the network conditions while visualizing the user's QoE when viewing video content.

We introduce here high-definition/high-presence content delivery network (CDN)*1 technology that has been developed with the aim of providing next-generation, high-quality services while controlling facility expansion. The element technologies for constructing a CDN that are described here are QoE visualization technology for grasping the user's state of video content viewing, QoE control technology for optimizing the delivery method according to the user's usage format and usage conditions, real-time large-capacity delivery technology for delivering large-capacity live video in an efficient and stable manner, and manifest control technology for achieving flexible control of content delivery.

2. QoE visualization technology

To provide users with an effective and enjoyable

*1 CDN: A network targeting content delivery. Here, a network for delivering video content.

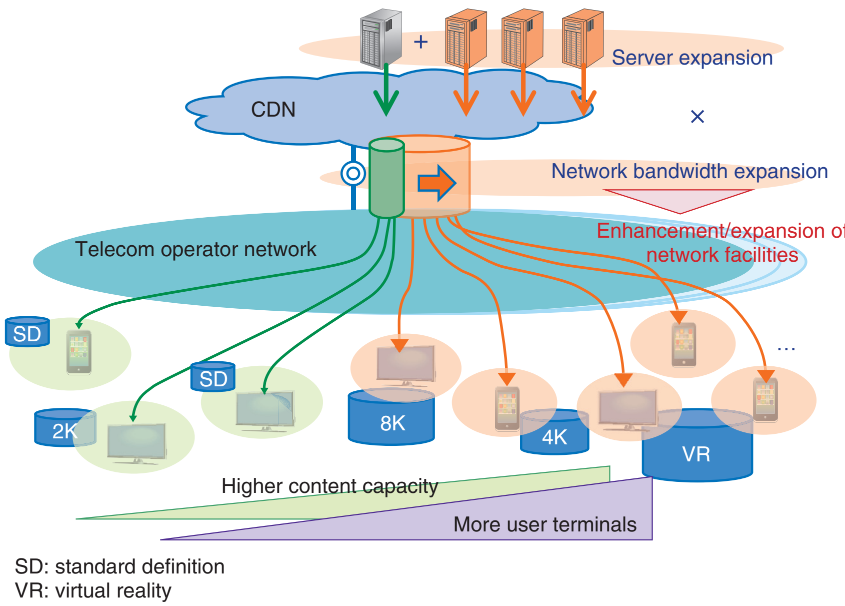

Fig. 1. Expansion of capacity and scale in existing content delivery network (CDN).

video content delivery service, it is necessary to observe the user's QoE when viewing video content and to control the CDN appropriately. This makes the visualization of QoE essential. Hypertext Transfer Protocol (HTTP) streaming*2 and the adaptive bit rate (ABR) system have come to be widely used recently in video content delivery services. In HTTP streaming, the viewing clients play back video content while downloading pre-divided video data (file segments/chunks) in sequence and storing the data in a buffer. Then the ABR system enables the viewing clients to dynamically adjust video quality (encoding bit rate) and download timing (pacing) to maintain the user QoE in accordance with the communication environment.

However, a major deterioration in the communication environment can impair the ABR operation and give rise to rebuffering, in which buffered data are depleted, and playback is temporarily suspended, resulting in a drop in QoE. In addition to such ABR-based autonomous operation by the viewing client, there are also control operations of the delivery server, various devices, and access lines, all of which make the visualization of QoE a difficult task.

The QoE visualization technology introduced here uses a QoE estimation model [1] proposed by the NTT laboratories to quantify the QoE of a video content delivery service using ABR. Specifically, this technology achieves QoE visualization by equipping the viewing client receiving video data with a function for collecting the video/audio encoding bit rate, video resolution, frame rate, and history of rebuffering, and by inputting such information collected while viewing video content into the QoE estimation model. At present, this model can estimate QoE for video content with Hi-Vision (high-definition television) screen resolution (1920 horizontal × 1080 vertical pixels) or less. Research and development of QoE estimation technology for high-resolution video content such as 4K/8K video is in progress.

The visualization of QoE makes it possible to respond quickly to a user's quality inquiry through operational actions such as assessment of conditions and cause analysis. In addition, such visualized information can be provided to content-delivery clients as evidence of the service state.

3. QoE control technology

In video content delivery services, both users and content providers need to maintain quality when

*2 HTTP streaming: A method for achieving live/on-demand video delivery using an ordinary HTTP server instead of a special video server. HTTP Live Streaming (HLS) and Dynamic Adaptive Streaming over HTTP (DASH), also known as MPEG (Moving Picture Experts Group)-DASH, are examples of HTTP streaming that have found widespread use.

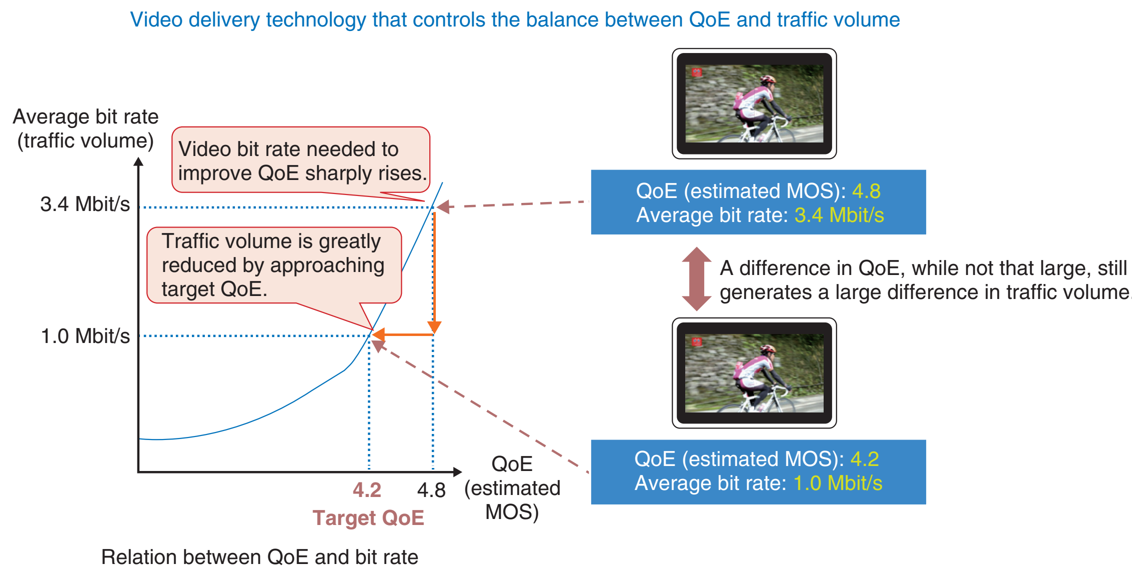

Fig. 2. QoE control technology.

delivering video content and to reduce traffic costs for delivery. The user, on one hand, feels dissatisfied if the quality of video content drops excessively, but if quality rises to a level higher than necessary, the traffic volume increases, resulting in higher communication charges. Therefore, it is necessary to reduce the traffic volume while maintaining a certain level of quality. The content provider, on the other hand, should prepare for a rapid increase in content volume or number of users by reducing the traffic volume within a range that is not unsatisfactory to the user. QoE control technology meets these needs by effectively manipulating the balance as desired between quality and accompanying traffic.

QoE control technology controls this balance by using the relationship between bit rate and QoE. This relationship between traffic volume (average bit rate) and QoE (estimated mean opinion score (MOS)[*3]) is shown in **Fig. 2**. As shown, raising the QoE from 4.2 to 4.8 requires the bit rate to be increased by more than three times from 1 Mbit/s to 3.4 Mbit/s. This tells us that in a high QoE region, a threefold increase in bit rate does not result in a dramatic improvement in QoE. Therefore, we make use of such QoE characteristics by setting a QoE target value given by the content provider or user. Our QoE control technology controls the bit rate of video content to achieve the minimum QoE delivery satisfying that target value. This prevents the QoE and traffic volume from becoming higher than necessary. In addition, performing optimization calculations here makes it possible to select a bit rate that generates the least amount of traffic for the same QoE.

This technology enables the provision of a video delivery service that can keep traffic cost to a minimum while maintaining service quality at a level required by the content provider or user. Therefore, we expect this technology to reduce network load significantly while maintaining QoE. In fiscal year 2017, we performed a field trial using NTT Plala's video delivery service for smartphones and succeeded in demonstrating the effectiveness of this technology in an actual service.

4. Real-time large-capacity delivery technology

Real-time large-capacity delivery technology achieves efficient and stable delivery of large-scale live/linear video content. Ordinary video delivery systems are achieved by sending HTTP-based unicast traffic between the video delivery server and terminals. However, if this ordinary scheme is applied to deliver real-time large-capacity video data as in the live delivery of popular content, viewing demand can

*3 MOS: A value quantifying the level of quality subjectively felt by humans with respect to a target of evaluation (audio/video media, etc.) based on an opinion score as specified by ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) Recommendation P.800.

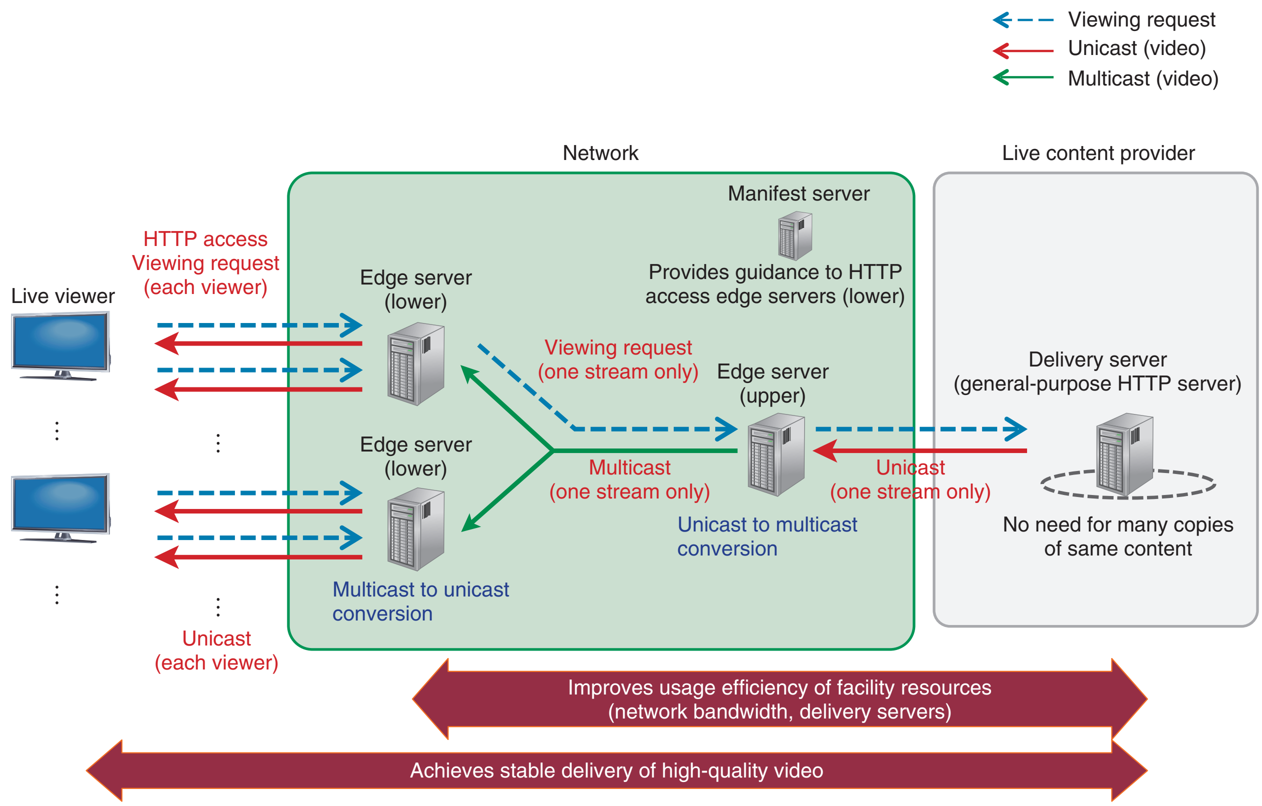

Fig. 3. Unicast/multicast conversion technology.

easily peak, thereby greatly increasing the load on facilities such as delivery servers and the network itself. Such facilities may not be able to bear that load, resulting in a severe deterioration in QoE.

In contrast, real-time large-capacity delivery technology delivers video data via multicast[*4] only in the CDN, while leaving the HTTP-based unicast interface unchanged at each delivery server and terminal. This scheme avoids duplicate delivery of the same video content, which improves facility usage efficiency even for the servers of content providers and achieves stable content delivery (**Fig. 3**).

Specifically, this technology involves placing an upper edge server at the network entrance facing the delivery server, converting traffic from unicast to multicast, placing multiple lower edge servers at the network exit connected to terminals on the opposite side, and converting the traffic from multicast to unicast. The video content is transferred via multicast in the network zone between the upper edge server and lower edge servers. Here, instead of relying on server performance as in the conventional method, data are copied at multicast-supporting routers within the network, which makes for efficient video delivery.

Additionally, for the same video content, traffic from the delivery server to the upper edge server and from the upper edge server to the lower edge servers consists of a single stream regardless of the number of users viewing content simultaneously. This technology can therefore drastically reduce traffic in the network compared to the unicast-only scheme while delivering high-quality video in a stable manner to each user. Moreover, while a system using conventional multicast technology requires delivery servers and terminals that support multicast transmission, this technology enables servers and terminals to use the existing HTTP-based system, thereby easing the burden of procuring and installing new equipment for both content providers and viewing users.

5. Manifest control technology

Manifest control technology can achieve flexible

*4 Multicast: The simultaneous transmission of a single set of data to specific terminals or switches.

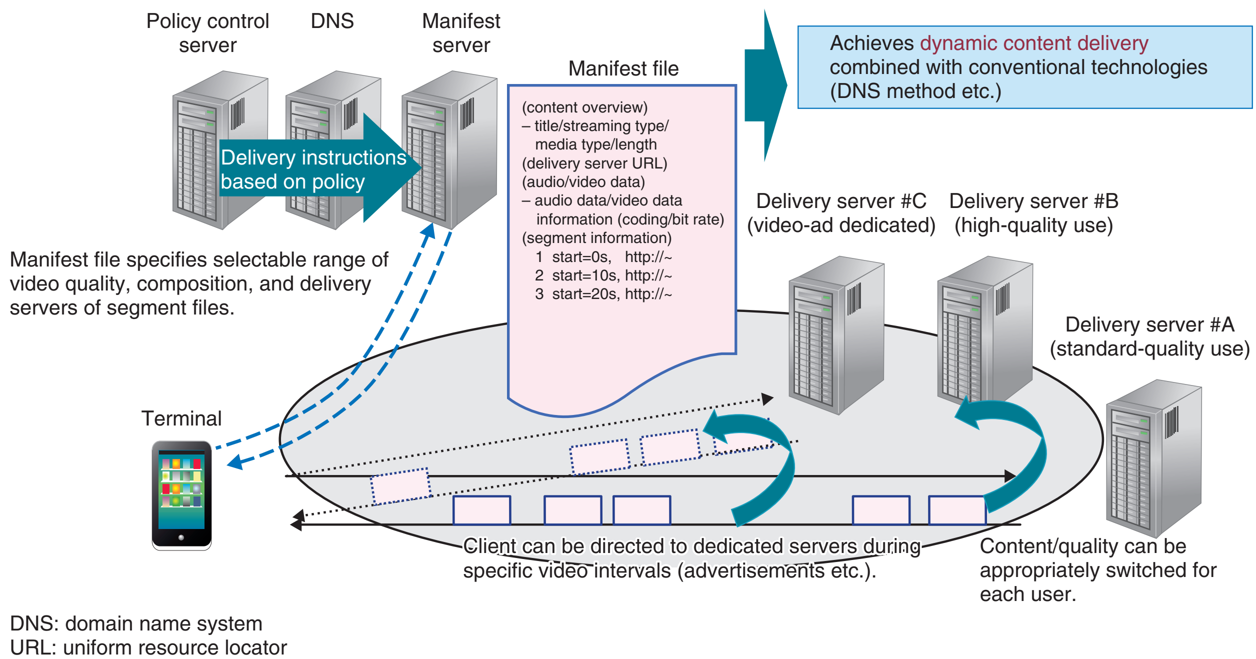

Fig. 4. Manifest control technology.

control of content delivery such as by specifying the bit rate of video content to the client in QoE control technology and directing the client to specified edge servers (lower) in real-time large-capacity delivery technology.

When a user makes a request to view video content, the client will request video-content files. For this purpose, major HTTP streaming schemes use a manifest file (e.g., a playlist in HLS or an MPD (Media Presentation Description) in MPEG-DASH). A manifest file contains information on how the video content is divided into segment files at what levels of video quality and from what locations the segment files should be requested [2]. With manifest control technology, the manifest server, on receiving a request from the client for a manifest file, sends the file based on the client's identification information. This approach achieves efficient delivery control that is dynamically operated (**Fig. 4**). Specifically, manifest control technology achieves flexibility through diverse types of delivery control such as switching content, limiting the selectable range of video quality for ABR, directing the client to dedicated servers during specific video intervals (advertisements etc.), and load balancing of global cache servers.

With conventional technology, the domain name system (DNS) directs the client to the CDN cache servers where video content files are downloaded when the client starts to play back content (DNS method). Here, however, DNS can only roughly identify the client by a group such as Internet service providers, and it takes time for DNS changes to be fixed in the network. Thus, the disadvantage of the DNS method is that it cannot identify the client finely or handle the load balancing promptly. With this in mind, we combined manifest control with the DNS method to achieve scalability and fine control.

6. Future development

We are conducting trials of the video content delivery technologies introduced here and will use the results to continue researching delivery platform technologies that are essential to the development of 4K/8K video coding schemes and high-definition user terminals.

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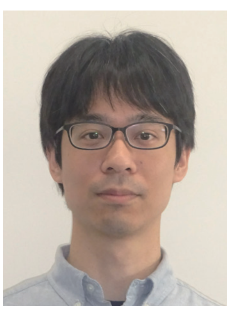

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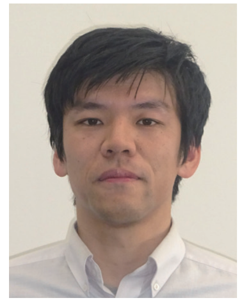

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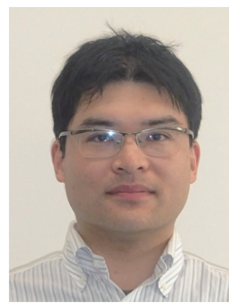

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Standardization of Automation Technology for Network Slice Management by ETSI Zero Touch Network and Service Management Industry Specification Group (ZSM ISG)

Yoshinori Goto

Abstract

The European Telecommunications Standards Institute established a new Industry Specification Group (ISG) on Zero touch network and Service Management (ZSM) that is working to produce a set of technical specifications on fully automated network and service management with, ideally, zero human intervention. This article describes the preparation and outcome of the recent ZSM ISG meetings.

Keywords: ZSM, network slice, ETSI

1. Introduction

The new concept called Zero touch network and Service Management (ZSM) is gaining attention from industry experts in the field of network operation. This is the vision that aims to realize fully automated network operation with ideally zero human intervention, in contrast to the conventional network operation requiring intensive human effort. The ZSM standardization is motivated by several underlying industry trends. For example, introduction of new network services is delayed because of the human involvement required in conventional network operation. New features of network services such as network slicing and edge computing will introduce additional complexities to network operation. Furthermore, maintaining the current level and number of network engineers is expected to be increasingly difficult due to demographic changes, particularly in developed countries such as Japan.

However, an unprecedented level of automation will become possible thanks to the development of new technologies such as network functions virtualization (NFV) and artificial intelligence. In view of these trends happening in the industry, the vision of ZSM has been discussed among members of the industry, who agreed to request the European Telecommunications Standards Institute (ETSI) to establish a new Industry Specification Group (ISG) to discuss this emerging subject.

2. Preparation for the new ISG

Preparation work for the new ISG on ZSM started in the spring of 2017. Employees from Deutsche Telekom, Ericsson, Hewlett-Packard Enterprise, Huawei, IBM, Intel, NEC, Nokia, NTT, NTT DOCOMO, Sprint, Telefonica, Viavi Solutions, and ZTE volunteered their time in this activity. Mr. Klaus Martiny of Deutsche Telekom led this work. The proposal to establish the new ISG was completed in November 2017 and approved by the ETSI Board.

In parallel with this, employees of telecom operators volunteered to produce the whitepaper that describes the motivation, industry trends, the necessity of standardization, and priority items of ZSM, which is available on the ETSI website [1]. ZSM is targeted for 5G (5th-generation wireless systems), particularly in network slice deployment. NTT has contributed to making this one of the directions of ZSM ISG.

3. Discussion at ZSM meetings

The discussion topics and outcomes of the meetings held by this working group are described in this section.

3.1 Kick-off meeting

The kick-off meeting of ETSI ZSM ISG was held at the ETSI headquarters in Sophia-Antipolis, France, from January 10 to 12, 2018. This was only one month after the official establishment of the ISG. Joining the kick-off meeting were 42 experts from 23 companies around the world, and 28 contributions from members were submitted. These contributions introduced the ideas of automation of network operation as well as proposals on the work methods of the ISG.

The first task of the kick-off meeting was to elect the ISG Chair and Vice-Chairs. There was a consensus among the participants that Mr. Martiny Klaus was the right person to lead this ISG because of the astute and effective leadership he demonstrated during the preparation work. Thus, Mr. Klaus was elected as Chair of the ISG. There were three candidates for two Vice-Chair positions, and thus an election was carried out. Voting rights in the election were limited to the Founding Members, which are the companies listed as supporting companies, including NTT, in the proposal of the establishment of the ISG. This privileged status given to the Founding Members enabled NTT to push its idea highlighting network slicing as an important subject of the ISG.

In this election, NTT contacted the three candidates and asked them to support the network slice proposal. All the candidates showed their support for the proposal from NTT. This is a good example that early involvement is critical for gaining influence in standardization work. The election was held, and Mr. Toche Christian of Huawei France and Ms. Sprecher Nurit of Nokia were elected as Vice-Chairs of ISG.

Most of the meeting was spent on brainstorming discussions on key concepts of ZSM. In the preparation work, the experts had already reached a common understanding on the objective of ZSM standardization as described in the whitepaper. However, even among such experts, there were still various opinions on the details of ZSM such as, for example, candidate technologies, likely use cases, and the relationship with other technologies. Even a formal definition of ZSM was heavily debated by the experts.

Furthermore, there were newcomers who were not involved in the preparation work but who joined after the ISG was officially established. Some of these experts are not regular participants in telecommunication standardization efforts but work in other industries such as the computer industry and have different backgrounds. This was a good exercise to get to know each other and create a constructive atmosphere.

ZSM ISG established the Network Operator Council (NOC), for which participation is limited to network operators. NOC is an advisory group expected to provide recommendations to the ZSM ISG from the viewpoint of network operators, although it has no binding power on the outcomes of the ZSM ISG. In the NOC meeting held as part of the ZSM ISG kick-off meeting, Dr. Khan Ashiq was elected as NOC Chair, and Dr. Manning Serge was elected as NOC Vice-Chair. The telecom operators in the NOC meeting exchanged their views and expectations of ZSM ISG.

At the end of the meeting, the Work Items (**Table 1**) were approved based on the discussions during this kick-off meeting. Network slice was identified as an important subject in ZSM; therefore, several Work Items refer to this issue. A study on automation technology was also included in the Work Items. Standardization work usually starts with requirements followed by architecture. The ISG follows this format, and these items are given high priority. ISGs in ETSI produce two types of deliverables, Group Specifications (GSs) and Group Reports (GRs). A GS is a normative document that defines the technical features of the system being discussed using binding terms such as “shall,” “should,” and “may.” A GR is an informative document that gives useful information about the system.

3.2 Second meeting

The second meeting was held at the Nokia Training Center near Helsinki, Finland, from March 13 to 15, 2018. There were 45 experts from 26 companies participating, and 35 contributions with technical

Table 1. Work Items of ZSM-ISG (as of March 2018).

Work Item	GS/GR	Title	Rapporteur	Timing	Remark
ZSM001	GS	Use Cases and Requirements	Michael Klotz (Deutsche Telekom)	Nov. 2018	
ZSM002	GS	Reference Architecture	Uwe Rauschenbach (Nokia)	Sept. 2018	
ZSM003	GS	End to End Management and Orchestration of Network Slicing	Lan Zou (Huawei)	Nov. 2018	Discussion started in May 2018
ZSM004	GR	Landscape	Jinhua Wu (ZTE)	Nov. 2018	
ZSM005	GR	Means of Automation	Andreas Krichel (Hewlett-Packard Enterprise)	June 2018	
ZSM006	GS	Proof of Concept Framework	Klaus Martiny (Deutsche Telekom)	Apr. 2018	Approved to start at the second meeting

GR: Group Report
GS: Group Specification

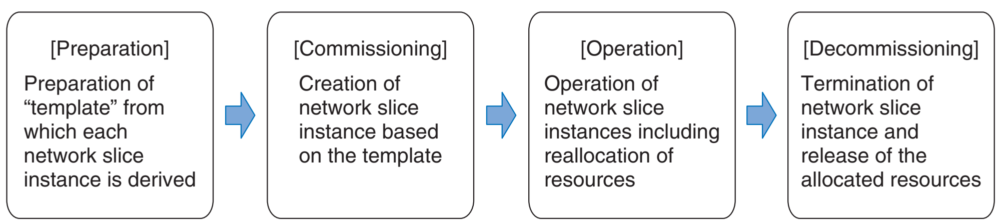

Fig. 1. Lifecycle management of network slice.

proposals were submitted. Among them, 18 contributions addressed scenarios and requirements, which were major topics at this meeting.

NTT submitted two contributions on network slice: lifecycle management of network slice, and isolation management. The basic concept of lifecycle management of network slice is defined in 3GPP (3rd Generation Partnership Project), a standards developing organization for mobile communications systems. As shown in **Fig. 1**, this concept consists of four phases: preparation, in which a template is prepared to be utilized to make network slice instances; commissioning, in which a network slice instance is produced based on the template; operation, in which the slice customer operates its own network slice instances including reallocation of resources; and decommissioning, in which the network slice instance is terminated, and allocated resources are released.

NTT explained that all phases of lifecycle management of a network slice require complicated operations such as finding relevant resources, reserving the needed amount of resources, and reallocating unused resources. Although there was a general understanding on the use of ZSM in slice management among the participants, the NTT contribution presented a clear rationale with detailed explanations. The proposal was accepted with minor updates based on the constructive discussion.

Isolation is a key characteristic of network slice and refers to the independence between network slice instances. However, there has been no agreed formal definition, and confusion has occasionally occurred in standardization discussions. The term *isolation* has been used to describe the situation where no interference occurs between radio or optical signals in the field of radio communications and optical transport. In the initial stage of discussion of network slice, a suggestion was made to apply this well-established definition of isolation. However, ensuring complete isolation, which is without any interference between network slice instances, is too difficult to achieve due to the characteristics of packet-based networks.

In view of this point, NTT proposed a new concept of network slice isolation that is more realistic if ZSM can successfully achieve certain capabilities. The proposed network slice isolation is the situation where negative impacts on network slice instances from other overloaded network slice instances are limited within the permissible level according to the requirements of the slice customer and its application

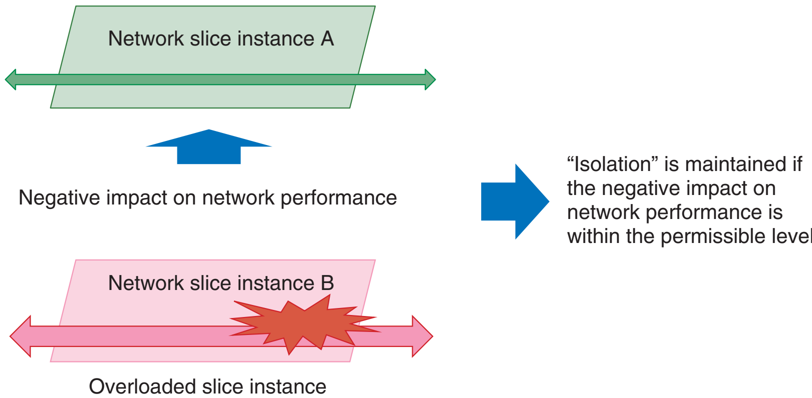

Fig. 2. Concept of isolation of network slice instances.

(**Fig. 2**).

This new concept drew attention from the participants and initiated some discussions. One of the discussions focused on how to handle a shared resource such as PON (passive optical network) or CATV (cable television) in the context of network slice isolation. In fact, the issue of resources shared among different slice customers is one of the challenges in network slice management, and substantial complexities are involved. NTT explained that ZSM should target this challenge, and the proposed approach was the starting point of this discussion.

Besides the NTT contributions, there were many contributions that addressed network slice from different viewpoints. The momentum for network slice discussion therefore increased during this meeting.

The term *ZSM* was used in the ZSM ISG as well as in the preparation work without a clear definition. The lack of a formal definition caused confusion during the discussion, and the meeting was therefore suspended so the term could be clarified. To avoid any further delays, the use of the "ZSM framework" as the formal expression for the technology to be discussed in the ISG was agreed to in the second meeting. The NOC played an important role in establishing this formal definition of ZSM.

The architecture of ZSM will illustrate how the entire ZSM system is divided into sub-level components and will indicate functions within the system and interworking with external functions/components. The architecture will be discussed after a set of scenarios and requirements are identified. The participants in the second meeting discussed the architecture principles that will guide how the architecture is illustrated. The concepts of modularity, extensibility, scalability, model-driven, open interface, closed loop management automation, security, authentication, and authorization were discussed and agreed.

The proof of concept (POC) is increasingly being recognized as an important step in standardization efforts. ZSM ISG is also undertaking the standardization of POCs to promote further standardization activity and to encourage implementation of the produced specifications. The guidelines and general procedure of POCs were discussed in the second meeting. A POC in ZSM is expected to follow current best practices such as having a POC team consisting of more than two vendors and one telecom operator, as already established in NFV and multi-access edge computing.

4. Future plan

Subsequent meetings have been regularly held via computer since the second meeting. The meeting frequency was reduced from weekly to every two weeks, but the discussions have been so active that some contributions have had to be carried over to the next discussion due to a lack of time.

The third meeting was held in Shenzhen, China, in June 2018, and the fourth meeting will be held in Kansas in the United States in October 2018. The current Work Items will be concluded by the end of this year. At that time, ZSM ISG will reveal how ZSM will achieve automation of network operation and how this technology will help the business operations of telecom operators.

Reference

[1] Zero-touch Network and Service Management – Introductory White Paper,
https://portal.etsi.org/TBSiteMap/ZSM/OperatorWhitePaper

Trademark notes

All brand names, product names, and company names that appear in this article are trademarks or registered trademarks of their respective owners.

Yoshinori Goto

Senior Research Engineer, Network Technology Project, NTT Network Technology Laboratories.

He received a B.E. and M.E. in applied physics from Tohoku University, Miyagi, in 1992 and 1994. He joined NTT Basic Research Laboratories in 1994. He has been researching and developing cable television systems, Internet protocol television (IPTV), and machine-to-machine technology. He has been engaged in standardization work for IPTV in the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) as a member of the IPTV Focus Group and Global Standards Initiative since 2006. He has also served as Rapporteur of Question 11 of ITU-T Study Group (SG)9, Questions 5 and 25 of ITU-T SG13, and Question 21 of ITU-T SG16. He has been a Vice-Chair of ITU-T SG13 since 2013. He is a member of the Institute of Electronics, Information and Communication Engineers.

Completely Rewriting Industry's Understanding of Transmitting High Quality Laser Processing Light over Long Distances

1. Introduction

NTT and Mitsubishi Heavy Industries, Ltd. (MHI) entered into a cooperative agreement in April 2014 to undertake projects with the goal of creating new value for each other and their customers by applying NTT's research and development results in the area of information and communication technology to MHI's social infrastructure products in fields such as energy, the environment, and transportation, and to plant sites in Japan and other countries [1].

NTT and MHI have demonstrated kilowatt-class, high power single-mode laser transmission over several dozen to several hundred meters by harmonizing NTT's photonic crystal fiber (PCF) technology and MHI's high power laser processing technology. The maximum transmission distance of over-1-kW single-mode laser light is limited to around only 10 m at present. Our achievement therefore makes it possible to transmit high power single-mode laser light much longer distances, that is, up to several dozen times farther than before.

Laser processing technology is being used in various social infrastructure products, including vehicles and airplanes, as an efficient method for cutting, hole forming, welding, and other processes, and its application field is expected to increase further. Our achievement enables us to transmit high power single-mode laser light for distances greater than was thought possible, while retaining the light's quality, to yield high accuracy laser processing sources. Consequently, this will be a key technology for accelerating the expansion in the application areas of laser processing technology and for fostering further innovation in social infrastructure products.

2. Summary of achievements

In this achievement, NTT and MHI overcame the limitations in transmission optical power and distance by employing PCF and achieved superior high power transmission performance and feasible optical fiber manufacturability simultaneously by proposing a novel cross-sectional hole arrangement.

These key advances enable us to design a PCF with high power transmission potential four times higher than that of existing single-mode fiber for high power single-mode laser transmission. Moreover, NTT and MHI successfully demonstrated 10-kW transmission over 30 m and 1-kW transmission over 300 m using a high power single-mode laser light source and a fabricated PCF. This achievement expands the application area of high power single-mode laser processing and is expected to dramatically advance manufacturing technology in various social infrastructure industries.

3. Details of achievements

In this section, the PCF is described in more detail, and the results of experiments we conducted are explained.

3.1 Reason for deployment of PCF (features of PCF)

The optical fiber used to deliver the light from high power single-mode laser to arbitrary processing sites must offer high output power and excellent beam quality. However, the optical power and distance in an optical fiber are limited by optical nonlinearity. The maximum transmissible optical power and output beam quality of an optical fiber can be improved

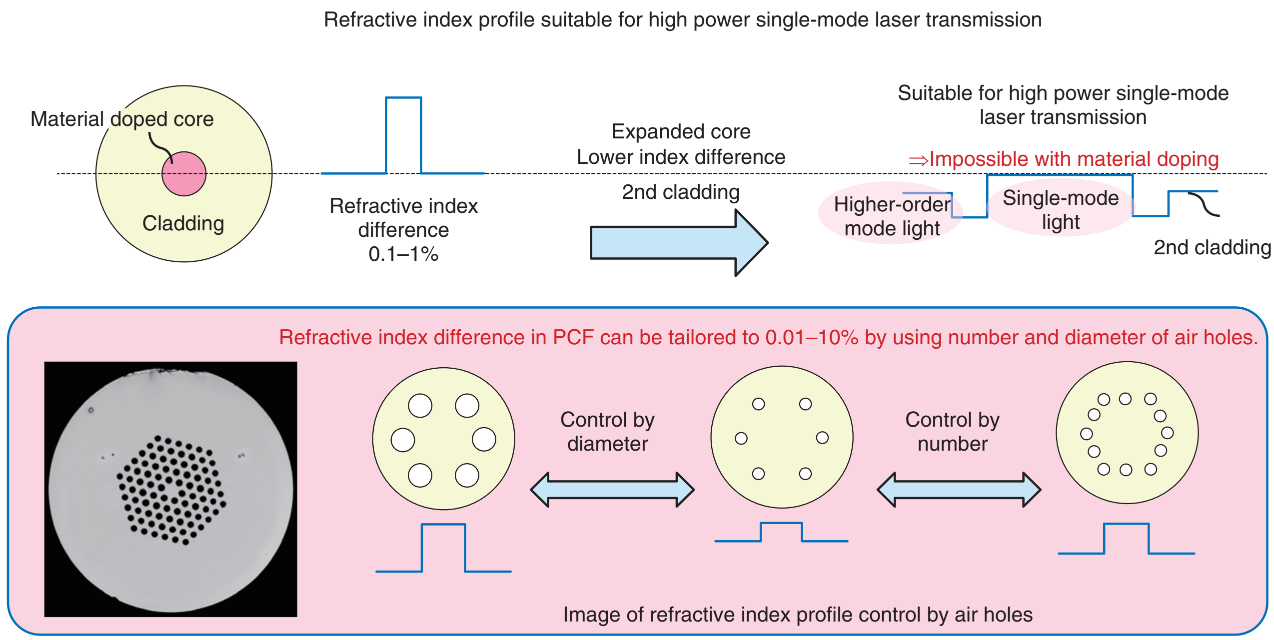

Fig. 1. Basic concept for improving the high power transmission potential in an optical fiber and the applicability of PCF.

by various means, as follows:

- Expanding the core area, as it acts as the optical light path
- Reducing the refractive index difference between the core and cladding
- Filtering unwanted light propagation components (higher-order mode light) to maintain processing accuracy

However, these requirements demand extremely precise refractive index control, on the order of 0.01%, which is impossible with conventional optical fiber as it has a material doped core.

The PCF, on the other hand, confines the light to a region surrounded by an array of air holes. The effective refractive index of the air hole array can be set arbitrarily by altering the diameter d and number (alternatively, pitch Λ) of the air holes. Thus, the cross-sectional refractive index of a PCF can be designed precisely to the order of 0.01–10%. This superior control of the refractive index enables us to achieve single-mode transmission at arbitrary wavelengths.

NTT has successfully developed a low loss PCF for realizing large capacity transmission at arbitrary wavelengths. Moreover, NTT created an optical fiber cord that can be used even if bent at 180 degrees without any optical signal degradation by combining the strong confinement effect of air holes with conventional optical fiber. As a result, NTT and MHI have succeeded in transmitting high power single-mode laser light to remote processing sites with no quality degradation by employing the superior refractive index control offered by the PCF (**Fig. 1**).

3.2 Novel quasi-uniform PCF and its optimization

As mentioned above, the transmission properties of the PCF can be precisely controlled by setting the diameter d and pitch Λ of air holes. Further improvement is possible by combining multiple d and Λ values to design the cross-sectional air hole arrangement. However, the complex cross-sectional design severely degrades the manufacturability of optical fiber. To eliminate this problem, we developed for the first time a quasi-uniform PCF; it has a constant d, but Λ varies. This enables us to expand the effective core area while ensuring feasible levels of manufacturability. Moreover, we numerically clarified that by optimizing the values of d and Λ, the proposed quasi-uniform PCF can achieve 420-kW·m high power single-mode transmission. Power at this level is four times higher than that of existing optical fiber.

3.3 High power single-mode transmission experiments

A 30-m-long quasi-uniform PCF was fabricated based on the design guidelines. The output of a 10-kW single-mode laser light source was successfully transmitted over 30 m, and experiments confirmed its high power transmission potential of 270 kW·m. Similarly, a 1-kW single-mode laser light was transmitted over 300 m, which corresponds to the high power transmission potential of 300 kW·m.

4. Future prospects

The achievements described here have enabled us to expand the transmission distance of high power single-mode laser light from several meters to several hundreds of meters. Such performance surpasses the limits currently deemed inevitable in the laser processing field and thus improves the effective use of high power single-mode laser sources. The application of single-mode lasers not only improves the cutting and hole-forming accuracy but also reduces processing time by using the laser energy more effectively.

This achievement can be used to implement remote processing, remote welding, and thick plate cutting in the existing manufacturing processes of vehicles, airplanes, marine vessels, and other products. This achievement is expected to trigger rapid expansion in the application area of laser processing technology to an extremely wide variety of social infrastructure products, and to lead to greater innovations in manufacturing.

Reference

[1] Press release issued by NTT and MHI, "NTT and MHI Conclude Tie-up Agreement in R&D Integrating Social Infrastructure and ICT," Apr. 24, 2014.
http://www.ntt.co.jp/news2014/1404e/140428a.html

For Inquiries
Public Relations, Planning Department,
NTT Information Network Laboratory Group
http://www.ntt.co.jp/news2018/1804e/180425a.html

External Awards

ITU-AJ Encouragement Award

Winner: Junichi Iwatani, NTT Access Network Service Systems Laboratories
Date: May 17, 2018
Organization: The ITU Association of Japan (ITU-AJ)

For his contribution to international standardization of the next-generation wireless local area network (LAN) IEEE 802.11ax and efforts to expand outdoor use of 5-GHz-band wireless LANs.

Best Paper Award

Winner: Tatsuhiko Iwakuni, Kazuki Maruta, Atsushi Ohta, Yushi Shirato, Takuto Arai, and Masataka Iizuka, NTT Access Network Service Systems Laboratories
Date: June 7, 2018
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE)

For "Null-space Expansion for Multiuser Massive MIMO Inter-user Interference Suppression in Time Varying Channels."
Published as: T. Iwakuni, K. Maruta, A. Ohta, Y. Shirato, T. Arai, and M. Iizuka, "Null-space Expansion for Multiuser Massive MIMO Inter-user Interference Suppression in Time Varying Channels," IEICE Trans. Commun., Vol. E100.B, No. 5, pp. 865–873, 2017.

TTC Information and Communication Technology Award, Minister of Internal Affairs and Communications Prize

Winner: Eikazu Niwano, NTT Secure Platform Laboratories
Date: June 14, 2018
Organization: The Telecommunication Technology Committee (TTC)

For his contribution to research and development, international standardization, and practical application of an IC (integrated circuit) card management system.

Cannes Lions 2018
Bronze Lion - Design Lions (Environment & Experience - Live Events)

Winner: Shingo Kinoshita and Takashi Miyatake, NTT Service Evolution Laboratories; Junji Watanabe, NTT Communication Science Laboratories; Akira Ono, Tetsuya Yamaguchi, Koji Namba, Koichi Furukado, Kiyoshi Tanaka, Katsumi Tanaka, Hikaru Takenaka, and Takuya Iwami, NTT Service Evolution Laboratories; Kazunari Moriuchi and Soichiro Usui, NTT Research and Development Planning Department
Date: June 19, 2018
Organization: International Advertising Festival Limited

For "REDEFINING DISTANCE."

The next-generation "5G" service will be put into practical use in 2020 by NTT DOCOMO. This experimental project demonstrates the speed, capacity, and low latency of 5G technology. It was performed by "Perfume," the group that is always on the leading edge of technopop. The members have always performed together on the stage since forming the group. For the first time in 17 years, however, the three women performed simultaneously on different stages in Tokyo, New York, and London in this event. The communications technology connected the three locations that are more than 10,000 km apart and combined the three respective performances into one without any time lag.

Young Engineer's Award

Winner: Azusa Ishii, NTT Device Innovation Center
Date: July 6, 2018
Organization: Japan Association of Corrosion Control

For "Comparison of Degradation Behavior of Poly(ethylene terephthalate) between Xenon-arc Accelerated Weathering and Outdoor Exposure Tests" (in Japanese).
Published as: A. Ishii, T. Miwa, and H. Koizumi, "Comparison of Degradation Behavior of Poly(ethylene terephthalate) between Xenon-arc Accelerated Weathering and Outdoor Exposure Tests," Proc. of the 38th Bosei Boshoku Gijutsu Happyo Taikai (Rust Prevention and Control Technology Conference), pp. 121–126, Tokyo, Japan, July 2018.

Papers Published in Technical Journals and Conference Proceedings

Resource-efficient Verification of Quantum Computing Using Serfling's Bound

Y. Takeuchi, A. Mantri, T. Morimae, A. Mizutani, and J. F. Fitzsimons

arXiv:1806.09138 [quant-ph], June 2018.

Verifying quantum states is central to certifying the correct operation of various quantum information processing tasks. In particular, in measurement-based quantum computing, checking whether correct graph states are generated or not is essential for reliable quantum computing. Several verification protocols for graph states have been proposed, but none of these are particularly resource efficient: Many copies are required in order to extract a single state that is guaranteed to be close to the ideal graph state. For example, the best protocol currently known requires $O(n^{15})$ copies of the state, where n is the size of the graph state. In this paper, we construct a significantly more resource-efficient verification protocol for graph states that needs only $O(n^5 \log n)$ copies. The key idea that achieves such a drastic improvement is to employ Serfling's bound, which is a probability inequality in classical statistics. Utilizing Serfling's bound also enables us to generalize our protocol for qudit and continuous-variable graph states. The flexibility of Serfling's bound also makes our protocol robust; our protocol accepts slightly noisy but still useful graph states, which are rejected by previous protocols.

Haptic Interface Technologies Using Perceptual Illusions

T. Amemiya

Proc. of HCI International Conference 2018, pp. 168–174, Las Vegas, USA, July 2018.

With virtual reality now accessible to anyone through high-end consumer headsets and input devices, researchers are seeking cost-effective designs based on human perceptual properties for virtual reality interfaces. The author has been studying a sensory-illusion-based approach to designing human-computer interface technologies. This paper overviews how we are using this approach to develop force displays that elicit illusory continuous force sensations by presenting asymmetric vibrations and kinesthetic displays based on a cross-modal effect among visual, auditory, and tactile cues of self-motion.

Vestibular Display for Walking Sensation in a Virtual Space

K. Shimizu, Y. Ikei, T. Amemiya, K. Hirota, and M. Kitazaki

Proc. of HCI International Conference 2018, pp. 334–339, Las Vegas, USA, July 2018.

This paper describes characteristics of walking sensation created by a vestibular display (a motion seat). An active input was introduced to a passive presentation of a walking stimulus. The participant triggered one step motion repeatedly by a game-controller button to introduce agency of motion. First, the magnitude of the seat motion was optimized to increase the walking sensation. Then, passive and partially active seat motion was evaluated. As a result, it was shown that added activity increased the walking sensation.

Airflow for Body Motion Virtual Reality

M. Kurosawa, Y. Ikei, Y. Suzuki, T. Amemiya, K. Hirota, and M. Kitazaki

Proc. of HCI International Conference 2018, pp. 395–402, Las Vegas, USA, July 2018.

The present study investigates the characteristics of cutaneous sensation evoked by airflow to the face of the seated and standing user during the real and virtual walking motion. The effect of airflow on enhancement of a virtual reality walk was demonstrated. The stimulus condition provided in the evaluation involved the airflow, the visual, and the vestibular presentations, and the treadmill and walk-in-place real motions. The result suggested that the cutaneous sensation of air flow was suppressed while the movement was performed actively with visual information provided. The equivalent speed of air flow for the participants was 5–29% lower than the air flow speed in the real walk.

Natural Language Inference with Definition Embedding Considering Context on the Fly

K. Nishida, K. Nishida, H. Asano, and J. Tomita

Proc. of the 3rd Workshop on Representation Learning for NLP, pp. 1–6, Melbourne, Australia, July 2018.

Natural language inference (NLI) is one of the most important tasks in NLP. In this study, we propose a novel method using word dictionaries, which are pairs of a word and its definition, as external knowledge. Our neural definition embedding mechanism encodes input sentences with the definitions of each word of the sentences on the fly. It can encode definitions of words considering the context of the input sentences by using an attention mechanism. We evaluated our method using WordNet as a dictionary and confirmed that it performed better than baseline models when using the full or a subset of 100*d* GloVe as word embeddings.
