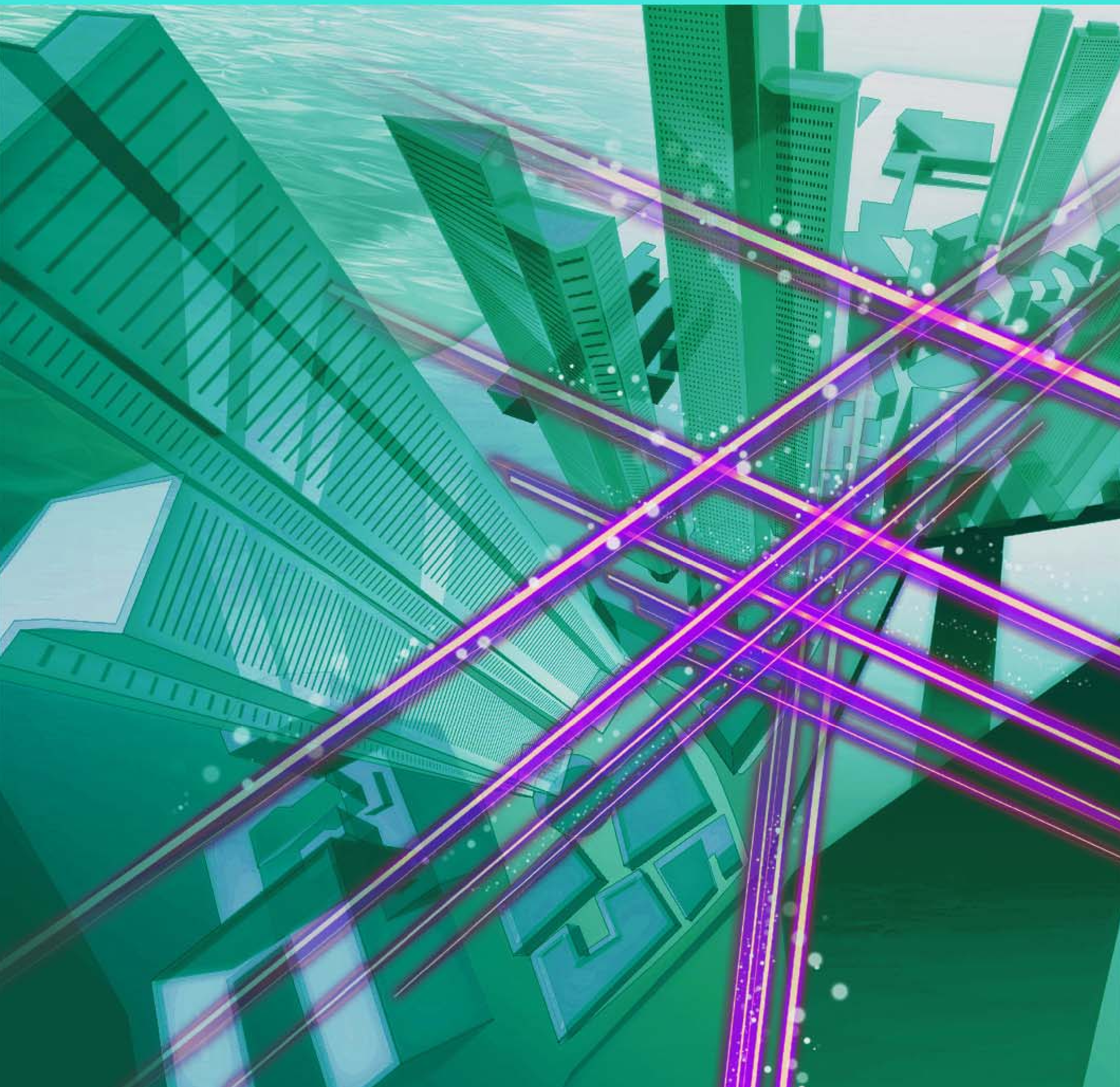
NTT Technical Review

4
2023



April 2023 Vol. 21 No. 4

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Global Standardization Activities

- ITU-T Study Group 16 Meeting Report and Recent Development in Standardization of Immersive Live Experience Technologies

Practical Field Information about Telecommunication Technologies

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External Awards

Create as Many Serendipities as Possible. Philosophy of the "Fountain of Knowledge" Is Shared among All Researchers and Laboratories

Atsuko Oka
Executive Vice President, Head of Research and Development Planning, NTT Corporation

Abstract
NTT laboratories are engaged in research and development (R&D) of new technologies to solve social issues in collaboration with NTT Group companies and other partners in various fields. We interviewed Atsuko Oka, executive vice president and head of R&D Planning, NTT Corporation, about her approach to R&D and attitude as a top executive striving to create a "smart world" in which people can enjoy the benefits of technology effortlessly.

Keywords: R&D, fountain of knowledge, contribution to society

Inheriting 75 years of history

—This is our second interview since 2019. How has your job changed since you became head of Research and Development (R&D) Planning from head of Technology Planning in 2022?

In June 2022, my position changed from head of Technology Planning to head of R&D Planning, the task of which is leading NTT laboratories. I started my career at NTT as a researcher, but I've been working outside R&D department and laboratories for a long time, so I feel like I've come full circle.

I'm often asked about the difference between the Technology Planning Department and R&D Planning Department, so I'll begin with a brief explanation of each department. The Technology Planning Department formulates policies and strategies concerning NTT's overall network and information technology infrastructures and promotes digital transformation (DX) by using current technologies; in contrast, the R&D Planning Department builds the foundations for current and future businesses and solving social issues by researching and practicalizing the next technologies.

In the Technology Planning Department, I was engaged in the formulation and promotion of policies for the entire NTT Group's business, including study and promotion of measures concerning construction, maintenance, and disaster countermeasures of telecommunications infrastructure, which is the basis of NTT's main business, smart-energy business, procurement, and next-generation networks. I also oversaw the promotion of DX using information and communication technology (ICT). While pursuing these missions, I realized the importance of addressing social issues.

In my current position, I feel a strong sense of

responsibility to help address those issues with the results produced by NTT laboratories. However, there is no infallible formula in research: some technologies will be put to practical use in two to three years, others will be implemented in the very distant future, and in some cases, they will be implemented only after the development of other technologies related to the research in question. That is why I believe it is important to not only conduct innovative research but also continue—in parallel with our daily research activities—research and improve the technologies that we have inherited from the past to produce concrete results while adapting to the times.

—NTT has a long history of R&D. Its R&D organization has been reorganized according to the times, hasn't it?

The Electrical Communication Laboratory of the Ministry of Communications was established in 1948 and became the Nippon Telegraph and Telephone Public Corporation's Electrical Communication Laboratory in 1952. While flexibly changing its R&D organization, NTT has been conducting R&D in accordance with the philosophy of the first director of the Electrical Communication Laboratory, Goro Yoshida, who said, "Do research by drawing from the fountain of knowledge and provide specific benefits to society through its practical use." It is said that no other telecommunications company in the world has an R&D organization of the scale of ours, and I believe this is one of NTT's unique characteristics and perhaps one of our greatest strengths.

The current NTT R&D organization consists of the following four laboratory groups in which about 2300 researchers are engaged in R&D in a wide range of fields from basic research to applied research: (i) the NTT Service Innovation Laboratory Group, which conducts R&D on innovative communication services that can be implemented on networks and technologies for predicting the future society and feeding them back to the real world; (ii) the NTT Information Network Laboratory Group, which conducts R&D on next-generation information-network-infrastructure technology that will support new services and environmental energy technology; (iii) the NTT Science and Core Technology Laboratory Group, which conducts advanced basic research to create new principles and new components, including world-class optical-related technologies; and (iv) the NTT IOWN Integrated Innovation Center, which conducts R&D on the All-Photonics Network (APN)—which embodies the Innovative Optical and Wireless Network (IOWN) concept—and cross-cutting technologies such as the convergence of "mobile and fixed" and "network and computing."

Commercialization of IOWN1.0 finally begins

—With such a rock-solid R&D organization, what research themes you are currently focusing on?

In addition to pursuing IOWN-related projects, we are focusing on collaborating with our partners to contribute to society by fusing our research with their technologies. To give you a recent example, I'll tell you about R&D for sustainable development concerning food-related issues and carbon neutrality that we are conducting with Kyoto University's venture company, Regional Fish Institute, Ltd. (RFI).

The oceans are said to absorb 34% of the carbon dioxide (CO_2) emitted into the atmosphere. With that fact in mind, we are conducting a demonstration experiment of a CO_2-conversion technology for reducing the amount of CO_2 dissolved in the oceans by applying genome editing technology to the food chain between algae and fish/shellfish. Through such experiments, we have established a method for selecting genes related to traits possessed by algae and have succeeded in identifying genes that are expected to increase the amount of CO_2 absorption. Genetically enhancing algae to promote those genes will allow the algae to absorb more CO_2 dissolved in seawater, and the side effect of that CO_2 absorption is more CO_2 being absorbed by the bodies, bones, and shells of the fish and shellfish that feed on the algae.

We will conduct genome editing on the identified genes and evaluate the CO_2 absorption capacity of the genome-edited algae and identify genes involved in other useful traits. Genes involved in absorption of CO_2 may be applicable to plants and other photosynthetic organisms; therefore, we are also creating a dataset on the relationship between genes and trait changes in various organisms and constructing a model for predicting trait changes on the basis of patterns and rules discovered using machine learning. We plan to use the results of this R&D in the Green Food Business project, which is being planned with RFI and other partners, to contribute to reducing the environmental impact of humankind and solving food shortages.

—I see that social contribution is a prerequisite for NTT's R&D. The implementation of IOWN is finally taking off, isn't it?

It has been four years since NTT announced the concept of IOWN. NTT has been conducting R&D on optical fiber since the 1960s, and when I joined NTT in the late 1980s, researchers at that time had already realized that optical technology would bring about technological innovation in the future. However, the optical technology to implement such innovation had not yet developed. Nevertheless, in 2019, it was reported in Nature Photonics that NTT Basic Research Laboratories had developed an electro-optic modulator and optical transistor that operate with the world's lowest energy consumption, and that achievement led to the concept of IOWN based on optical technology. The research activities concerning IOWN have accelerated since then.

The initial target was to implement IOWN by 2030; however, the recent rise in expectations for technological innovations that contribute to addressing social issues, such as reducing the environmental impact and electric power consumption, has increased the pace of R&D and brought forward the launch date. In response to this situation, we need to start developing infrastructure ahead of commercialization, so we have started construction of the IOWN testbed and other network environments.

In March 2023, NTT EAST and NTT WEST launched "IOWN1.0" as the first APN service. The prime value of the new APN service is ultra-low latency. We intend to commercialize a low-power consumption server equipped with the photonics-electronics converged devices that are currently under development in 2026. By combining this server

with the APN, we will achieve low-power-consumption, large-capacity, and low-latency communications.

At Expo 2025 Osaka, Kansai, Japan, in addition to exhibiting a pavilion, we plan to provide virtual venues, "personal agents" for visitors, and announce the IOWN2.0 service as a showcase for IOWN.

Do not force people to use our technologies

—Could you tell us what is important to you as the head of R&D Planning?

Now that I'm an executive vice president of NTT, I feel more strongly than ever the responsibility to steadily achieve goals set in our medium-term management strategy and other plans. I cannot do much on my own to solve the problems that arise in the process, so I seek help from those around me as I proceed. Once a month, I meet with the heads of each laboratory group to share policies and strategies to ensure that our direction is consistent. Since the number of collaborations between the laboratories that make use of one another's originality and unique research themes is increasing, I want to create many collaborative projects.

We cannot always know where to apply our research results and developed technologies, and we should not force people to use our technologies. I want to make every effort to turn our research results into business with a goal of solving social issues.

Cooperation with a variety of people is key to achieving this goal. To make sure that our partners, many of whom are not ICT experts, choose us for their collaborations, we make every effort to communicate with them, plan collaborations, and explain technologies in a way that is easy to understand. For example, at the NTT R&D Forum in 2022, which was held online and in-person for the first time in three years after the COVID-19 pandemic, we improved the presentations and exhibits in various ways, such as enlarging the pop-up panels to make them easier to understand and deepen the understanding of the audience. Let me introduce an example of such efforts with the bio-digital twin, which is a use case in the medical and healthcare field of Digital Twin Computing, a component of IOWN. With the bio-digital twin, a model of the human heart is created in digital space by inputting heart-rate and blood-test data. When explaining this technology, we not only provide information on whether the patient's current cardiopulmonary function is average or slightly declining but also information that stimulates the curiosity of the audience, such as a simulation that predicts the cardiopulmonary function at future intervals and instantly shows how it will deteriorate if it is not improved. In this manner, we try hard to deepen the audience's understanding by providing explanations that take into account the viewpoints of the general public and physicians.

—What is your message to researchers and partners and your thoughts about the future?

As I mentioned above, the philosophy and purpose of NTT's R&D are summed up in the words of our first director, Goro Yoshida. Under this philosophy, I believe that we are required to return the knowledge we accumulate to society. Since we are the research institute of a company, NTT, we also naturally need to contribute to NTT's business. On top of meeting that necessity, we will continue to maintain the mindset and DNA of contributing to society through our business.

Each laboratory and each researcher has different phases of development and missions, and the timings at which they produce results also differ. Even so, I believe that the philosophy of the "fountain of knowledge" is universal. In this rapidly changing world, there is a limit to what one person can do, so I encourage researchers to communicate with a variety of people to get inspiration and tips to brush up their skills.

I also hope many people want to co-create with us, but I have heard comments like "NTT is a large company, so it is difficult to approach them." If that is the case, NTT researchers will provide a thorough and easy-to-understand explanation of their research, so nobody will hesitate to contact us.

Finally, with 116 members (as of February 6, 2023) from all over the world, the IOWN Global Forum aims at global technological innovation. I expect to develop more products and services with the IOWN name in cooperation with those members. We hope to create as many serendipities as possible through our collaboration and produce and discover more value than we could have ever imagined.

Interviewee profile

■ Career highlights

Atsuko Oka joined NTT as a researcher at Software Research Laboratories in 1988. After serving as the director of the IP Services Department of the Net Business Division of NTT Communications Corporation from 2006 to 2010, she became the president and CEO of NTT NaviSpace Corporation in 2010, a board member and general manager of the Solution Business Division of NTT Resonant Incorporated in 2017, and senior vice president and head of Technology Planning, NTT Corporation in 2019. She assumed her current position in June 2022.

Researchers Are the Source of Social Progress. Be Confident in Your Research Theme and Aim for the Next Big Topic

Takehiro Moriya
NTT Fellow, NTT Communication Science Laboratories

Abstract

In the wake of the COVID-19 pandemic, remote work, for which image and voice communication using personal computers and smartphones plays a vital role, has become commonplace. NTT Fellow Takehiro Moriya has been engaged in research on speech- and audio-signal coding for about 40 years to improve and innovate communication and quality of life. We interviewed him about the changes in technology development in the field of speech- and audio-signal coding and his attitude as a researcher.

Keywords: speech and audio coding, IVAS, standardization

Pursuing speech- and audio-signal coding

—Could you tell us about the research you have conducted over the past 40 plus years and how it has changed over time?

I have been investigating speech- and audio-signal coding, namely, digitizing voice and music signals and compressing them efficiently and with high reproducibility. For example, the music we enjoy through portable music players and digital broadcasting is not simply digital data of the original signal; it is compressed data in which the volume of the digital data is reduced by about 90%.

Nippon Telegraph and Telephone Public Corporation focused on researching analog speech (including speech quality) transmitted over the limited bandwidth of the telephone and significantly contributed to developing international standards set by the CCITT (Comité Consultatif International Télégraphique et Téléphonique), the predecessor of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T).

Along with the progress in research on the digitization of telephone networks and terminals, research on the digitization and compression of analog speech signals has also progressed, and this research is the origin of our research on speech- and audio-signal coding at NTT. With the digitization of relay networks, NTT's "INS Net 64" and "INS Net 1500" ISDN (Integrated Services Digital Network) services began in 1984, and as those services became widespread, speech- and audio-signal coding became more important. In the 1990s, second-generation

(2G) mobile phones, which use digital technologies, appeared, and expectation for speech- and audio-signal coding increased thanks to its ability to ensure quality under the severe limitations on transmission bit rates, etc. imposed on mobile networks compared with fixed networks. Our coding technology satisfying certain conditions, such as ensuring sound quality at low bit rates even if a transmission-code error occurs, was adopted in Japan's standard coding scheme for 2G mobile phones following a competitive process. Our elemental technologies were also adopted in 3G mobile phones and Internet protocol (IP) phones, contributing to the improvement in speech quality of mobile telephony throughout the world.

—You have achieved research results that have had an impact on the world.

Speaking of global impact, NTT teams have contributed to several international standardization efforts since the 1990s. The standards to which we have contributed include a speech coding for IP telephony in the ITU-T standards and a low-bit-rate audio coding and lossless coding (which does not allow distortion) in the ISO/IEC (International Organization for Standardization/International Electrotechnical Commission) MPEG (Moving Picture Experts Group) standards. Around 2010, the 3rd Generation Partnership Project (3GPP), an international standardization organization for mobile communication systems, began developing a speech-coding standard. This is because there was a strong need to establish a new speech-coding scheme for Voice over Long-Term Evolution (VoLTE), the speech communication standard for worldwide 4G mobile communication systems. In response, the NTT Group and many other experts from around the world competed and cooperated to develop an integrated speech and audio codec called Enhanced Voice Services (EVS), which became an international standard in 2015.

Until then, speech-coding standard for mobile phones had used the Code Excited Linear Prediction (CELP) algorithm, which emulates the human voice production mechanism, to transmit human voice at a low bit rate and high quality. Combining the CELP algorithm with newly developed low-latency coding modules for music, EVS enabled low-latency transmission of speech (including background noise and music) and music with high sound quality, which had not been possible before. In the process of its standardization, EVS was subjected to large-scale subjective quality evaluation tests under various conditions (with different sound sources and languages) by a third-party organization, and the test results confirmed that EVS achieves much higher quality than that achieved with conventional schemes.

As a result, the EVS codec has been simultaneously adopted by telecommunications carriers, telecommunications-equipment manufacturers, and chip manufacturers worldwide. With the adoption of EVS, the smartphones currently in use around the world can provide high-bandwidth, high-quality calls, regardless of telecommunications carrier or equipment manufacturer. This is the result of a long and repeated process of trial and error by NTT's teams and leading researchers and engineers around the world to improve the sound quality of telephones.

Challenge to establish IVAS standards

—It seems that sound quality is becoming even more important these days.

Due to the COVID-19 pandemic, the number of web conferences and other online activities has increased rapidly. Under such circumstances, NTT Data Institute of Management Consulting and the audio manufacturer Shure conducted demonstration tests to examine the effects of differences in digital audio quality on biological stress reactions during online meetings, and the test results revealed that 85% of users were dissatisfied with the audio quality of web conferencing. The specific complaint is that poor sound quality in meetings causes participants considerable stress as well as prevents them from understanding the content.

Although international standardization set by the 3GPP has improved the sound quality of calls between smartphones, the voice quality in web conferencing is still unstable due to delays and packet loss, which occur because conversations are conducted via personal computers (PCs) and best-effort Internet services are used. The quality of web-conferencing applications for PCs and other devices often deteriorates because processing delays and packet loss are not sufficiently addressed. However, society is increasingly demanding technologies that give the participants in a web conference a "sense of presence" or "immersive experience" as if they were meeting in the same place, including new communication venues such as the metaverse. Although many people think a high-definition image is a major factor

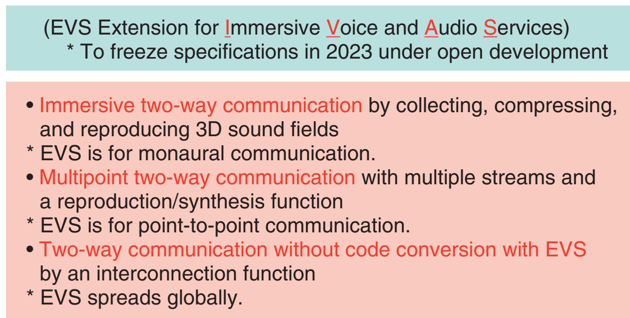

Fig. 1. Goals with IVAS.

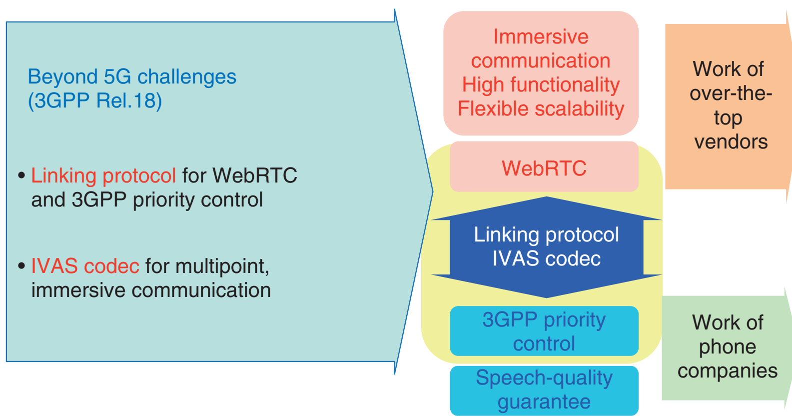

Fig. 2. High-functionality phones with guaranteed speech quality.

in achieving an immersive experience, a great deal depends on the quality of speech and audio. With that background in mind, we are working on standardizing an extension of EVS called Immersive Voice and Audio Services (IVAS). IVAS is under open development to freeze its specifications by the 3GPP in 2023. The aims with IVAS are as follows: (i) immersive two-way communication by collecting, compressing, and reproducing three-dimensional (3D) sound fields, (ii) multipoint two-way communication with multiple streams and reproduction/synthesis function, and (iii) two-way communication without code conversion with EVS by an interconnection function (**Fig. 1**).

The 3GPP aims to (i) ensure reliable communication suitable for voice communication over, for example, optical-fiber (VoIP) and mobile (VoLTE) networks, which have been built by network experts, and (ii) design a protocol that is compatible with Web Real-Time Communication (WebRTC), enabling various functional extensions to be made freely. Therefore, more-stable, higher-quality voice communication than that provided with current web conferencing will be guaranteed, and it is expected to lead to communication with higher functionality and immersive experiences as well as to various new forms of communication, including XR (cross reality) and the metaverse (**Fig. 2**).

—While new technologies are being created one after another, you continue to pursue speech technology, which has a great impact on the immersive experience.

As a company that provides both mobile and fixed-line telephone services, the NTT Group needs to be committed to developing speech-related technologies, and I have been pursuing those technologies with this need in mind. As a researcher at NTT, which has a long history of research into speech in telephony, I have always wanted to create something that could be used in the business world.

Regarding IOWN (the Innovative Optical and Wireless Network), which the NTT Group is researching and developing to finalize specifications in 2024 and implementation in 2030, speech technology may seem somewhat subdued compared with the glamour of high-speed, large-capacity transmission technology, high-definition-image technology, and so on. However, working in the field of speech, which has a significant effect on our immersive experience, I want to focus on achieving high-quality voice communication regardless of the medium. That is my goal because high speed and large capacity alone do not necessarily improve sound quality.

Research on artificial intelligence (AI) is currently all the rage, and many researchers are in a fierce competition to obtain the best performance. However, only a handful of researchers make it to the top. There are many important fields studied around the world that are not affected by trends. I think one way to be a researcher is to carry out one field of research that interests you. Although research on speech is not a glamorous topic today, it is certainly an important one and is what I chose to pursue. It has many issues that need to be resolved. I want to connect the skills of experts—inherited from my predecessors—to those who will come after me in a manner that paves the way for resolving issues that will not be resolved in my time.

After almost 40 years, AI is currently experiencing its third wave. Thus, a fad focused on one topic does not last very long, but another wave is sure to follow. I think it would be best to find a research theme with an eye on that next wave. In the field of speech, the importance of the digital speech compression and coding technology that I have been researching was reaffirmed in the 1990s with the digitization of mobile phones. Although we should not be complacent, we should be confident in our own research themes and aim for the next big topic.

The pursuit of speech and sound quality contributes to saving lives

—It is important to have confidence in one's own research theme, isn't it?

I believe that themes that can contribute to the world are more important than themes that attract the world's attention or are in vogue. In that sense, for example, the number of fatalities due to traffic accidents has dramatically decreased in Japan since 1995, and that trend must be due to the widespread use of mobile phones, which have made it possible to call an ambulance immediately after an accident. Due to the COVID-19 pandemic, restrictions have been imposed on visiting hospitals and nursing homes. Under such circumstances, many people have been comforted by being able to communicate with loved ones remotely via mobile phones and other means of communication. The spread of mobile phones is partly due to the pursuit of speech and sound quality that we, including our predecessors, have been focusing on, and the results of that pursuit have not only made our society more convenient but also made us realize that the mobile phones held in our hands save lives.

Although some say that the research field of digital compression and coding technology for speech will taper off as communication speeds and capacities increase, it is not unnecessary research. We are currently working on international standardization at the 3GPP as well as research and development with an eye toward Beyond 5G and 6G. Of course, it goes without saying that we aim to contribute to society. As a corporate researcher, it is only natural that I should do what is beneficial to the company. Having said that, I want to work on my research with a smile when I think of contributing to society beyond NTT.

—What do you think a researcher is to society?

I think that researchers are the source of social progress. I often compare politicians with researchers. For example, if 200 people need something that can only be given to 100 people, a politician might consider either giving it to those who really need it out of the 200 or giving everyone a half share of it. On the contrary, researchers take on the challenge of creating value by turning 100 into 200 or even 1000. This way of thinking is exactly what led me to halve the amount of transmitted information by compressing the speech data so as to double the efficiency of utilization of the radio waves when the digitization of mobile phones began.

Although I have passed retirement age, I am continuing my research on speech as an NTT Fellow. I consider my status as proof of the importance that NTT attaches to research on speech. Accordingly, I want to strive to continue research on the theme of speech by explaining to younger researchers the importance and value of the research on speech and by conveying its appeal to them. It is important to maintain the belief that this research is important, even if society does not yet recognize its importance.

As a researcher, you should be sensitive to research trends, but do not follow fads. While it is important to pursue research in depth, you should not be splitting hairs. Writing papers is important, but it is also important not to end your research with self-satisfaction just because you have written a paper. I hope that young researchers will become long-lived researchers who pursue a theme that they can stay true to while keeping up with trends.

■ **Interviewee profile**

Takehiro Moriya received a B.S., M.S., and Ph.D. in mathematical engineering and instrumentation physics from the University of Tokyo in 1978, 1980, and 1989. Since joining the Nippon Telegraph and Telephone Public Corporation (now NTT) in 1980, he has been engaged in research on medium to low bitrate speech and audio coding. In 1989, he worked at AT&T Bell Laboratories, NJ, USA, as a visiting researcher. Since 1990, he has contributed to the standardization of coding techniques for the Japanese Personal Digital Cellular system, ITU-T G.729, G.711.0, ISO/IEC MPEG, MPEG-4 General Audio Coding, MPEG-4 Audio Lossless Coding, and 3GPP EVS. He is an honorary member and Fellow of IEICE (Institute of Electronics, Information and Communication Engineers), Life Fellow of IEEE (Institute of Electrical and Electronics Engineers), member of the Information Processing Society of Japan, and honorary member of the Acoustical Society of Japan.

Petabit-class Optical Transmission Using Spatial Multiplexing Technology Opens a New Era with a Paradigm Shift

Kohki Shibahara
Distinguished Researcher, NTT Network Innovation Laboratories

Abstract

Over the last 40 years, various innovations in technology have improved our communications infrastructure, but it is becoming clear that the transmission capacity of current optical fiber technology will eventually reach its physical limits. In this interview, Distinguished Researcher Kohki Shibahara comments on the next generation of optical transmission technology that will overcome these limits, in particular, a dense space-division multiplexing based on a new kind of optical fiber that will enable a dramatic scale-up from the current terabit-class to petabit-class capacities.

Keywords: dense spatial multiplexing, cyclic mode permutation, interference cancellation

Petabit-class dense spatial-multiplexing optical transmission technology targeting an unknown optical communications infrastructure

—What is petabit-class dense spatial-multiplexing optical transmission technology?

This technology uses a new kind of optical fiber, that we call space-division-multiplexing optical fiber, to achieve much higher transmission capacity than is possible with current technology. As you know, the optical communications infrastructure, which uses optical fiber as the transmission medium, enables us to communicate in real time across the globe. Although the transmission capacity of optical fiber has steadily increased over the years thanks to various innovations in technology, we expect it to eventually reach a physical limit if the existing forms of optical fiber cannot be improved. The reason is that optical fiber is made of glass, which may melt by the high optical power originating from a large number of wavelength channels. Another problem is that the optical signal is distorted by the physical properties of the glass medium. As a result, the maximum transmission capacity of long-distance networks is estimated to be about 100 terabits per second per fiber.

Space-division-multiplexing optical fiber will enable us to achieve a dramatic scale-up from the current terabit class of transmission capacity to the petabit class, and we are working now on developing optical transmission technology that uses this optical fiber.

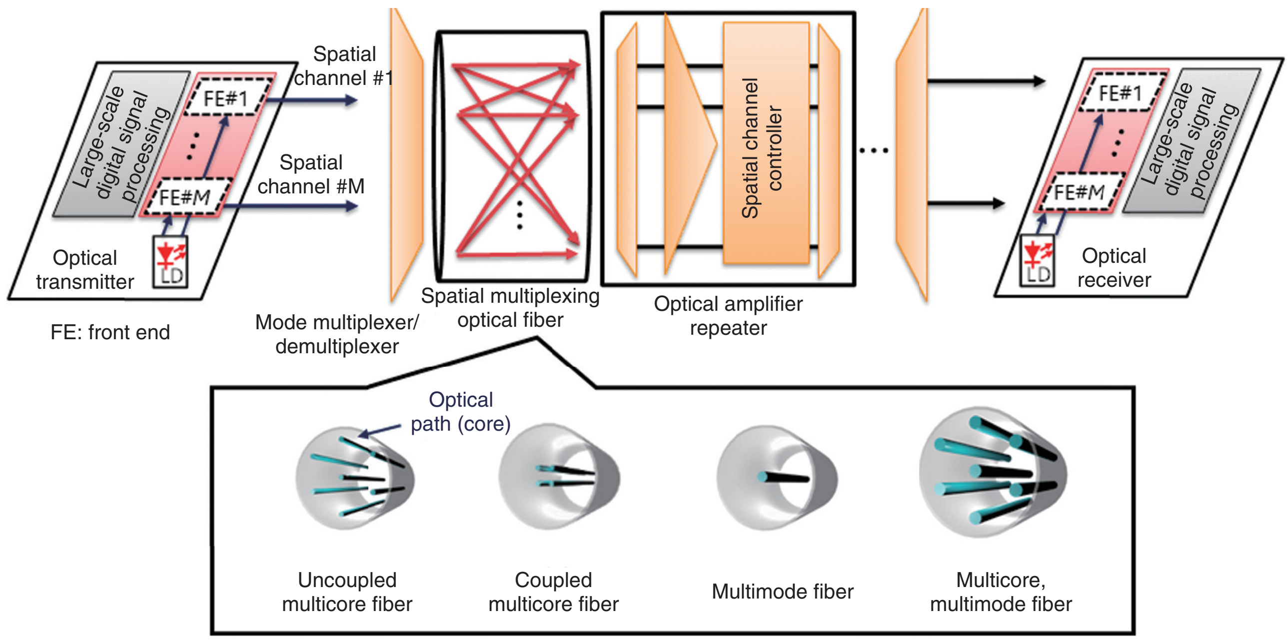

Fig. 1. Overview of research on petabit-class, dense spatial-multiplexing optical transmission technology.

—Specifically, what sort of research are you doing on this new technology?

Up to now, the capacity of the optical communications infrastructure has grown by developing new multiplexing axes. For example, in the wavelength-division multiplexing currently in use, multiplexing is done on the wavelength axis. That is, different information is carried by different colors of light that are bundled together and transmitted over a single optical fiber. In a similar way, the space-division multiplexing used in our research bundles together multiple light paths, namely cores or modes, along the spatial axis in an optical fiber to expand capacity. In this approach, the theoretical transmission capacity scales in accordance with the number of cores in a multicore fiber (**Fig. 1**).

A major problem, however, is that modal dispersion and mode-dependent loss occur in a transmission through multimode fiber, which can carry multiple optical signals in different ways through a single core. Modal dispersion causes a variation in the signal arrival time at the receiver due to there being a spread in transmission times for different modes in a multimode fiber. An intuitive explanation for modal dispersion is like this: light propagation in a fiber is often likened to the phenomenon of total internal reflection. In conventional single-mode fiber, the angle of reflection is very large, but when the number of modes is high, the angle of reflection becomes small, and this difference results in a delay in the signal arrival time. The increased time difference becomes a performance-limiting factor. Mode-dependent loss causes differences in the intensity distributions of the various modes in the fiber and it tends to occur when there is a misalignment of cores at the fiber connection points.

The effects of mode dispersion and mode-dependent loss accumulate over distance, and this was a particularly important problem that had to be solved for long-haul terrestrial and submarine optical networks to be capable of high-capacity and high-quality transmissions over distances exceeding 1000 km.

—How are you trying to solve the technical problems related to the capacity and quality of transmissions?

To reduce the effects of the problems I mentioned earlier, my colleagues and I are proposing cyclic mode permutation and interference cancellation as key technologies. In 1000-km class transmissions, optical-amplifier repeaters amplify the signal along the link. So, instead of a long-distance transmission in a single mode, the spatial mode is changed in each repeater section, thus averaging out the effects of modal dispersion and mode-dependent loss. We achieved high-quality transmissions by using an interference canceler to eliminate crosstalk, which is interference between the signals in the optical transmission. Interference cancelers are widely used in radio communications, but we modified them to work over the rapidly changing environment in optical transmissions. We were the first in the world to apply cyclic mode permutation and interference cancellation and are considering how to use them to solve various problems.

—Can you tell us some of your recent results?

My colleagues and I at NTT have set world records for optical transmission distance using multimode fiber and multicore-multimode fiber, achieving 6300 km with three-mode fiber in 2018, 3000 km using multicore-multimode fiber, also in 2018, and 3250 km using six-mode fiber in 2020, all world records in terms of distance.

Those results demonstrated that long-distance optical transmission can be achieved with multimode fiber as well as with multicore fiber. The key aspects one has to consider when fabricating cables comprising spatial multiplexing fiber include manufacturing cost, durability, and connectivity with peripheral devices as well as transmission performance. We therefore believe that increasing the number of candidates for future submarine optical networks will help to lower the cost of future systems.

We also believe that the accumulation of mode dispersion and mode-dependent losses over distance remains an issue when it comes to constructing long-haul transmission systems, so it will be important to continue doing experiments on mode-multiplexing transmission over long distances to verify its feasibility as infrastructure.

On the joy of doing research that has resulted in a new paradigm

—Could you tell us about your research objectives and vision for the future?

New applications and services that use telecommunications are coming out every day and the optical communications infrastructure that supports them "under the hood" must also continue to evolve to fully accommodate the continually increasing telecommunications traffic. The All-Photonics Network (APN) initiative, one area of work in support of the Innovative Optical and Wireless Network (IOWN), has set as a target an increase in transmission capacity by a factor of 125, and space-division multiplexed optical transmission technology is needed to achieve that target. To realize the IOWN concept, we will continue to expand transmission capacity by combining with relevant technologies that have shown remarkable progress, including optical bandwidth extension technology using efficient optoelectronic devices and high symbol-rate technology that makes the use of the signal space more efficiently.

The actual system deployment of spatial multiplexing technology will start in the mid-2020s with, I believe, up to ten light paths per optical fiber. However, the transmission capacity that can be supported with ten paths per fiber will become insufficient very soon after that. We would therefore like to work on a long-haul optical transmission infrastructure with the goal of having 100 or so spatially multiplexed optical fibers with even more optical paths. This research and development would support sustainable development of the optical communications infrastructure (**Fig. 2**).

—What are some important aspects of research for you?

I hope to do work that will leave a legacy even hundreds of years into the future. The spatial-multiplexing optical transmission technology that I am working on is an attempt to change the structure of optical fibers, which has not changed significantly in the last 40 years. This technology is creating a tidal change in the optical fiber field, but the effects also extend to related peripheral technology, such as optical transceivers, optical amplifiers, optical devices, and connections. That makes it challenging to set up an experimental verification system that integrates prototypes of optical and electrical devices that have not yet reached technological or market maturity. But, on the other hand, it has been a great joy for me, as a researcher, to be involved in the development of technology that has led to an important paradigm shift after such a long interval of time. People set records in various endeavors, such as sports or architecture, but, for me, it is working hard to perform the worlds-first or world-class research and have it published in international journals and conference proceedings. When my work is published in a scientific journal, I feel that I've contributed to the history of human science, even if it is just a small step, and that is very rewarding.

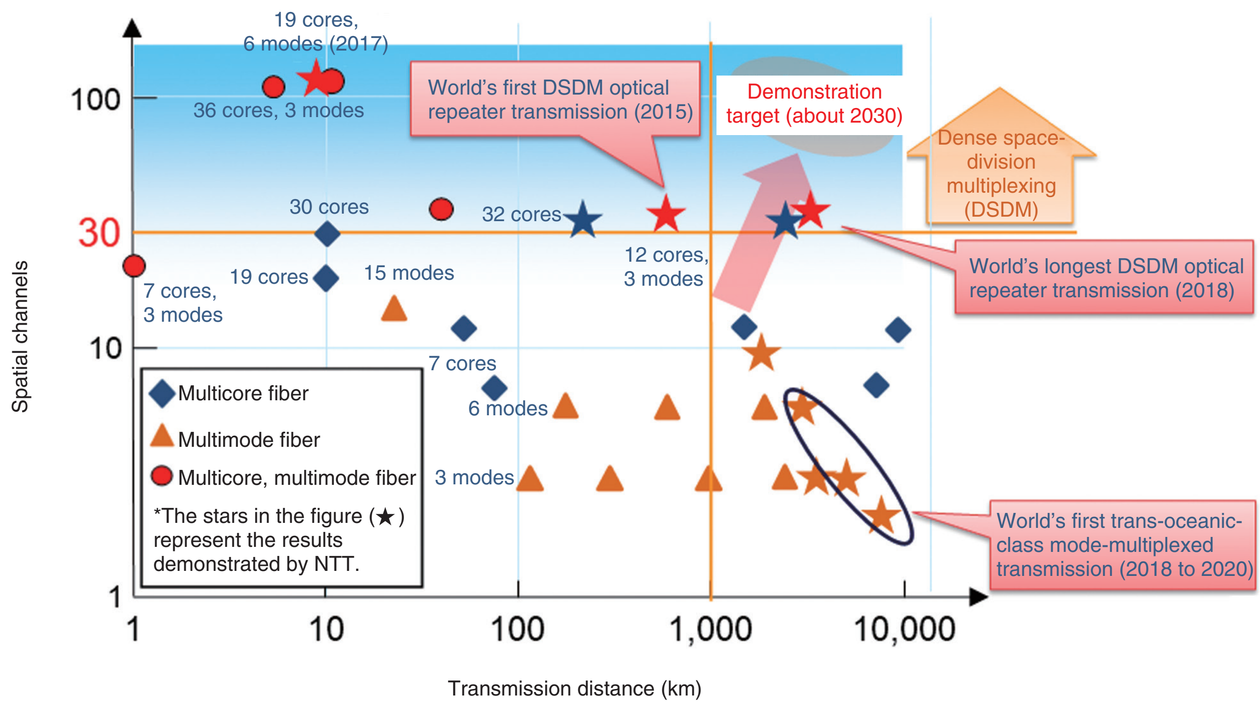

Fig. 2. Research results and prospects.

—Dr. Shibahara, please leave us with a message for other researchers, students, and business partners.

NTT Network Innovation Laboratories, where I work, covers a very broad range of fields that include technologies that push the limits of communications, such as radio and optical communications, as well as technologies for achieving high efficiency and high functionality. That means there is much interaction and collaboration with various other laboratories at NTT that deal with devices, systems, and applications. I think that is a strength which facilitates technical exchanges with fields that are peripheral to communications, both within NTT and outside the company. In optical communications, for example, we have experts on devices such as optical fiber, optical amplifiers, and optical modulators, as well as experts in key technologies related to optical transmission systems, such as networking. These people are all within our company, so that makes consultation with experts easy.

Before joining NTT, I had never been involved in information and communications technology at all, because I majored in geophysical science up to my master's degree. When I became involved in optical communications technology in my work at NTT, however, I came to realize how broad this field of technology is and how it can absorb various peripheral fields of technology, and that continues to surprise me even now.

When focusing on electrical and electronic engineering and communications engineering in relation to basic communications systems and related devices, for example, knowledge of light propagation and control, statistics for analyzing and processing signals, computer science, information theory, and signal processing theory are all very useful. Optical devices also relate to material science and quantum chemistry.

For applications, there have been many studies of application to cryptography, quantum computing, and machine learning and deep learning, which have become popular fields with the rise of artificial intelligence.

So we can see that communications technology is an extremely challenging and rewarding field that brings together the best of cutting-edge science and technology and offers opportunities for people of many backgrounds to play active roles. Also, when outside the company, there are many situations in which I feel the benefits of the strong connections with industry, government, and academia that have grown from the achievements of my predecessors. NTT laboratories are fully equipped for research and development; our people and facilities are producing world-class results in many challenging areas of research. I hope that those who wish to contribute to society through research and development will come to NTT and work together with us in this new era.

■ **Interviewee profile**

Kohki Shibahara joined NTT in 2010, after receiving an M.S. degree from the Department of Geophysics at the Graduate School of Science of Kyoto University. He received a Ph.D. from the Department of Communications and Computer Engineering of the Graduate School of Informatics at Kyoto University in 2017. He has been engaged in research and development on next-generation high-capacity optical transmission systems as a Distinguished Researcher at NTT Network Innovation Laboratories since 2022. He received the Tingye Li Innovation Prize from Optica in 2016 and the Academic Encouragement Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2017.

Latest Developments Concerning Grand Challenges to Implement the Digital Twin Computing Concept

Takao Nakamura, Koya Mori, and Ryo Kitahara

Abstract

One of the major pillars of the Innovative Optical and Wireless Network (IOWN) being promoted by NTT is the concept known as Digital Twin Computing (DTC), which aims to enable future predictions and optimization by combining the real and digital worlds, and NTT has set *grand challenges* as ambitious research and development goals to implement DTC. In this article, our efforts toward the common use of digital twins and our recent activities to achieve these grand challenges are introduced.

Keywords: Digital Twin Computing, IOWN, grand challenge

1. Efforts concerning Digital Twin Computing concept and the grand challenges

The concept known as Digital Twin Computing (DTC) is a key component of NTT's Innovative Optical and Wireless Network (IOWN). By combining highly accurate digital information about objects, people, and society in the real world, DTC aims to enable (i) large-scale and highly accurate future predictions and simulations that transcend the limits of conventional information and communication technologies and (ii) advanced communication with new value. It will accelerate the creation of a smart society by solving various social issues around the world and creating innovative services (**Fig. 1**).

DTC is a technology that covers a wide range of application fields—ranging from the microscopic world of individual humans to the macroscopic world on the global scale. We aim to actualize the DTC concept by setting the following four *grand challenges* as major research and development (R&D) goals (**Fig. 2**).

(1) *Mind-to-mind communication* transcends not only differences in language and culture but also differences in personal characteristics, such as experience and sensibility, in a manner that creates a new form of communication that enables people to directly understand one another's thoughts and feelings.

(2) *Another Me* expands opportunities for people to play an active role and grow by having another person (digital reproduction of a real person) act autonomously as that person beyond the constraints of reality and share the results as the real person's own experience.

(3) *Exploring Engine for the Future Society* aims to create a mechanism that digitally represents society and people with high precision, interacts with them to search for a future society, and allows individuals to choose their desired behavior.

(4) *Global Inclusive Sustainability* presents multiple options for transformation of social systems leading to an inclusive equilibrium that harmonizes the autonomy of the global environment and the autonomy of the social and economic systems that are part of it.

2. Efforts toward common use of digital twins

To achieve the above grand challenges targeting the implementation of the DTC concept, building applications by combining various digital twins, such as humans, vehicles, buildings, and weather environments,

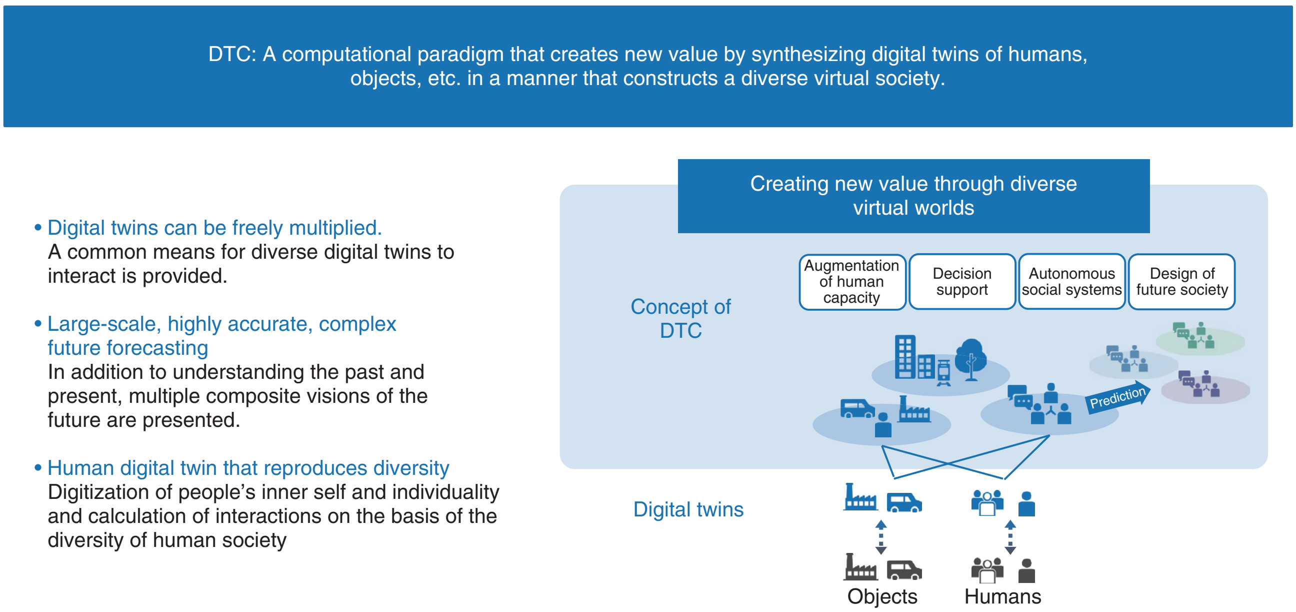

Fig. 1. What is DTC?

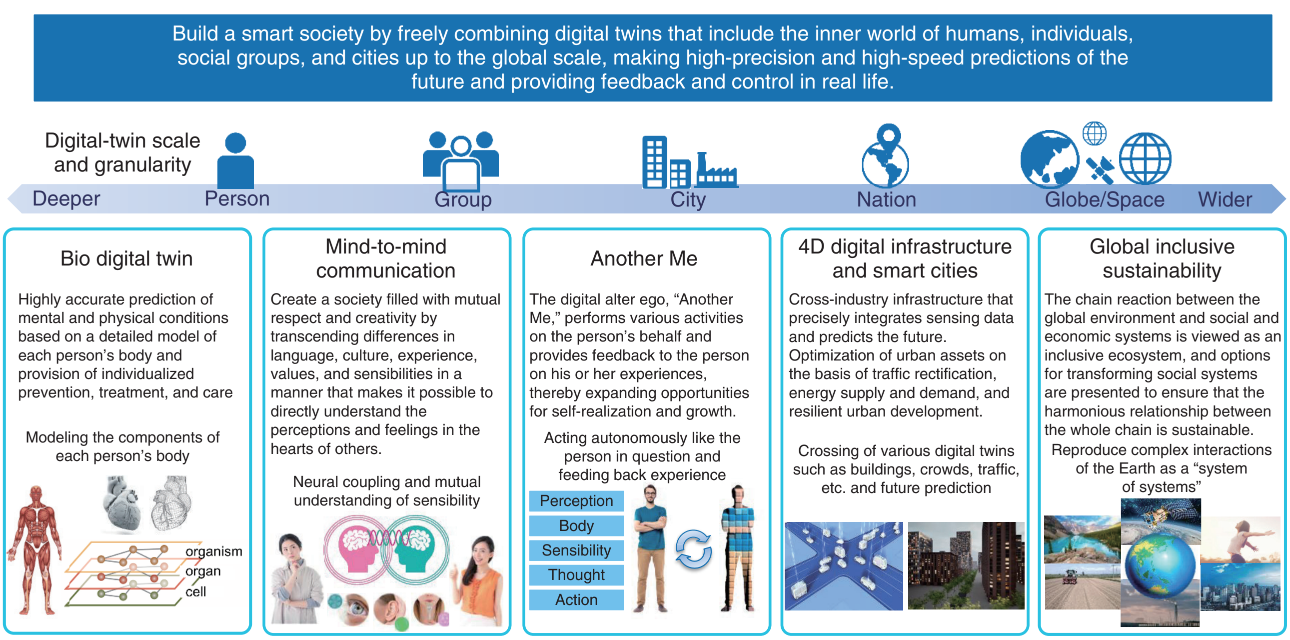

Fig. 2. Expansion of DTC.

will require the ability to freely combine such various digital twins and compute their interactions. It is essential to ensure the interconnectivity of digital twins. Accordingly, we are making efforts toward common use of necessary digital twins while focusing on collaboration with various stakeholders in related industries at the IOWN Global Forum (IOWN GF).

The DTC concept is not something that we at NTT can make a reality on our own; that is, we need to work together with related companies, universities, and research institutes to determine its technical specifications and framework. IOWN GF is considered an ideal forum for discussions with such organizations because it covers everything from network infrastructure to the application layer and includes a wide range of specialists from technology providers to users. By combining the requirements and findings acquired from these broad perspectives, we can discuss effective schemes to ensure interoperability of digital twins.

In February 2022, IOWN GF launched a task force called the "Digital Twin Framework" to begin discussions on interoperability of digital twins. As of November 2022, about 30 specialists from more than 10 companies, universities, and research institutes from Japan, the U.S., and Europe regularly participate in discussions and create documentation through bi-weekly online meetings and the remote team workspace Confluence.

We have started with use-case analysis and gap analysis and begun discussions by clarifying the technical scope that should be defined by IOWN GF in the future. Many of the use cases defined by IOWN GF use digital twins effectively in terms of energy efficiency, reduction of greenhouse-gas emissions, and safety monitoring in smart cities, and by analyzing these use cases, issues to achieving the interoperability of digital twins can be clarified. As a result, a common recognition is emerging: data-model interoperability and access control are important issues in regard to the process by which many stakeholders exchange, process, and modify digital-twin data, and we plan to discuss addressing these issues in the task force.

3. Latest developments concerning the grand challenges

The Feature Articles in this issue describe our research on the above-mentioned grand challenges, the status of development of technologies necessary for achieving them, and our recent activities as summarized in the following order.

3.1 Applied neuroscience technology for enabling mind-to-mind communication

Regarding mind-to-mind communication, we aim to construct a new communication modal that allows people to directly understand one another's sensibilities, such as how they perceive and feel. In this issue, the following applied neuroscience technologies that use human-brain information (including mind-to-mind information) are introduced: technology for decoding the sense of discomfort or satisfaction from electroencephalogram data, technology for perceiving the state of the brain containing sensory information as a representation in the brain, and neural-coupling technology for enhancing mutual understanding [1].

3.2 Creating "Shido Twin" by using Another Me technology

Regarding Another Me as a social implementation of creating a human digital twin that reproduces the appearance and inner self of a real person and acts autonomously, a digital twin of kabuki actor Shido Nakamura was built and performed in a kabuki performance. In this issue, automatic body-motion-generation technology that can reproduce an individual's subtle habits from a small amount of data as well as deep neural network-based text-to-speech synthesis technology that reproduces a variety of speakers and tone at low cost are introduced [2].

3.3 Digital twins for streamlining road-traffic flow

Regarding Exploring Engine for the Future Society, our aim is to construct a mechanism to digitally represent a society in which people are active with high accuracy and to explore the future with iterative changes in people's behavior. In this issue, reproducing and predicting traffic flow with a digital twin and traffic-demand-estimation technology to generate realistic traffic-demand data by interpolating known fragmentary cross-sectional traffic-volume data are introduced [3].

3.4 Research and development of co-simulation technology for attaining inclusive sustainability

Regarding Global Inclusive Sustainability, our aim is to evaluate the effects of policies with an understanding of the complex interactions among the environment, economy, and society to attain inclusive sustainability. Accordingly, we are building a system for evaluating those interactions by reproducing them on a computer. In this issue, a co-simulation technology for coordinating multiple simulation models, policy-evaluation prototyping, and their future prospects are introduced [4].

4. Concluding remarks

Our grand challenges are bold visions for the future that may seem unattainable at first glance. Achieving these challenges is difficult simply by improving technologies or adding new ideas. It is therefore important to use an approach to research called back-casting, i.e., goals are reached by identifying problems to be solved so that challenging goals can be reached in the shortest time. To enable this approach, it is necessary to establish promising use cases, identify areas to focus on, identify technical issues, and evaluate the impact of social implementation.

For mind-to-mind communication and Another Me, we used the sci-fi prototyping method to express concretely—in novel form—a future society that may occur when these technologies are implemented (i.e., highlighting possible social changes and the perceptions and issues of the people living there) and feeding this information back to R&D. These efforts are introduced in a special report in this issue [5].

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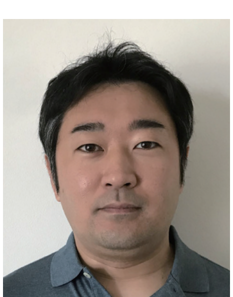

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Applied Neuroscience Technology for Enabling Mind-to-mind Communication

Airi Ota, Shinya Shimizu, Ai Nakane, and Yoshihito Muraoka

Abstract

This article introduces the following four technologies we are developing that apply neuroscience for creating a world in which people with different sensibilities can understand and respect one another: (i) technology for decoding the sense of discomfort or satisfaction from electroencephalogram data, (ii) technology for making brain states containing sensory information perceptible as representations in the brain, (iii) neural-coupling technology for enhancing mutual understanding, and (iv) mental-image-reconstruction technology for reproducing the images in the mind.

Keywords: mind-to-mind communication, digital twin, brain tech

1. Neuroscience for enabling mind-to-mind communication

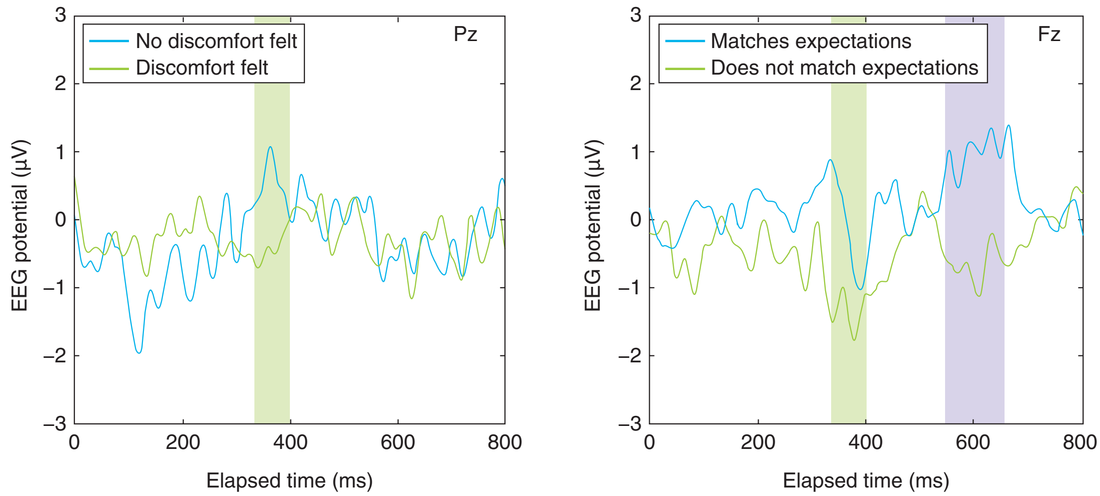
Mind-to-mind communication using Digital Twin Computing aims to achieve mutual understanding that transcends differences in individual characteristics, such as experience and sensibility, in a manner that creates a world in which mutual respect is promoted and cooperation and creativity are enhanced. We aim to create new communication media that enable us to directly understand one another's feelings, such as understanding how we perceive and feel things in our minds, and enable mind-to-mind communication by handling human-brain information that contains sensory information, subjective perception (e.g., discomfort and acceptance), and states of mind (e.g., emotions, and cognitive states). We are currently focusing on scalp electroencephalogram (EEG) data, which can be applied to the field of communication because it is inexpensive, non-invasive, and portable, and engaged in various research and development projects using brain information obtained from EEG data.

2. Brain-decoding technology for detecting subjective perception for advice

Reactions, such as discomfort or acceptance, in regard to another person's words are important subjective perceptions in communication. However, it is not easy to convey these reactions to others in an appropriate manner through current communication. For example, in situations in which instructors give advice to a student, sometimes, the receiver is unable to appropriately convey their feelings of discomfort or the receiver is not satisfied even after following the advice, and these communication discrepancies are thought to hinder effective instruction. Considering those discrepancies, we have been researching *brain-decoding technology* for detecting subjective perception, such as discomfort and acceptance, through EEG measurement.

Previous studies have reported that a specific brain response (event-related potential[*1]) is generated by the discomfort that occurs when presented with

*1 Event-related potentials: Brain potentials that temporally fluctuate in relation to internal and external events.



(a) Short-instruction task: N400 response when discomfort is felt in response to presented instructions (electrode position: Pz)

(b) Shogi task: N400/N600 response when the presented move does not match the expected move and causes discomfort (electrode position: Fz)

Fig. 1. Results of EEG measurements for short-instruction and shogi tasks.

extremely unnatural writing [1, 2]. The event-related potentials associated with discomfort are known as N400[*2] responses that occur when a person experiences a feeling of discomfort. However, the sentences presented in these studies were not natural sentences as used in communication; rather, they were obvious semantic errors (e.g., "He put a sock on the warm bread.") and world knowledge errors (e.g., "Dandelions are black."). Understanding the subjective perceptions of others is also extremely important not only in verbal communication, as reported in the above studies, but also in nonverbal communication. In this study, we investigated the brain responses of participants performing (i) a task in which they were presented with short instructions written in more natural sentences than those of the previous studies and (ii) a task in which they were presented advice on moves in *shogi* (Japanese chess).

The results of the short-instruction task (**Fig. 1(a)**) indicate that (i) even when instructions in more natural sentences than previous studies were presented, the same N400 response was observed as reported in a previous study when the receiver felt the instruction uncomfortable, and (ii) the N400 response was stronger when the receiver felt uncomfortable and chose not to accept the instruction, i.e., when the receiver showed strong rejection of the instruction.

The results of the shogi task (**Fig. 1(b)**) indicate that the same N400 was observed as in the short-instruction task when the receiver felt uncomfortable because the move did not match the expected move, but N400 was attenuated when the receiver accepted the move even though it did not match their opinion. We also observed an apparent N600 response along with N400. Since N600 has been reported to occur during the process of finding solutions to contradictions in logical thinking and understanding of rules, it is likely that, in this case, it was caused by a cognitive process of trying to interpret a move that felt uncomfortable.

These new findings, which expand on previous research, suggest the possibility of using EEGs to estimate the presence or absence of discomfort and whether agreement can be reached in general verbal-communication situations in which natural sentences are exchanged as well as in nonverbal-communication situations. For future work, we will investigate the precise conditions under which each response occurs and work toward achieving real-time brain decoding that detects states of mind from EEG data.

3. Brain-representation visualization technology for enabling the perception of brain expressions

Through conventional verbal and nonverbal

*2 N400 and N600: Negative EEG potential fluctuations seen at approximately 400 and 600 ms, respectively, after the event.

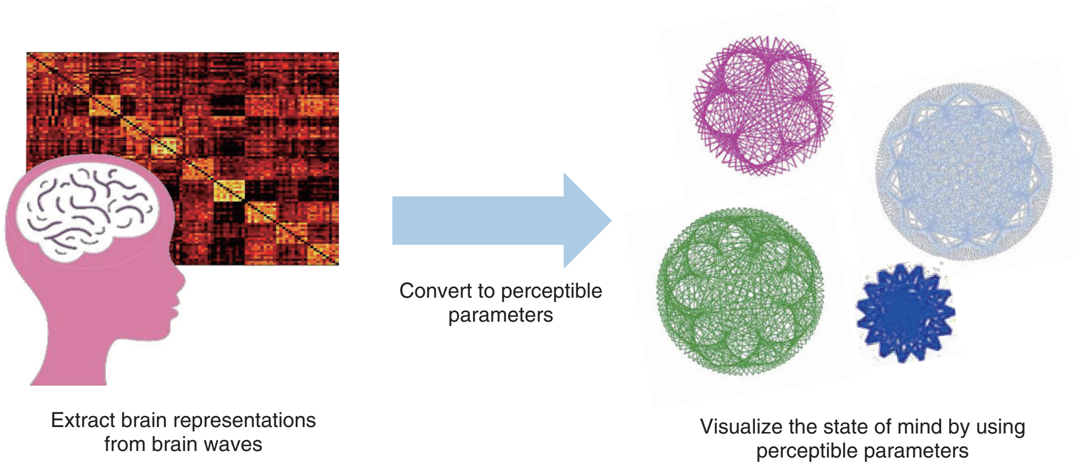


Fig. 2. Perceptualization of brain representations of states of mind using EEG data.

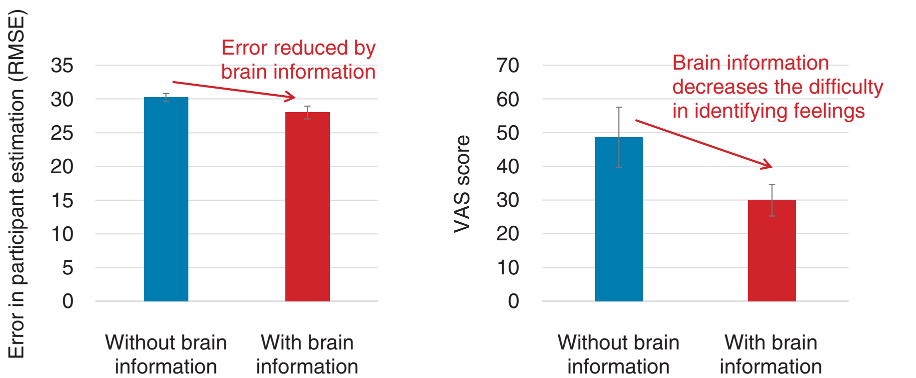
communication, it is impossible to convey individual's states of mind such as emotions, and cognitive states to others with 100% accuracy. It is not easy to fully understand the state of mind, even within ourselves. Most studies on sensory communication have focused only on emotions, which are the most well-known and easy to handle types of states of mind. Emotions are mostly evaluated in terms of several categories or in two dimensions, and it is difficult to fully express new emotions or detailed differences in emotions. However, we believe that various states of mind can be expressed by visualizing the state of the brain activity during a certain emotion. Therefore, we developed brain-representation visualization technology that enables real-time perception of brain activities in a multi-dimensional representation.

To enable the transmission of various states of mind, this technology extracts brain information (i.e., brain representations) related to subjective perceptions and states of mind from EEG data, compresses those representations into seven dimensions, and uses them as parameters for perceptibility. It then draws various geometric figures in accordance with the state of mind and displays them as animations in real time (**Fig. 2**).

Considering individual differences in brain representations, an individual model of brain representations is created using EEGs obtained in advance. The EEGs used for model creation determine the type of sensory information to be included according to the purpose, for example, EEG data are acquired while recalling various emotions or tasting various dishes. A geometric figure called Rose of Venus*3 is used to express various states of mind in terms of the size, color, and pattern shape of that figure.

We experimentally verified the effectiveness of this technology through a task in which a participant estimated using the visual analogue scale (VAS) whether another person felt a type of food was delicious. The results indicate that the estimation error was reduced by watching the other person's brain representation; in other words, the brain representation facilitated understanding of the other person's preference (**Fig. 3(a)**). We conducted another task in which we asked participants to describe their feelings through the VAS after an emotional episode while looking at their own brain representations. The results from this task indicate that the effect of looking at their brain representations was to reduce the difficulty of identifying their feelings; that is, it enabled them to identify their feelings through their brain representations (**Fig. 3(b)**). Our future work includes investigating changes in the accuracy of reading brain representations when this technology is used continuously in communication situations, verifying its long-term effectiveness, and studying more appropriate visualization methods. We will also continue our efforts in generating facial expressions from brain representations of people with various diseases such as ALS (amyotrophic lateral sclerosis) and in situations where facial expressions cannot be made (such as virtual reality environments).

*3 Rose of Venus: A "five-petaled flower" figure that can be drawn by connecting the respective positions of Venus and Earth with lines at regular intervals in a manner that uses the difference in their orbital periods.



(a) Error in estimating the other person's perceived deliciousness of food when the participant sees or does not see the other person's brain representation

(b) Difficulty in identifying one's feelings with and without brain representations

RMSE: root mean squared error

Fig. 3. Results of experiments to verify the effectiveness of brain-representation visualization technology.

4. Neural-coupling technology for synchronizing the brain and promoting empathy and cooperation

We are striving to create an environment of mutual understanding and cooperation as well as detect states of mind and make subjective perceptions communicable. A previous study reported that a synchronous phenomenon was observed in the brain activities of two people when they were empathizing with each other or performing cooperative tasks [3]. Given that finding, we thought that it might be possible to create a state of easy empathy and cooperation by inducing a synchronized state through intervention. We believe that neurofeedback*4—which provides feedback on the current state of brain-wave synchronization—may induce a synchronized state of brain waves. Accordingly, we are researching neural-coupling technology to increase the quality and quantity of communication, thus making shared tasks smoother.

This technology executes neurofeedback by separating EEG data into four frequency bands (i.e., δ, θ, α, and β waves), calculating the coupling rate of each frequency band in real time, and outputting the calculation results. Therefore, it is possible to perform cooperative tasks and communicate while viewing the current coupling rate and its overall trend on a screen (**Fig. 4**).

In an experiment to verify the effectiveness of this technology, participants played a cooperative video game as a cooperative task. From the result, we confirmed that there is a correlation between the coupling rate of alpha waves in brain waves and the efficiency of cooperative work (**Fig. 5**). For future work, we will (i) confirm the effects of improving the coupling rate on the quality and quantity of communication and on task efficiency during cooperative work and (ii) investigate appropriate intervention methods to increase the coupling rate.

5. Mental-image-reconstruction technology for reproducing mental images

It is difficult to accurately express the images in one's mind (i.e., mental images), and this difficulty directly leads to the problem of being unable to accurately convey the mental image one wants to convey to the other person in a conversation. With the recent developments in artificial intelligence in image generation, various image-generation techniques using textual information have been developed; however, generating mental images from textual information alone is limited. Referencing previous studies [4, 5] on functional magnetic-resonance imaging (fMRI) and intracranial electroencephalography (electrocorticography, ECoG) for decoding mental images, we are now striving to attain mental-image decoding using EEG, which is easier to measure than using fMRI and ECoG.

*4 Neurofeedback: A type of biofeedback that uses brain information (obtained by EEG, fMRI, etc.) to adjust brain activity.

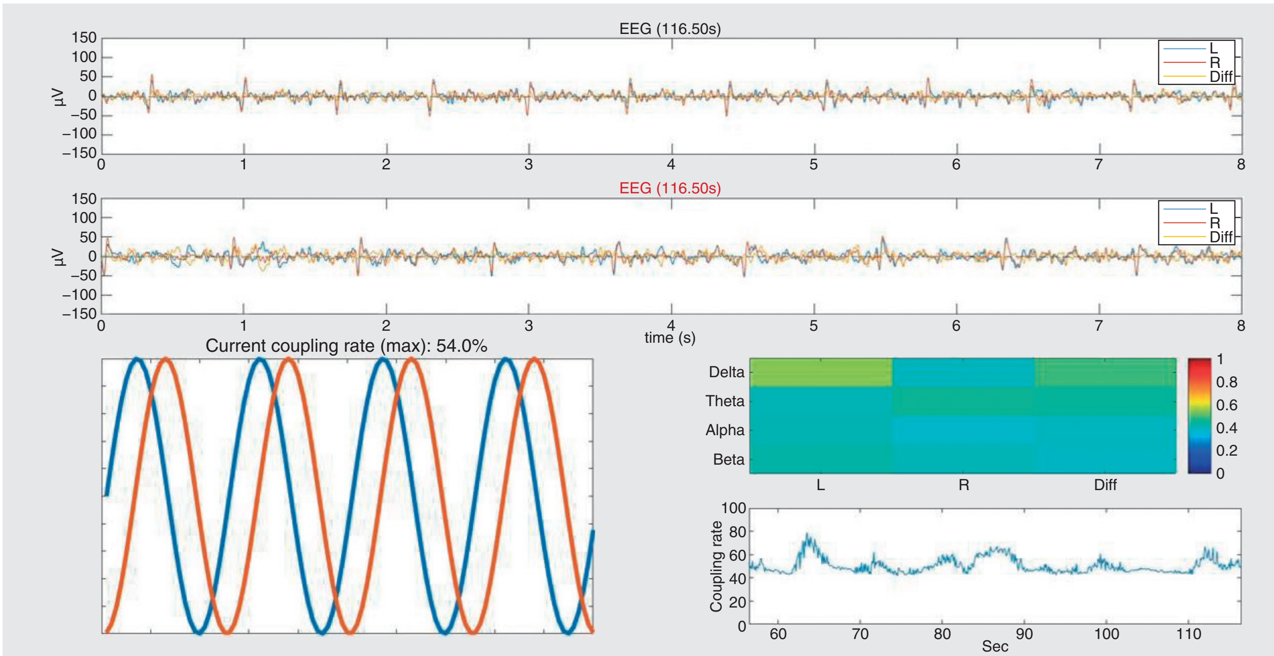


Fig. 4. Feedback screen showing coupling rate of two parties.

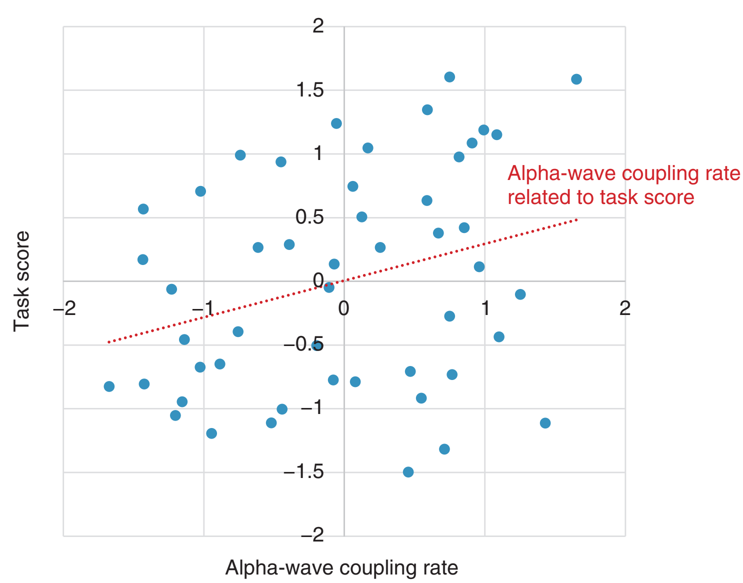


Fig. 5. Relationship between coupling rate of alpha waves in EEG and efficiency of cooperative work.

As a first step in our efforts, we used a category-classification task, which has been used in previous studies, to experimentally verify estimating the content of perceived and imagined images. The estimation accuracy concerning the three categories of images (landscape, vehicle, and human face) used in this experiment exceeded the chance level for perceived images, but there is room for improvement for imagined images. For future work, we will attempt to improve the accuracy of category estimation by studying models optimized for decoding perceived and imagined images and selecting EEG features. We will also aim to achieve mental-image reconstruction by studying decoding other than decoding of categories.

6. Concluding remarks

By using the various technologies that apply neuroscience introduced in this article, we aim to enable (i) communication that promotes awareness of one another's differences, empathy, and compassion and (ii) communication that enables mutual understanding by making it possible to express states of mind that were not possible until now. To achieve these aims, we will continue to work toward a world in which we can understand and cooperate with one another by making it possible to share the subjective perceptions and states of mind necessary for mutual understanding and mutual respect rather than by transmitting all our true feelings and inner thoughts.

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Creating “Shido Twin” by Using Another Me Technology

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Abstract

“Cho Kabuki 2022 Powered by NTT,” a kabuki play sponsored by Shochiku Co., Ltd., is the first social implementation of Another Me, a technology for creating a human digital twin that reproduces the appearance and internal aspects of a real person while acting autonomously. We created a digital twin of the star of Cho Kabuki, Shido Nakamura, and call it “Shido Twin,” which performed in the play alongside virtual diva Hatsune Miku. This article overviews this initiative and describes the main technologies behind Cho Kabuki 2022, i.e., automatic body-motion generation and deep neural network-based text-to-speech synthesis.

Keywords: digital human, AI, kabuki

1. Introduction

Another Me, one of the grand challenges concerning Digital Twin Computing (DTC), aims to extend opportunities for self-realization and personal growth beyond constraints such as time, space, and handicaps by having a digital twin of a real person act in place of that person in society. We have set *identity*, *autonomy*, and *oneness* (**Fig. 1**) as requirements for creating one’s Another Me and are researching and developing technologies to satisfy those requirements.

For a person’s Another Me to act as that person in society, it must first have *identity*, which means that it is recognized as that person by reproducing their external characteristics, such as appearance and movements, as well as their internal aspects, such as personality and values. To overcome time, physical, and cognitive handicaps, one’s Another Me must then have *autonomy* so that it can understand situations, make judgments, and act in the same way as the person it represents without that person having to operate or give instructions at every step. To acquire a sense of accomplishment through self-realization and personal growth from the results of the activities of one’s Another Me that fulfill the first-two requirements, it is necessary to maintain *oneness* between the person and their Another Me by feeding back the results to the person with a real feeling as if that person had experienced them.

2. Initiative to create Shido Twin

An entity that completely satisfies all three requirements can be called Another Me; however, in reality, it is necessary to determine which requirements should be satisfied to what extent in accordance with the application area of that entity. Taking the first step in the social implementation of Another Me, we focused on creating identity and took on the challenge of recreating an actor on a theater stage as a venue for this creation. In cooperation with Shochiku Co., Ltd., which has been working on “Cho Kabuki”—combining kabuki (Japan’s traditional theater) and NTT’s latest technologies, i.e., automatic body-motion-generation and deep neural network (DNN) text-to-speech (TTS) synthesis, we created a digital twin (called Shido Twin) of the star of Cho Kabuki,

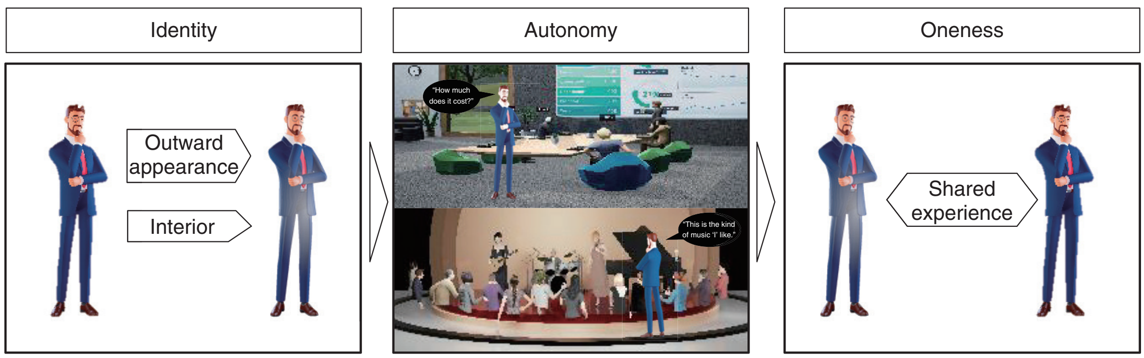

Fig. 1. Three requirements of Another Me.

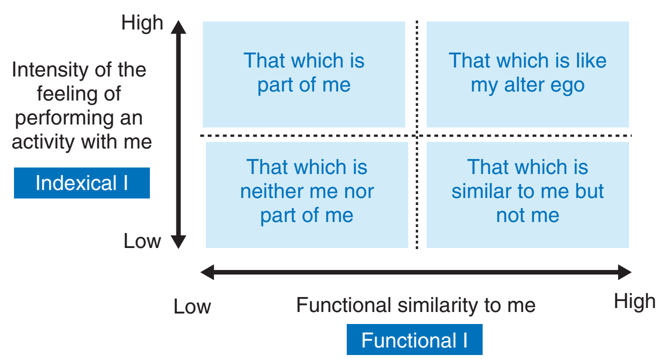

Fig. 2. The two-layered structure of the "I" concept.

Shido Nakamura, and had Shido Twin greet the audience in place of him. Since many in the audience of Cho Kabuki are fans of Shido Nakamura and Cho Kabuki, satisfying the demand of a high level of personal identity, especially in terms of external appearance, is challenging. That demand leads to the question of what does it mean to recognize the identity of an entity such as Another Me that is not the actual person? We have explored this question through co-creation with experts in philosophy and have come to understand identity along two axes: "Functional I" and "Indexical I" (**Fig. 2**).

Functional I refers to the fact that a person's external characteristics, such as appearance and movement, as well as skills and abilities, are the same as those of the person in question. In consideration of this fact, this project involved about half a day of studio recording to create an elaborate three-dimensional computer graphics model of Shido Nakamura and construct a machine-learning model that can generate the gestures and voice similar to the actor.

In contrast, Indexical I is the idea that Another Me can share *indexicality* (consciousness that points to the person such as "he," "she," and "I") by making the past experiences that characterize the person felt by Another Me. For the project, targeting fans of Cho Kabuki, we asked Shido Nakamura to perform the gestures and vocalizations that fans have come to know from past Cho Kabuki performances to reproduce the rousing of the audience. Costumes and dialogues that would not be out of place in a traditional cultural setting as well as the interactions with the live performers on stage were finalized after close consultation with Shochiku. The technologies for creating Shido Twin are described in the following sections.

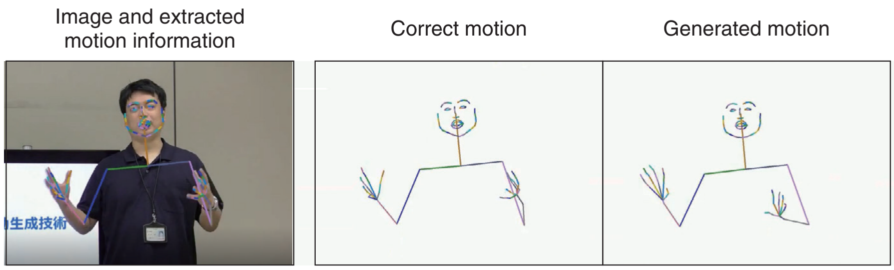

Fig. 3. Example of motion generated using automatic body-motion-generation technology.

3. Automatic body-motion-generation technology that can reproduce even the most subtle individual habits from a small amount of data

It is considered important for Another Me to be felt as having the same personality, voice, speech, and body motion of the real person, not to mention appearance. We have previously shown that differences in body motions, such as facial expressions, facial and eye movements, and body gestures, are major cues for perceiving differences in personality traits [1] and identifying others [2]. It is therefore important to control the motion of Another Me so that it automatically generates the body motion of the person in question, which is a difficult technical challenge from an engineering standpoint. We have been investigating technologies for generating human-like body motions and body motions based on personality traits from spoken text [3, 4]; however, we have not been able to generate motions that can mimic the subtle habits of a specific person in real life.

We developed a technology for automatically generating body motions, in a manner that mimics the subtle habits of a real person during speech, on the basis of Japanese speech and its textual information. Simply by preparing video data (time-series data of audio and body images) of a real person, it is possible to construct a generative model that automatically generates body motions that are typical of that person. By using this generative model, a user can automatically generate a person-specific behavior during speech by simply inputting speech sounds and their text information. First, speech-recognition technology is used to extract speech text from the speech data contained in the video of the target person, and the positions of joints of the body are automatically extracted from the image data. Next, a deep-learning generative model called a GAN (generative adversarial network), which can generate the positions of joints of the body from speech and speech text, is trained. To construct a model that can generate a wide range of motions by capturing even the most detailed habits of a person during training, we devised a mechanism for appropriately resampling the training data during training and have maintained the world's highest performance in subjective evaluation of human-like qualities and naturalness (as of November 2022) [5]. With this technology, we constructed a model for generating body motions by using Japanese speech as input. Examples of the input video of the person, result of body-motion generation, and actual correct body motion in the input video are shown in **Fig. 3**. We are also currently developing a learning method using the mechanism *few-shot learning* that can train models with only a small amount of data and without using a large amount of video data (training data) from a specific individual. With this method, we constructed a motion-generation model that can reproduce even the most subtle habits of Shido Nakamura from a small amount of video data (approximately 10 minutes) of him speaking and used the motion-generation results to control the motion of Shido Twin.

4. Saxe, a low-cost DNN TTS synthesis engine that reproduces a variety of speakers and tones

Voice is one of the most-important elements in reproducing a person's personality. TTS synthesis technology should be able to reproduce the desired speaker's voice with high accuracy. However, generating high-quality speech of a desired speaker requires a large amount of speech data uttered by that speaker, for example, up to 20 hours to produce high-quality synthesized speech with the concatenative TTS method Cralinet [6]. Consequently, the cost of recording voices and constructing databases has been

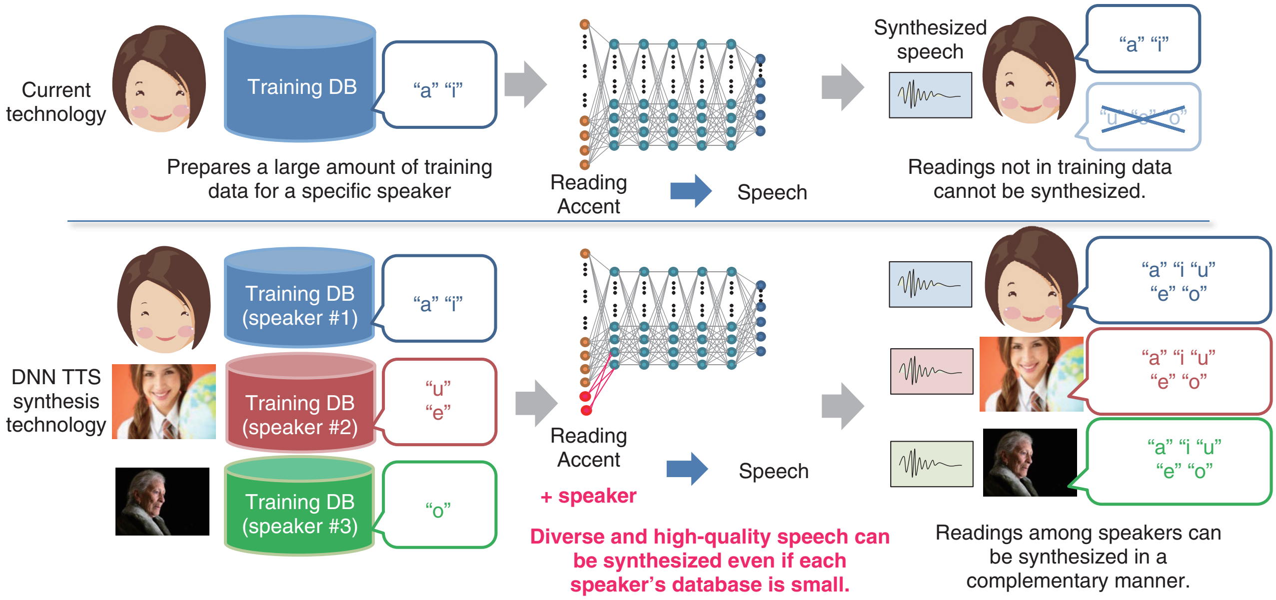

Fig. 4. DNN TTS synthesis technology for reproducing diverse speaker characteristics.

a major issue in regard to achieving TTS of desired speakers.

To address this issue, we developed a TTS engine called Saxe, which is based on a DNN [7]. Saxe uses a speech database (built from the utterances of a large number of speakers) and deep learning to synthesize high-quality speech of the desired speaker from a small amount of speech data. The characteristic feature of Saxe is that a large amount of speakers' speech data is modeled with a single DNN (**Fig. 4**). Information necessary for speech production, such as pronunciation and accent, is learned from a large amount of pre-prepared speech data, and the speaker characteristics of a desired speaker are learned from a small amount of speech data of the desired speaker. It is thus possible to generate high-quality speech even with a small amount of speech data of the desired speaker.

It is also important to reproduce the performance as well as the voice of the person by reproducing speech features, such as inflection and speech rhythm, as well as the tone of the voice. However, very specific articulations, such as those used in acting, make it very difficult to reproduce speech rhythms from a small amount of speech data. In response to this difficulty, we are developing a technology for extracting inflection and speech rhythm from a small amount of speech data of a desired speaker. When a small amount of speech is input to the DNN, the DNN outputs a low-dimensional vector of the inflection and speech rhythm of that speech [8]. During speech synthesis, the resulting low-dimensional vectors are combined with the aforementioned speech-synthesis DNN to generate synthesized speech with the desired tone, inflection, and speech rhythm of the speaker's voice.

5. Concluding remarks

Shido Twin created with these technologies performed in "How to Appreciate Cho Kabuki," an explanation of the appeal of Cho Kabuki, as one of the performances in "Cho Kabuki 2022 Powered by NTT," and it was well received (**Fig. 5**). This initiative showed that the Another Me technology can reproduce identity at a quality that can satisfy the demands of commercial performances. We will continue to develop the identity and autonomy of Shido Twin and strive to demonstrate the social value of Another Me in a variety of settings.

Shido Twin

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https://group.ntt/jp/newsrelease/2022/08/03/pdf/220803aa.pdf

Fig. 5. Scenes from the performance of Shido Twin.

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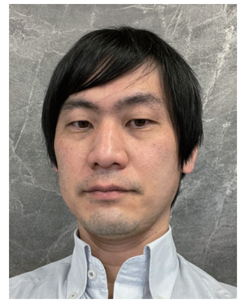

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Digital Twins for Streamlining Road-traffic Flow

Miho Fujishima, Masaru Takagi, Masato Yokoya, and Ryota Nakada

Abstract

We are studying the use of digital twins to optimize traffic flow so that traffic congestion will not occur. To reproduce current real-world traffic flow and predict future traffic flow using digital twins requires traffic-demand data with fine granularity in time and space. Due to recent increasing activity to create smart cities, we can now obtain cross-sectional traffic-volume data for short time intervals of five minutes, but such measurements are still only being taken at a relatively small number of locations, so spatial granularity is large. In this article, we introduce our OD (origin-destination)-estimation technology that uses cross-sectional traffic volume on arterial roads to interpolate such fragmented cross-sectional traffic data to generate realistic traffic-demand data.

Keywords: Exploring Engine for the Future Society, digital twin, traffic-flow simulation

1. Smart city and digital twin technology

Smart city initiatives have become more active as measures to address urban issues such as the rapidly aging population and increasingly frequent natural disasters, and digital twin technology has been attracting attention for implementing such initiatives. This is because it reproduces real-world conditions in digital space, based on detailed geospatial and sensor data, and makes it possible to conduct social experiments and simulations that would be difficult or impossible to do in the real world. For example, it can be used to simulate changing traffic conditions when poor weather causes flooding and blocked roadways, or to evaluate the effects of changing the shape or placement of buildings on weather factors such as wind. We are using digital twin technology to create a highly accurate representation of human activity in society and conducting research and development on an "Exploring Engine for the Future Society," which provides a mechanism for exploring possible futures by iteratively making changes to human behaviors.

2. The difficulty of reproducing traffic flow

Traffic is one essential element that must be simulated using digital twins of human activity. Traffic-flow simulation on a digital twin can simulate traffic on the actual roads of a town on the basis of current data from sensors in the real world and can be used to evaluate measures to address general traffic issues such as draft or preliminary measures to mitigate congestion and optimizing routes for on-demand bus operation. To reproduce the flow of vehicles on a wide-area road network such as a city requires three essential elements: map data, traffic-demand data, and vehicle models. However, very few comprehensive datasets from actual society exist for any of these, and it is very difficult to obtain true values. Traffic-demand data has three aspects: survey frequency, roadways covered, and vehicles covered; and there are no datasets that satisfy all three. Thus, all available data are difficult to use for digital twins, which need to reproduce the movements of each vehicle with fine granularity in space and time. As such, we have developed origin-destination (OD)-estimation technology to estimate traffic demand on the basis of cross-sectional traffic-volume*1 data and

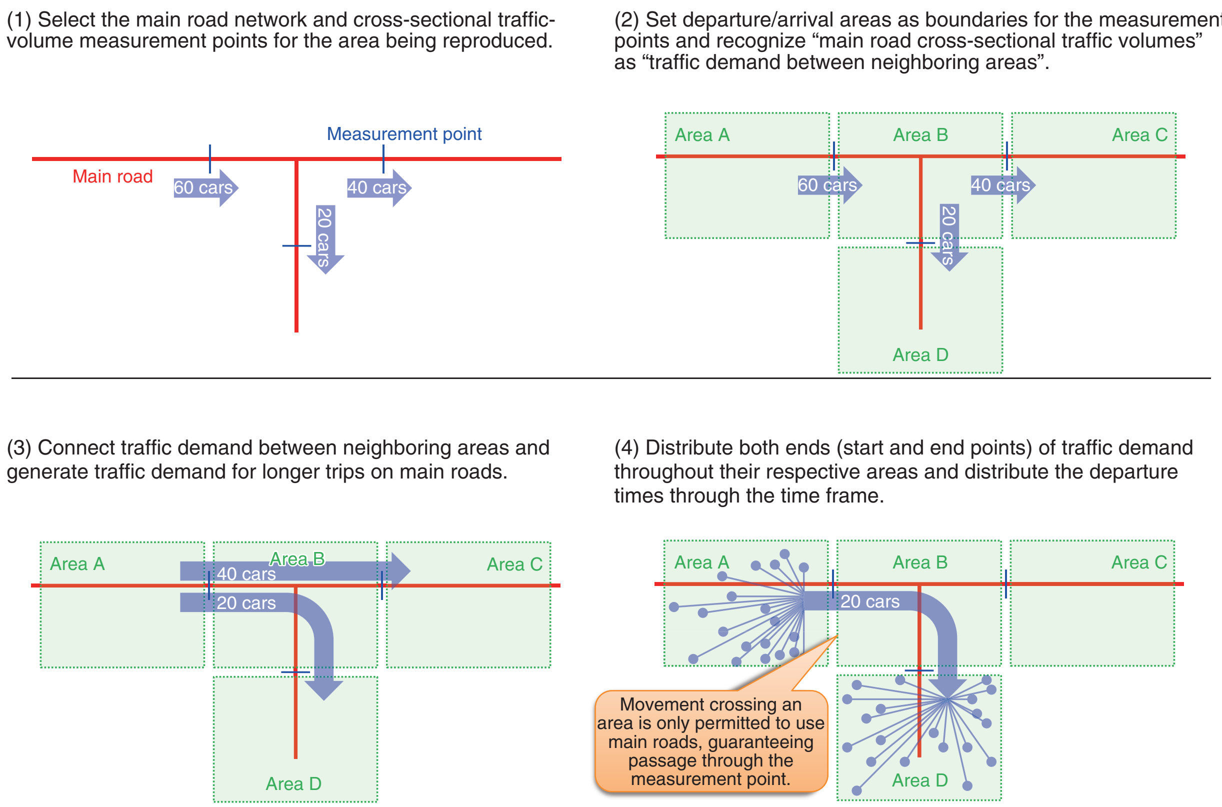


Fig. 1. Our OD-estimation technology that uses cross-sectional traffic volume on arterial roads.

estimate traffic volume on segments where traffic counters are not installed. The available five-minute cross-sectional traffic-volume data satisfy the survey-frequency and vehicle-type aspects but only covers some roadways, so our OD-estimation technology compensates from the perspective of roadways covered.

3. Estimating traffic demand on basis of cross-sectional traffic-volume data

Traffic-demand estimation had generally been done with a four-step model[*2], using results from person-trip studies and surveys to obtain data on the start, end, and route-taken by moving people and vehicles. Person-trip surveys aggregate the number of people (or vehicles) moving per unit time for pairs of starting and ending locations and conducted every five to ten years by local and national governments. Although it has the advantage of fine spatial granularity, it is only an average value for a specific day of the week, since the survey is conducted once every 5 to 10 years, and does not take into account variations related to seasons and days of the week. Thus, we focused on using cross-sectional traffic-volume data with five-minute granularity collected by local police agencies using traffic counters installed on major roadways throughout Japan. These counters are installed at relatively few locations so the spatial granularity is coarse, but the spatial data can be interpolated between neighboring installations, making it possible to estimate the movements of vehicles to some extent.

With our OD-estimation technology, we first extract the structure of the main road network and the placement of points where cross-sectional traffic volume is measured in the area being reproduced (**Fig. 1(1)**). We define vehicle departure and arrival areas such as Area A and Area B as the boundaries for

*1 Cross-sectional traffic volume: Refers to the volume of traffic (number of vehicles) on each roadway at an intersection, by cross-section.

*2 Four-step model: A model for estimating future traffic demand consisting of five estimation steps: (1) estimate generated traffic volumes, (2) estimate occurring/concentrated traffic volumes, (3) estimate traffic-volume distributions, (4) choose a traffic mode, and (5) select traffic routes. It is widely used for estimating traffic demand.

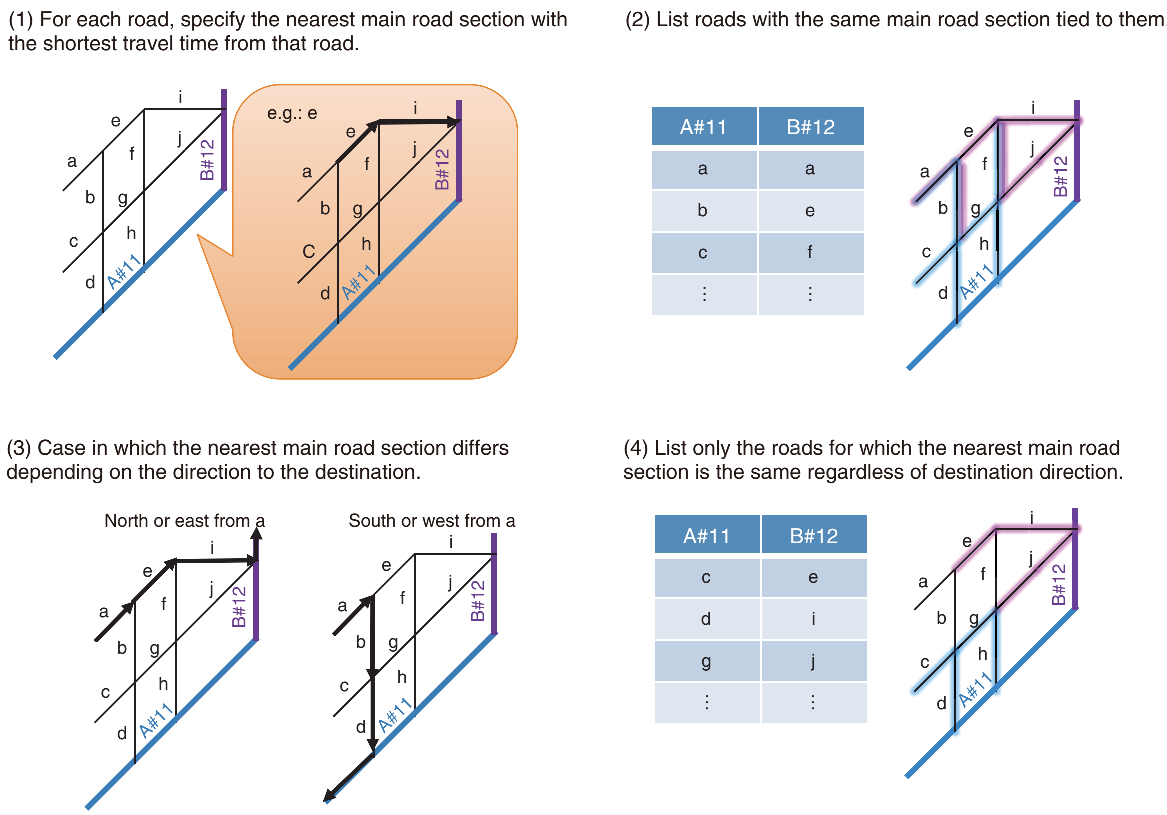


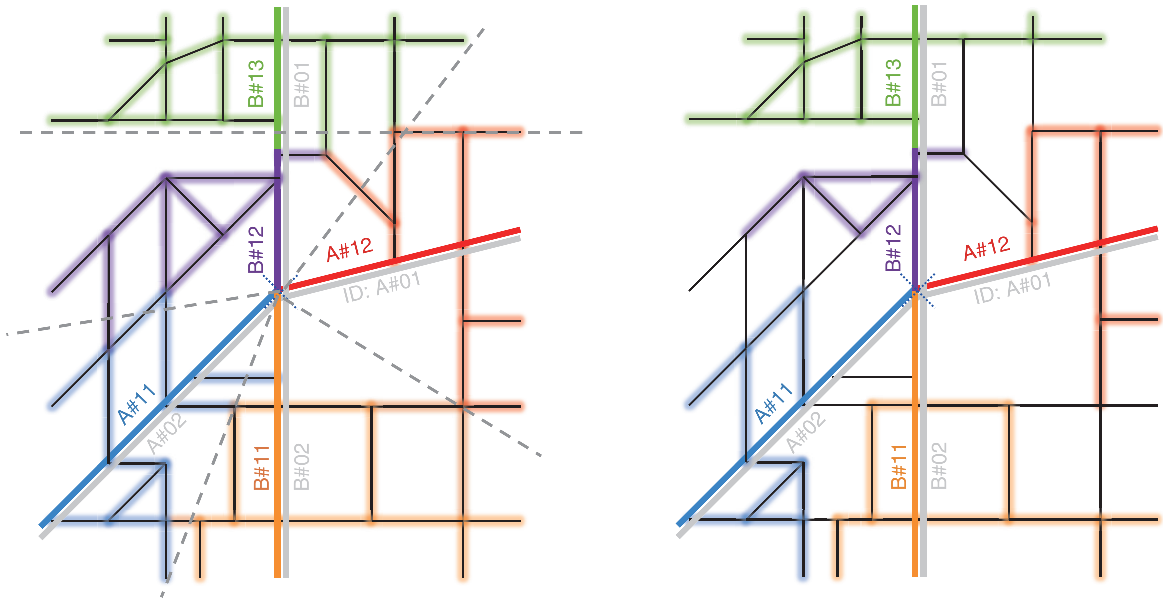
Fig. 2. Procedure for setting departure/arrival areas.

these measurement points and interpret the cross-sectional traffic volume on main roadways as the traffic demand between adjacent areas (**Fig. 1(2)**). We then generate traffic demand for longer trips by concatenating traffic demand for very short trips between adjacent areas while giving priority to routes that run along specific main roads (**Fig. 1(3)**). Next, we distribute the traffic demand at both departure and arrival ends over the roads throughout the respective areas (**Fig. 1(4)**). This enables us to reconcile the cross-sectional traffic volumes at all measurement points and generate real travelling routes on main roadways, including left and right turns. We are also able to improve the accuracy of interpolating spatial information by adjusting distribution conditions for departure and arrival points in accordance with factors such as the location and scale of large commercial facilities and differences in day and night population distributions. This technology has enabled us to estimate traffic demand at fine time granularity of five-minute intervals and space granularity of several square kilometers.

4. Setting departure and arrival areas

We now describe setting the departure and arrival areas (Fig. 1(2)) in more detail.

We define departure and arrival areas to correspond to sections of the main roadways, segmented by the points where cross-sectional traffic volumes are measured. To consider traffic originating and arriving at smaller roads surrounding the main roadways, we select roads connected to each of the main-road sections. At first glance, it may seem that defining areas geometrically would be good, but considering how geography is divided by changing terrain, rivers, roadways, one-way roads, and speed restrictions; however, this produces areas that do not seem to surround routes naturally taken by vehicles. Intuitively, we want to choose roads that are closest to that section of the main road, so we developed a method that partitions areas from the perspective of travel time using road-map data. This method identifies, for each road, the nearest main road section with the shortest travel time from that road using the traffic flow simulator's route-search function (**Fig. 2(1)**). Finally, a list



Geometric area partitioning

With partitioning method

Thick lines: main road sections (with cross-sectional traffic-volume measurement locations by color)

Fig. 3. Example of partitioning departure/arrival areas.

of roads identified as the same main road section is compiled and linked to that section to define departure and arrival areas (**Fig. 2(2)**). There will still be cases in which the main road sections are different depending on the direction of the destination (**Fig. 2(3)**). In such cases, movement straddling areas can occur on back streets and can be separate from traffic volumes on main roads, so we solve this by only listing roads that are judged to be the nearest to the same main road, no matter what destination is selected (**Fig. 2(4)**). Accordingly, we can guarantee passing the specified measurement point by simply specifying the departure and arrival areas without specifying a route. The roads that are not colored in the right image of **Fig. 3** are those excluded when making the list using this partitioning method because there are multiple main roads nearby, so the main road taken will differ depending on the direction to the destination. The computational cost for this method is O(n) with respect to the number of roads, n. This is much less than a brute-force approach, which would be O(n^2). By selecting departure and arrival areas in this way, we can avoid having main road traffic volumes straying too far from real values, even when converting to traffic demand between areas.

5. Estimating traffic volumes where there are no traffic counters installed

Our OD-estimation technology can generate real traffic demand, but it is only applicable to sections that have traffic counters installed. To expand the applicable range to include areas without traffic counters, we introduced the idea of equilibrium assignment. Equilibrium assignment is an approach that focuses on the travel time required when allocating numbers of vehicles to various roads for routes between locations.

When there are multiple routes connecting a departure and an arrival point, drivers generally try to select a route to minimize the travel time required to move between the points. We also assume that drivers always have complete information regarding the available routes. Travel time depends on the amount of traffic, so it will vary depending on the route that each driver selects. For example, if many drivers select route 1, traffic on route 1 will increase, causing congestion and increasing the time required to move between points, but since route 2 is being selected

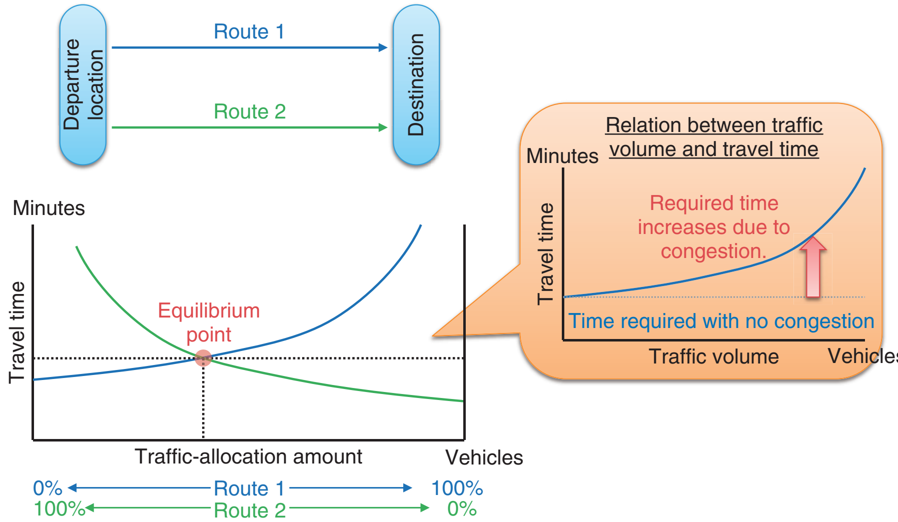


Fig. 4. Equilibrium assignment.

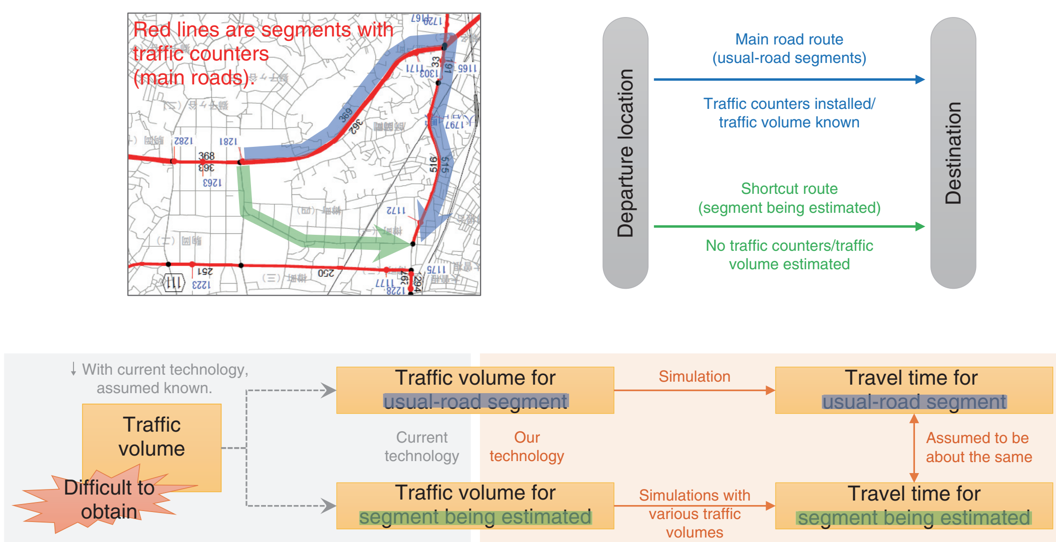


Fig. 5. Difference in function between our technology and current technology for segments without traffic counters installed.

less often than route 1, its traffic and travel time will decrease on route 2. This relationship between traffic volume and travel time has been formalized, and equilibrium can be reached through balance of supply and demand. Therefore, if drivers have sufficient information, the travel time on all used routes will equalize, and be less than unused routes, or converge to be mostly equal (**Fig. 4**).

The difference in function between our technology and current technology is shown in **Fig. 5**. We describe the process using an example of main roads and shortcuts that connect the main roads. We assume that traffic counters are installed on the main roads but not on the short-cut roads. We use this approach to estimate the traffic volume on the shortcut.

First, we find the short-cut route (green in Fig. 5) and the usual route using main roads (blue). We then estimate the travel time for both routes. We have traffic-volume data from traffic counters on the main-roadway route, so these data can be used to simulate traffic flow and determine the travel time. However, there are no traffic-flow data for the shortcuts, so various assumptions must be made to simulate traffic flow and determine the travel time. Even using the same route, travel time will depend on the traffic volumes, so we expect the computed travel time to differ depending on the assumed traffic volume. In this case, returning to the equilibrium assignment idea, the travel time for both routes will naturally be the same. Thus, we can use the traffic volume that would yield the same travel time as the main-roadway route. With this approach, without using total traffic as with current technology, we expect to extend our OD-estimation technology to segments where traffic counters are not installed.

6. Future prospects

We introduced technology for generating realistic traffic-demand data as needed to recreate past traffic conditions using cross-sectional traffic-volume data. To increase the accuracy of reproduced traffic conditions and predict future traffic conditions using current conditions as a starting point, we will study ways to use vehicle-probe data from connected cars, which are starting to become more common. Vehicle-probe data can be obtained more closely to real-time than can cross-sectional traffic-volume data. Such data are easier to process and can provide more details about vehicle behavior, such as the route and travel time, so they are expected to be an essential data source for recreating digital twins in real time. Connected cars are still just beginning to permeate society, so there is not much data yet, and it is still difficult to get an overall perspective on traffic conditions. Therefore, we are also studying ways to use the behavior of connected cars to estimate the behavior of non-connected cars.

At NTT, we will continue to develop traffic-flow digital-twin-generation technology by integrating technologies to estimate, predict, and reproduce traffic flows.

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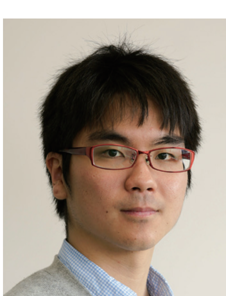

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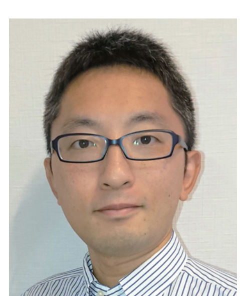

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Research and Development of Co-simulation Technology for Attaining Inclusive Sustainability

Tetsuya Fukuda and Masahiro Maruyoshi

Abstract

To achieve inclusive sustainability, policies must be drafted and evaluated with an understanding of the interactions among the environment, economy, and society. To address this issue, NTT Human Informatics Laboratories is reproducing the environment, economy, and society on computers and using these simulations to evaluate policies. This article gives an overview of a co-simulation technology that will enable multiple simulation models to work together to achieve this goal. It also introduces prototyping of policy evaluation and discusses future prospects for this technology.

Keywords: co-simulation, sustainability, system of systems

1. Toward inclusive sustainability

The NTT Digital Twin Computing Research Center in NTT Human Informatics Laboratories has defined *inclusive sustainability* to mean sustainability that enables harmonization of the autonomy of the global environment, inclusive of the economic and social systems that are part of that environment [1]. To achieve inclusive sustainability, we seek to evaluate the effects of policy on the basis of an understanding of the complex interactions among the environment, economy, and society. However, it is difficult to understand all potential interactions by only observing the real world and difficult to evaluate such effects in the real world due to the cost of enacting them, time required for the effects to manifest, and fact that the effects may be irreversible. Therefore, we are investigating the modelling of environmental, economic, and social systems computationally and building a system that can be used to evaluate policies.

2. Developing co-simulation technology

Our approach to computer simulation of the environment, economy, and society follows the Digital Twin Computing (DTC) concept. Digital twin simulators of each phenomenon are created and combined in a simulation in an attempt to replicate reality. In an example described later in the article, a simulation of the water cycle in the natural environment is combined with simulations of human agricultural activity.

To adopt this approach, a technology to link individual simulators together is needed. We call this type of technology co-simulation technology. We have extracted requirements for co-simulation technology from our DTC White Paper [2], a survey paper on co-simulation [3], current specifications, such as FMI (Functional Mock-up Interface), HLA (High-Level Architecture), DCP (Distributed Co-simulation Protocol), and by prototyping use cases we have formulated. By selecting requirements from the following three perspectives, we aim to provide co-simulation technology that can be applied to various use cases with minimal revisions to software.

(1) Provision of basic co-simulation functionality
(2) Provision of functionality to analyze the speed and accuracy of computation
(3) Reusable models and data

The selected requirements are summarized in **Fig. 1** and described in detail as follows.

Requirements from perspective (1). A unified mechanism, called logical time, is needed to manage

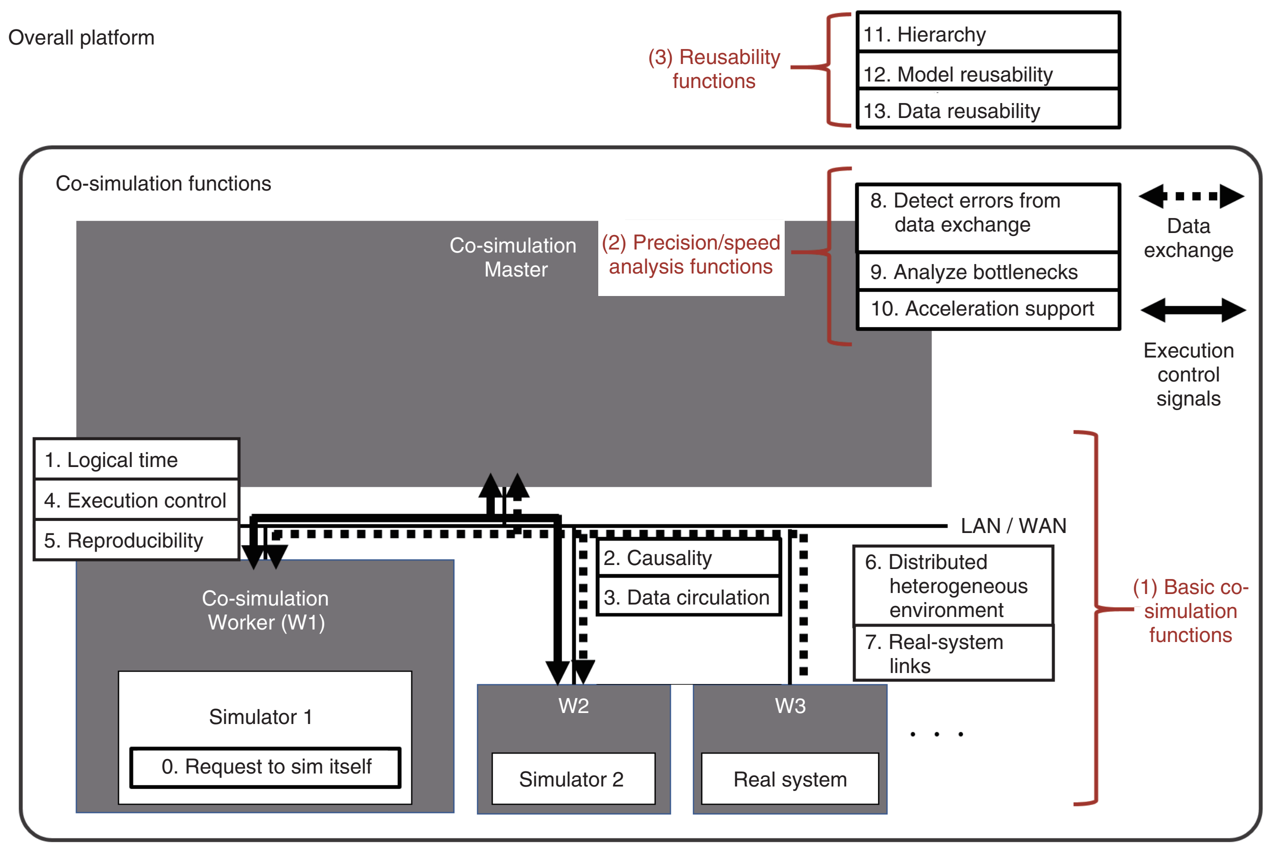


Fig. 1. Overview of co-simulation platform-technology requirements.

the internal time maintained independently within each simulator. There must also be a mechanism to exchange data among the simulators in accordance with the causality among simulator variables. This also requires management and control of the progress of each simulator in accordance with logical time so that such data exchange can occur at times appropriate for the simulators. Except for cases in which each simulator intentionally introduces a random disturbance, the computation results must be reproducible. This must be possible even if the various simulators are operating in separate environments distributed over a network. To further increase the range of application, real systems should be treated as simulators and participate in co-simulation.

Requirements from perspective (2). Regarding the accuracy and precision of computation, it is necessary to be able to detect any error that is introduced or magnified in the process of exchanging data and correct it. Speed of co-simulation greatly depends on the performance of simulators involved in co-simulation, so it will be necessary to provide easy-to-use functionality to analyze the computational bottleneck of each co-simulation architecture and accelerate processing, including use of surrogates.

Requirements from perspective (3). These requirements are directly related to having good user experiences on the platform. By enabling the re-use of the set of models and the connection models between them, they can be re-used easily in other co-simulation experiments, greatly reducing the time required to build co-simulations. They can also be used as a reference, which will be helpful when customizing a simulation. Providing reusable data and the information that should be used for which model enables the platform to be provided in a form that is easy to use, even for beginners. Ideally, we will provide reusable models and data in various repositories and data stores and expand them by accumulating real practical examples from users.

Figure 1 summarizes these requirements in a simple architecture. Perspectives (1), (2), and (3) have a total

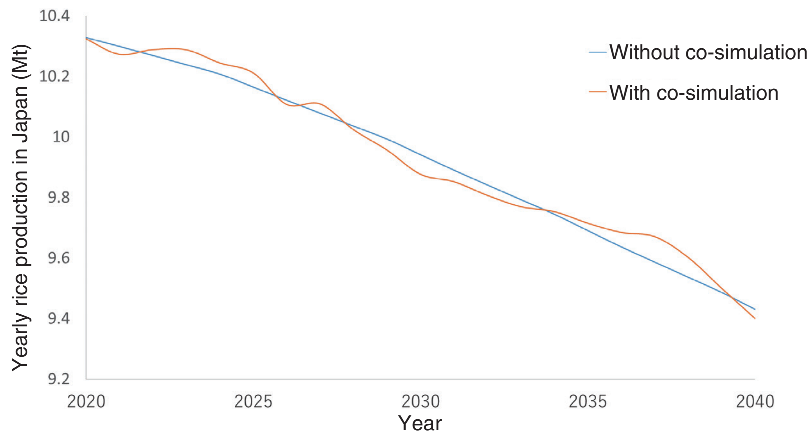


Fig. 2. Comparison of results with and without co-simulation (Yearly production of rice in Japan from 2020–2040).

of 13 requirements, which are mapped onto them.

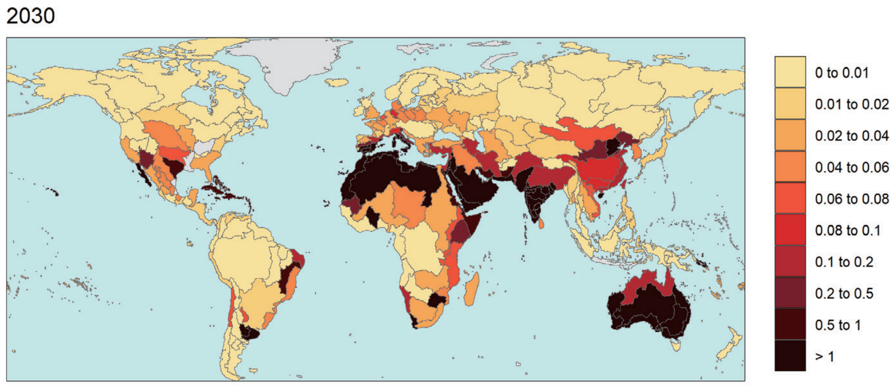
We developed software for providing the basic co-simulation functions (perspective 1) and using them in experiments. We describe an implementation method as follows, which is not the only implementation method. We assume a Master-Worker-type architecture, as shown in Fig. 1. Data between workers and simulators are exchanged using a format used by each simulator, such as accessing files or an application programming interface. The Master component manages the internal clocks of each simulator uniformly by mapping each worker to the logical time and issues instructions to workers so that the simulators run appropriately at the right times. Workers receiving these instructions, receive data intended for them from a data-exchange area (queue, etc.), carry out any required conversion, update any simulator state variable at the appropriate time, and conduct the indicated time-span of simulation. The simulation-execution time stamp is repartitioned as necessary and substituted or execution is processed. After conducting the simulation, the worker receives results to pass to other simulators, processes them, and sends them to the data-exchange area. This process is repeated until the entire co-simulation time has completed.

3. Co-simulation of environment, economy, and society and prototyping policy evaluation

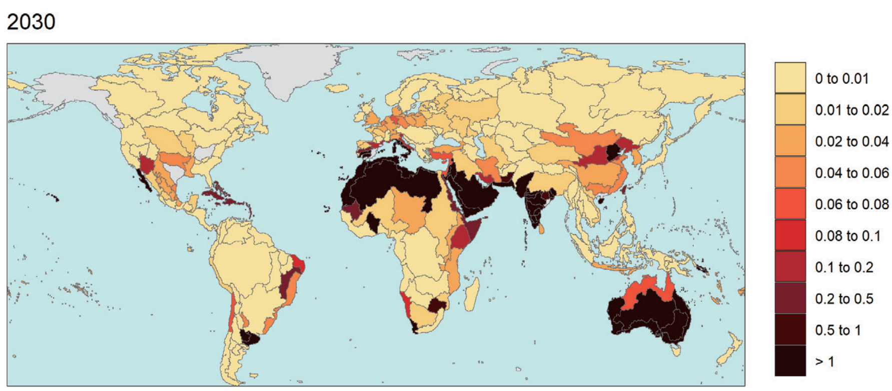
We are currently constructing a proof of concept (PoC) to realistically evaluate relationships between water cycles and food production under climate change. We are using the Integrated Land Simulator (ILS) [4] to compute approximately how much water is present at different locations on land. To compute food production, we are using the Global Change Analysis Model (GCAM) [5], which is a type of integrated evaluation model representing details of water use in the economy and society. This is the first attempt of this type of online co-simulation with detailed simulations of environmental and socio-economic conditions.

ILS computes data in 0.5-degree increments [01] of latitude and longitude with one-hour time stamps and outputs computed results as daily summaries. With the GCAM, however, geographical regions using water resources are (with some exceptions) defined in terms of polygon data for large-scale drainage basins (e.g. Japan is represented by a single drainage basin and one polygon), with time-stamps in units of years. The first task is to cover the gaps in space and time resolution between these two simulators. We took the average daily runoff values (approx. equal to available water) output by ILS, integrated spatially over drainage basins, then temporally over the whole year. This enabled us to substitute short-term data output over a grid for long-term data defined in terms of polygons.

Through this procedure, by substituting detailed surface-water amounts computed by ILS for available water amounts that can be used with the GCAM, we are able to observe the behavior of a socioeconomic model under realistic water-volume conditions. **Figure 2** shows the annual rice production figures for Japan from 2020 to 2040. The results differ between not using (blue) and using (orange) co-simulation, so the effects of data exchange in the co-simulation can be observed. Of course, the



(a) Water stress when water-consumption price is low



(b) Water stress when water-consumption price is high

Fig. 3. Policy evaluation prototyping (change in water stress due to setting of water-consumption price).

production values are not the same but remain within a close range, which suggests that simulator computations are proceeding appropriately. However, we found that there were problems with some of the results when we extended the period of the computation further. We attribute this to the fact that the socio-economic simulator is traditionally given results for a specific environment simulator and computes results on the basis of that assumption. Finding a solution for this is beyond the scope of this article, but this is the first problem identified through co-simulation, and we are currently studying ways to solve it.

Next, we present the results from using the co-simulation system for prototyping policy evaluation. We observed changes to global water stress when we changed the price of water consumption as an environmental policy. In this article, we define water stress as an index of the environmental burden due to water use. We evaluated it by comparing the demand for water (consumed amount) with the available amount of water.

Figure 3 shows a comparison of water stress when water consumption prices are set low and high. For simplicity, we set the same price for the whole world. Except in some areas, we observed that the overall water stress tends to be lower when the water price is high (Fig. 3(b)) than when it is low (Fig. 3(a)).

This indicates that, when simply considering water stress, setting a water-consumption price is an effective policy for lowering the environmental burden. However, this figure does not show the effects of increasing the price of water consumption on productivity and prices in agriculture and energy, so different evaluation methods are needed. We will select indices other than water stress by considering aspects such as well-being and evaluate their suitability for evaluating policy.

4. Conclusion and future prospects

We introduced an environment, economy, and society co-simulation PoC and conducted a one-way co-simulation of the effects of the environment on society and the economy. We are currently conducting co-simulation of the effects of society and the economy on the environment and plan to implement bidirectional co-simulation soon. The co-simulation of the environment, economy, and society we introduced has a global and macro scope, but we have also used our co-simulation technology to conduct local and micro environmental and social co-simulation. We conducted co-simulation with three simulators, i.e., for rivers, floodplains, and evacuee agents, to compute guidance for evacuees when floods occur.

In the discussion on the speed of the co-simulation technology, we mentioned the use of surrogates to increase speed. This has been a focus in the climate field and is currently attracting attention as a good match for modeling global demand. There are also requirements for user-friendly co-simulation that must be satisfied. We plan to continue developing our designs as we examine practical-usage scenarios and publish our results in the form of a co-simulation platform. We also plan to re-examine our ideal requirements according to our objectives, to address issues that arise with current society and economy simulators, and create appropriate designs in software. We also plan to summarize and publish these results.

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The Future of New Technologies of NTT Envisioned with Sci-fi Imagination

WIRED Sci-Fi Prototyping Lab, Miki Kitabata, Chihiro Takayama, Shin-ichiro Eitoku, Hajime Noto, Atsushi Fukayama, and Takao Nakamura

Abstract

Science fiction (sci-fi) is sometimes a rehearsal of the future, and it gives us ideas to prepare for that future. The future of the technologies "Another Me" and "mind-to-mind communication," which NTT has been researching and developing, are depicted by NTT Human Informatics Laboratories, sci-fi writers, and WIRED Sci-Fi Prototyping Lab—the research institute of the technology and culture magazine WIRED JAPAN. Thus, what are the results of their depictions?

Keywords: digital twin, sci-fi prototyping, sci-fi novel

1. Introduction

Our goal is to use science fiction (sci-fi)-based imagination to expand the future possibilities of current technologies. With that goal in mind, NTT Human Informatics Laboratories, together with WIRED Sci-Fi Prototyping Lab [1] and sci-fi writers Ryo Yoshigami (**Photo 1**) and Itsuki Tsukui (**Photo 2**), have created a vision of the future brought about by two technologies: "Another Me" [2] and "mind-to-mind communication" [3].

This article reviews the process and results of the project involving NTT Human Informatics Laboratories, WIRED Sci-Fi Prototyping Lab (Tomonari Cotani, director (**Fig. 1**) and Michiaki Matsushima, head of editorial content of WIRED Japan (**Fig. 2**)), Naoki Ito, chief creative officer and founder of PARTY (**Fig. 3**), Satoshi Yamabe, legal strategist of PARTY (**Photo 3**), and sci-fi writers Ryo Yoshigami and Itsuki Tsukui.

2. The digital twin of "me" and new communication that transcends differences in individual characteristics

NTT has been researching and developing Another Me, which is technology that aims to expand opportunities for people to play an active role and grow by having "another person," a digital reproduction of a real person, act autonomously as that person beyond the constraints of reality, and share the results of that autonomous action as the person's own experience. In other words, Another Me can be described as a digital twin of "me," and it is envisioned to be used for a variety of purposes—such as acting as a substitute for work, overcoming physical disabilities, and simulating human relationships.

NTT has also been researching and developing mind-to-mind communication, which is technology aimed at enabling a new type of communication that transcends differences in individual characteristics, such as experience and sensitivity, as well as language and culture in a manner that lets us directly understand each other in terms of how we perceive

Photo 1. Ryo Yoshigami, sci-fi writer.

Fig. 2. Michiaki Matsushima, head of editorial content of WIRED Japan.

Photo 2. Itsuki Tsukui, sci-fi writer.

Fig. 3. Naoki Ito, chief creative officer and founder of PARTY.

Fig. 1. Tomonari Cotani, director of WIRED Sci-Fi Prototyping Lab.

Photo 3. Satoshi Yamabe, legal strategist of PARTY.

and feel in our minds. These two technologies are key pillars of the Digital Twin Computing initiative [4] announced in June 2019, which aims to create the foundation for building digital twins for autonomous social systems, expansion of human capacity, and automated decision making.

3. With imagination, you can go anywhere

Shingo Kinoshita, director of NTT Human Informatics Laboratories, says, "Because both technologies have such a large impact on society, we thought it was necessary to imagine a wide range of futures, from utopia to dystopia, so we subjected them to sci-fi prototyping." Sci-fi prototyping is a method of envisioning the future through sci-fi, namely, *back-casting* from that starting point in the future and considering what we have to do from now towards that future. A sci-fi-prototyping program was implemented in collaboration with WIRED Sci-Fi Prototyping Lab, which was jointly launched by the Japanese edition of WIRED, a tech-culture magazine that "implements the future," and the creative crowd called "PARTY." The method developed by the Lab envisions four steps: hypothesis, sci-fi, convergence, and implementation. We carried out the two steps from hypothesis to sci-fi illustration. Tomonari Cotani, director of the Lab, talks about the characteristics of sci-fi prototyping as follows.

"Sci-fi prototyping can precisely depict people living in a future society through narratives. Considering the aspects of a future society through a story is, consequently, akin to perceiving that society as a whole at once in a manner like grasping the whole story intuitively. Albert Einstein once said, 'Logic can only go from A to B, but imagination can go anywhere.' I believe that the value that sci-fi prototyping offers is to explore a 'possible future' that differs from the usual perspective by bringing imagination to the front lines of business, research, and government."

4. Envisioning the future through a collective creative process

What exactly was the process followed by the project? After receiving input from NTT Human Informatics Laboratories and interviewing researchers, WIRED Sci-Fi Prototyping Lab, sci-fi writers, and NTT researchers held regular meetings to generate and discuss ideas, which led us to establish various future use cases for Another Me and mind-to-mind communication. To examine the future from a more multifaceted perspective, as well as the editors of the Japanese edition of WIRED, creators, a copywriter, a legal strategist (attorney), and other members of PARTY participated in the project.

Michiaki Matsushima, head of editorial content of WIRED Japan, recalled that "WIRED Japan's approach to covering specific new technologies in conjunction with other emerging technologies and broader, cross-disciplinary perspectives on liberal arts, culture, and lifestyle probably provided the starting point for speculative questioning during the project."

Naoki Ito, who leads PARTY, reflected, "I think we were able to combine the capability of NTT's researchers specializing in engineering and science with the power of sci-fi and creativity in a manner that encouraged speculative questions." In this process, we examined various use cases that had not been envisioned before, such as Another Me for dementia patients and using Another Me for increasing the number of people who get involved with the community. In fact, sci-fi writer Ryo Yoshigami recalls the town-wide use of Another Me, which enables dementia patients to live without a caregiver by implementing a partial Another Me that assists their brain functions, was the starting point for writing a novel.

5. What is the legal status of Another Me?

It should be noted that a legal strategist participated in the project. Technologies that have the potential to be widely used in society cannot be separated from laws and regulations. Accordingly, the participation of a legal expert, an attorney, made it possible to discuss the hurdles in implementing the technologies in question in society. Satoshi Yamabe, a legal strategist of PARTY, gives his thoughts from a legal perspective as follows.

"We repeatedly discussed the legal subjectivity of Another Me, the digital twin of 'me.' It is socially impossible to grant Another Me all the human rights that real people naturally enjoy. For example, if an Another Me's right to life is guaranteed, even the owner cannot erase it without permission, and the Another Me may legally defend itself against other people. On the contrary, if we have a mechanism for guaranteeing the decision-making concerning the management and disposal of property, I think it may be possible to either recognize property rights to a certain extent or achieve a similar result by utilizing existing systems such as juridical foundations. These discussions with sci-fi writer Ryo Yoshigami were reflected in the plot of his sci-fi prototyping novel."

"The process of discussions among the project members with various specialties—bringing together a wide variety of ideas from different positions and perspectives and incorporating them into a single theme (or story)—seemed to me to be similar to the process of screenplay production, which is a collective creation," said sci-fi writer Ryo Yoshigami. For sci-fi prototyping, the final product is a novel, so the final storytelling decisions are left to the writer. Therefore, he continued, "Sci-fi prototyping is a creative activity that cannot be accomplished by a single artist alone, because it lies between writing a novel and developing a screenplay. It thus utilizes the best parts of both processes to provide an answer to the subject matter of technology in the artist's own unique narrative style while also gaining a broader perspective than the artist could achieve alone."

6. Keywords such as "pain," "rural area," and "family" are integrated into the novels

Through the above-described process, the novels "Another pain." by Ryo Yoshigami and "Developing Sensibility Society (in Japanese)" by Itsuki Tsukui were completed. "Another pain." is a novel set in the year 2054 in Cape Kannon, the northeastern tip of the Miura Peninsula in Yokosuka City, Kanagawa Prefecture, and it features a girl named Migiwa and her "grandmother" Misaki, who live in the town facing the sea. Migiwa is the entity called Another Me, and Migiwa's "main body" is Misaki, but for some reason, Misaki calls Migiwa, who is her own digital twin, "grandchild." And Migiwa is set up with a "pain-feeling function" that should be turned off in Another Me. As Migiwa unravels the questions, "Why am I Misaki's grandchild?" and "Why do I feel pain?", the way in which Another Me is used is described.

The starting point of the story, besides the legal consideration of Another Me that appeared in the aforementioned discussion with Satoshi Yamabe, was the "rural area" and "family and partnerships" perspectives. Ryo Yoshigami explained, "Although the implementation of technology in urban areas can be thought of on an individual basis, in rural areas, we must think in units of communities and groups. Moreover, considering the process of new technology spreading to rural areas, we must imagine the future of Japan as a whole in which the technology spreads throughout society." In the workshops, he also focused on a point that often appeared, "relationships with the family through Another Me," and he thought about questions related to the view of life and death, "How do you handle your widowed partner or family member's Another Me?" and "What kind of existence will Another Me become in society after the real person it represents dies?" He continued, "I gradually established the theme of the story, namely, the relationship between people and tools. That relationship could be one in which people sometimes treat their Another Me, who has accumulated experiences that are more like the real person than that the person actually is, as a convenient tool or, at other times, as a companion that should be more than a tool."

After reading this sci-fi-prototyping novel, Atsushi Fukayama, who has been engaged in research on Another Me, raised several points. One point was that in Ryo Yoshigami's story, the evolutionary steps of Another Me are taken in the order of "tool," "servant," "personality," and "delegation." Another point was the introduction of the concept of "pain" felt by Another Me. He stated, "As for pain, it is the axis of one way of thinking. I was able to feel the reality of the future by talking about the line between people and technology/tools through multifaceted aspects such as sadism, mind, and personality. Even unexpected usage is discussed by stating, 'If there is such a technology, it will be used in this way.' I thus believe that we were able to examine use cases from various perspectives."

7. Depicting processes from the measurement of sensitivity to how it is used

In "Developing Sensibility Society" by Itsuki Tsukui, an "immersive-sensitivity test" is used to measure and analyze sensitivity on the basis of "impression resolution" (i.e., how finely different impressions of things can be perceived) and "degree of impression selection" (i.e., the degree to which each distinguishable impression is preferred), and a setting through which a unique sensitivity code is derived for each individual is introduced. The main character is Alicia Koizumi, who works for a company called Estesia Corporation developing immersive-virtual reality (VR) games, which have become a huge hit by allowing game creators to use their own sensibilities to create games and market them to people with similar sensibilities. She is transferred from the star-performer First Development Office to the Sixth

Development Office, and the story explains how she participates in an experiment called "immersive sensibility deepening" (or "sensibility training"), which artificially enhances the impression resolution of a specific part of human sensibility in a manner that makes it possible to decipher the possibilities of using sensibility.

Since mind-to-mind communication covers a wide range of specific research, and the definition of "mind-to-mind" (sensitivity) and approaches to "communication" varied, Itsuki Tsukui narrowed down the definition of "mind-to-mind" (sensitivity) to some extent and summarized it in his work. One of the studies that inspired the idea of "Developing Sensibility Society" was to analyze the decisions of professionals in the cases of *shogi*, Japanese chess, and car racing. Mr. Tsukui said, "It is difficult to digitize each person's 'view of things' and their 'aesthetics.' Even so, I was convinced that a means of recording and comparing behavior under specific rules and circumstances might reveal a person's sensibilities, namely, preferences for various impressions and the sharpness of their discerning eye."

Based on such research, the work ("Developing Sensibility Society") incorporates a setting of "immersive-sensitivity test" that measures and analyzes human behavior in a simulated experience space similar to that of a VR game. Mr. Tsukui recalls that, starting from this test, he expanded the world of his work by thinking about how to express the test results and how to use them in the fields of business and education. Hajime Noto, who has been engaged in research on mind-to-mind communication, says that the creation of the work "created a common understanding among fellow researchers." He continued, "By having the participants draw a consistent picture of the process from the measurement of sensitivity to its concrete use, we were able to clarify one of the goals of the research, which is centered on the theme of sensitivity, and I believe we were able to organize the issues to be considered. In doing so, I believe that the image of how this technology will be accepted by people has become clearer thanks to Itsuki Tsukui's concrete description of how the technology will permeate society."

8. Incorporate the envisioned future into research plans

Since this sci-fi prototyping program took us up to the second step, sci-fi, in which the future is depicted, we will now move on to the backcasting process, in which the depicted future image is incorporated into research plans.

Hajime Noto says, "I believe that the output novels will help convey to NTT internal members the depictions of Another Me and mind-to-mind communication being accepted as a service. I also feel that they will be effective in terms of dissemination of information to the outside world. I hope that such novelization of our research will generate interest, facilitate a deeper understanding of the concepts and worldview of our research, and facilitate discussion from there. In turn, those outcomes will lead to further examination of our technology and its penetration into society."

"Another pain." by Ryo Yoshigami and "Developing Sensibility Society" by Itsuki Tsukui are also published in the booklet included in the NTT Technical Journal and on our website [5] (the novels are in Japanese only). We hope that our readers will take a look at them and discuss with us how the world in which Another Me and mind-to-mind communication are widely accepted will change and what challenges will arise in that world. We believe that discussions with our readers, starting with sci-fi prototyping, will advance our research to the next step.

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WIRED Sci-Fi Prototyping Lab

The WIRED Sci-Fi Prototyping Lab is a research institute offering a program in which the future is envisioned in conjunction with sci-fi writers. It was established in June 2020 in collaboration with the Japanese edition of WIRED—the world's most-influential technology magazine—and the creative crowd "PARTY." In addition to developing the workshops and methods that form the basis of the program, it disseminates information on sci-fi prototyping through its website, WIRED.jp, and other media.

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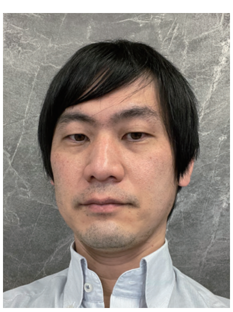

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Data Governance for Achieving Data Sharing in the IOWN Era

Katsuhiko Suzuki and Daigoro Yokozeki

Abstract

There is a move around the world to tighten the handling of data, but there is also a move to establish technologies and rules for processing data safely to accelerate data sharing. After surveying global trends that are having an impact on data sharing, this article describes the concept behind data governance for controlling data so that data owners can safely share their data with others and describes the requirements for data governance in the IOWN (Innovative Optical and Wireless Network) era.

Keywords: data sharing, data governance, data trust

1. Background

The spread of Internet of Things (IoT) devices and progress in digital transformation (DX) activities are driving the digitalization of even information that up to now could not be easily handled while dramatically increasing the volume of that data. There is talk about the coming of a totally new Smart World that will ultimately be achieved by fusing the physical space composed of things and people and cyberspace that reproduces society in its entirety as digital twins, analyzing the links between the two, and feeding back analysis results to the physical space (**Fig. 1**). This will require data sharing beyond individuals, business fields, and industries, and since such data are bound to include sensitive information, there will also be a need for a mechanism that can support safe and secure data sharing. We first outline global trends that are having an impact on data sharing. We then describe the concept of data governance mostly from the viewpoint of security as an essential means of supporting data sharing in the Innovative Optical and Wireless Network (IOWN) era.

2. Trends in data sharing

Trends in data sharing include moves to tighten and limit data sharing as well as moves to promote data sharing through the formulation of agreements, etc. (**Fig. 2**).

2.1 Tightening of data management as in personal information protection

Movements to protect personal information are progressing in many countries. The General Data Protection Regulation (GDPR) in Europe is well known as a general regulation covering data protection, but the California Consumer Privacy Act (CCPA) in the United States, and in Asia, China's Personal Information Protection Law, and other personal information protection laws in Korea, Thailand, India, etc. have also been enacted. Therefore, there is a growing demand for stricter management on how information related to individuals is shared.

In Europe, issues related to data collection by hyperscale companies (hyperscalers) are rising to the surface and the need is growing for strengthening the protection of diverse types of data including non-personal data. In the face of this trend, efforts in constructing federated data ecosystems that place particular importance on transparency and trustworthiness are moving forward by organizations such as the International Data Spaces Association (IDSA) [1].

2.2 Appearance of diverse data spaces

Moves toward the construction of data spaces with a focus on Europe have begun as efforts to stimulate data sharing (**Fig. 3**). A data space refers to a

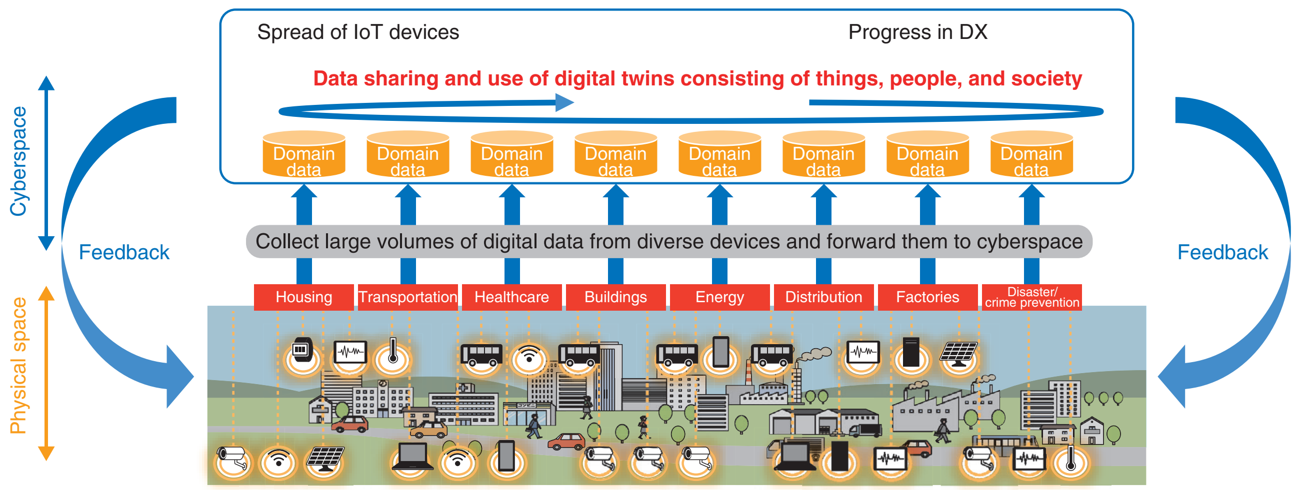

Fig. 1. Data sharing in the IOWN era.

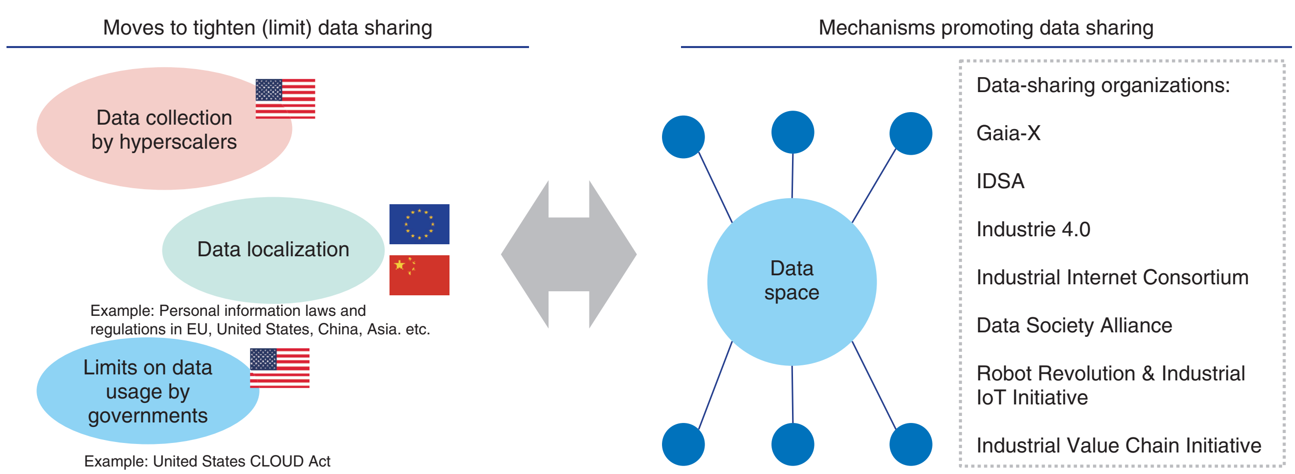

Fig. 2. Global trends in data sharing.

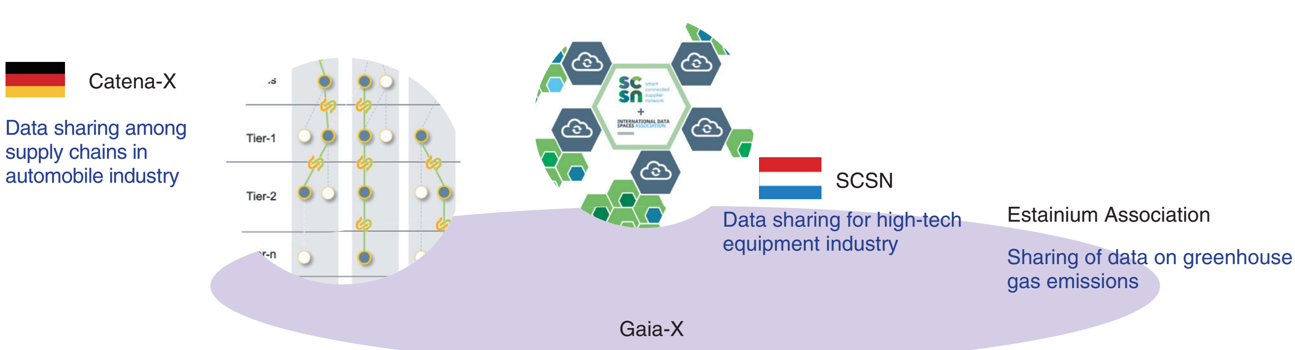

Fig. 3. Appearance of data spaces.

community having systems and rules for achieving highly secure data sharing. In Europe, the construction of industry-specific data spaces on a scale of 1000 companies has begun centered about the manufacturing industry. Companies, as a rule, do not like to release their data, and even when they do, they are apt to set requirements such as the tracing of data-usage history. Thus, against the background of emerging standards for the secure handling of data such as IDSA, many data spaces are being formed. These include well-known data spaces such as Catena-X in Germany that shares data among its entire automobile supply chain with the aim of bolstering the competitiveness of the country's automobile industry [2], Smart Connected Supplier Network (SCSN) that aims to share complex, small-volume, and diverse parts data among high-tech equipment manufacturers in the Netherlands [3], and the Estainium Association that aims to share data on greenhouse gas emissions among companies on supply chains in a cross-industry manner on a blockchain-type open platform [4]. Country-specific and industry-specific data spaces are now appearing, so the above movement is expected to accelerate. We have introduced data spaces centered about companies, but considering the need for exchanging data in a secure manner within social media, within the metaverse, etc., we can think of "data space" in a broader sense.

2.3 Integration and connection of data spaces

The integration and connection of these emerging data spaces can also be seen. For example, there is a movement related to battery regulations in Europe to manage the history of storage batteries from material procurement to recycling in a system called "battery passport" with the aim of reducing greenhouse gas emissions [5]. The tracing of battery history across multiple data spaces in different countries requires the integration and connection of those data spaces. This initiative is already underway in the automobile industry, but expanding it to other industries in relation to batteries is expected to further increase the opportunities for integrating and connecting data spaces across multiple industries.

2.4 Resilient and global supply chain

The COVID-19 pandemic, natural disasters, and international developments have generated many instances of short-term and frequent rearrangements of supply chains. Cases can be found in each industry of delays in procuring materials and decisions to change suppliers, and the impact of an insufficient supply of semiconductors on a wide range of industries is probably still fresh on everyone's mind.

As a trend that runs counter to conventional globalization, there are moves to support domestic production in relation to critical components from the viewpoint of economic security and configure supply chains only among specific affiliated countries.

From the viewpoint of data sharing, there is a need for supporting such rearrangement of supply chains and facilitate dynamic and smooth data sharing with new business partners.

2.5 Advances in information-processing technologies

Finally, we can point out advances in information-processing technologies such as quantum computers, the fifth-generation mobile communications system (5G), 6G, and IOWN. The coming of ultra-wide bandwidth, low-latency, and low-power-consumption networks will drive new demand for remote medicine, self-driving cars, drone control, and other novel services, so there will be a need for mechanisms that can securely handle sensitive data that could not flow on networks in the past. By significantly decreasing data transportation costs, the appearance of new data-processing architecture such as the Internet of distributed datacenters and seamless edge-cloud integration can be expected. Going forward, there is certainly a need for data processing that can achieve both efficiency and security.

3. What is data governance?

Although there is no standard definition of data governance, which is sometimes called "data sovereignty," it refers to following the policy governing the handling of data as specified by the data owner over the lifecycle of that data from the time of its creation to its destruction. For example, a policy may state that no copy of the data is allowed and that the data must always be in encrypted form. Based on the global trends affecting data sharing as described in the previous section, the following describes the requirements envisioned for achieving data governance in the IOWN era (**Fig. 4**).

3.1 Dispersed and distributed data management

As can be seen from the above examples of data spaces, the forecast is for data to be increasingly distributed and managed as such. There are limitations in collecting data by a single company, and it is expected that the inability to collect data at only one

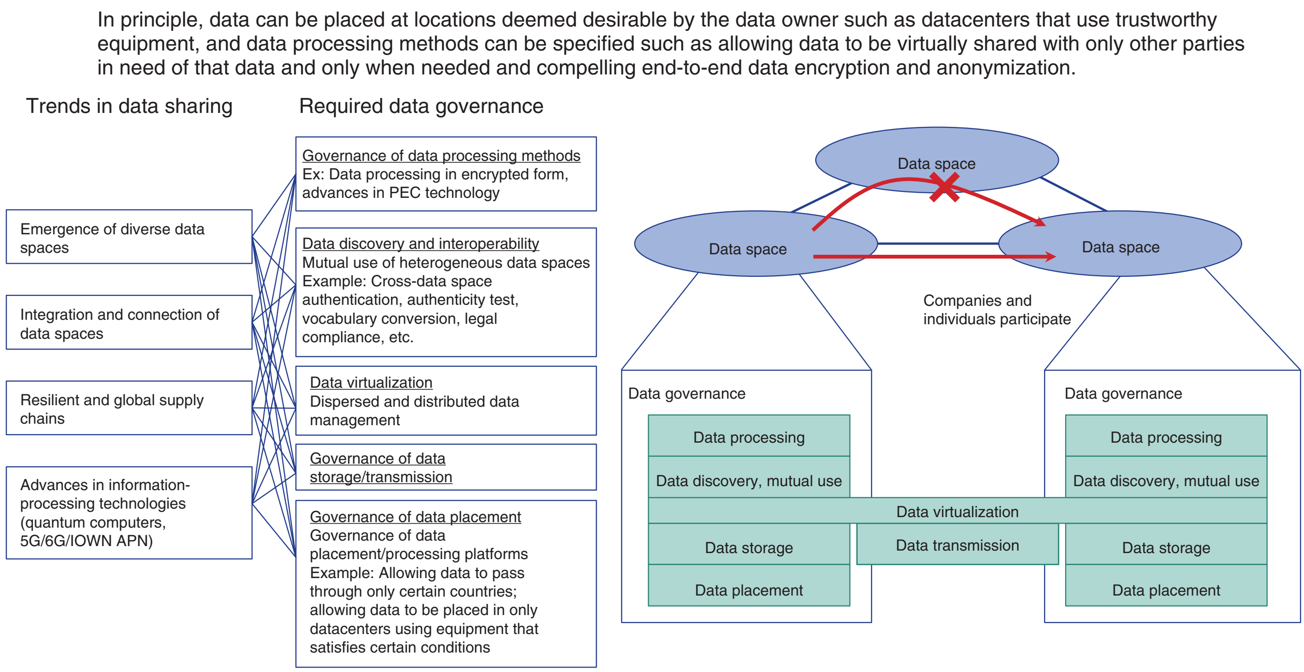

Fig. 4. Targeted data governance.

location will only increase considering differences in legal systems from one country to another. Assuming the widespread of ultra-wide bandwidth, low-latency networks such as the IOWN All-Photonics Network, the cost of moving data should dramatically decrease compared with conventional systems. Data management in the future must, in principle, be able to manage data at locations deemed desirable by the data owner, and when sharing those data with others, be able to do so in a virtual manner according to need. Calculations and processing will be carried out against data collected in a virtual manner after which those data will be destroyed when no longer needed. In contrast to a data lake in which data are collected at one location, technology that makes distributed data appear to be located at one location is called "data virtualization." Data virtualization is currently being used within a relatively small area such as a single datacenter, but going forward, there will be a need for technology that can virtually integrate data in a dynamic manner across countries and data spaces [6].

3.2 Discovery and interoperability of data spaces

The configuration of resilient and global supply chains requires the interoperability of multiple data spaces. Since individual data spaces are generally operated on the basis of various participants and rules, enabling dynamic data sharing with a new party requires a mechanism for mutually connecting and using heterogeneous data spaces. A mechanism for discovering business partners and data is also needed, and once a partner is found, it must be possible to mutually check the authenticity of a partner by some means such as authentication federation between different data spaces. This is because data-space participants, such as individuals or companies, are managed by independent authentication platforms unique to each data space. In the same way, while there are means of checking the authenticity of data within a certain data space using blockchain technology, the need for interoperability between the blockchains of different data spaces should arise. Eventually, there will be a need for even semantic interoperability such as by converting rules and vocabularies used by different communities and regions.

3.3 Governance of data storage and transmission

The prime approach to data protection is encryption by cryptography, which is used as a matter of course when storing and transmitting data to take measures against eavesdropping and other data-related risks. However, there are concerns that existing cryptosystems such as RSA (Rivest–Shamir–Adleman algorithm) will one day be compromised due to the appearance of quantum computers, so there is a need for cryptography appropriate for the post-quantum cryptography (PQC) era. The National Institute of Standards and Technology (NIST) in the United States is now working on the standardization of PQC technologies. In the near future, there will be a need for data-storage and transmission platforms using those technologies, and the need for making seamless transitions from existing cryptosystems to PQC and for dealing with the compromising of PQC [7].

3.4 Governance of data-processing methods

Although data are encrypted when being stored and transmitted, traditional cryptographic technology requires decrypting those data to plaintext before calculations or other types of processing. A new cryptographic technology that enables calculations on encrypted data without decrypting them has entered a period of practical use. In particular, privacy-enhancing computation (PEC)* is attracting attention as a general term for technologies that protect privacy while processing data, including such new cryptographic technology. The Gartner consulting firm, for example, refers to those technologies in its report. PEC consists of a wide range of technologies including, but not limited to secure computation technology that performs calculations on data in an encrypted form on the basis of homomorphic encryption and secret sharing; confidential computing technology that executes calculations and processing in a trusted area using a trusted execution environment (TEE) enabled by hardware-based memory encryption technology; and data anonymization and differential privacy that reduce the risk of identification and privacy breach of individuals. It can be said that requests made to cloud operators to protect data and privacy formed the background to this growing interest in PEC. We can expect these technologies to enable end-to-end data processing on encrypted data and data utilization without exposing unnecessary privacy information and to be commonly used in the same way as encryption in data transmission [8].

3.5 Governance of data placement/processing platforms

From the viewpoint of economic security, the need must be met for a function that enables the data owner to select data-storage locations and data-processing locations and for a function that enables the range of data distribution to be controlled as in the permissible range of transmission. In this regard, today's Internet is designed with importance placed on efficiency and fault tolerance, which serves as a basis for selecting the data-delivery path. Going forward, however, it should be possible to specify the countries, regions, data spaces, etc. where data storage and processing are permissible. There will be need for a function that specifies the permissible range of data transmission and supports data sharing on the basis of economic security as well as economic efficiency, such as a function that guarantees that transmission range even when using a detour route during a network fault [7].

It should also be possible to place conditions on the cloud that executes data storage and processing and place conditions on the storage equipment, network equipment, and computing equipment to be used as conditions placed on datacenters used by the cloud. An example of the former would be the allowing of processing only on a domestically operated cloud within the country when handling truly sensitive data. Examples of the latter would be the processing of data only on products of certain equipment manufacturers and the allowing of data processing only if the software being used can be tested for any quality problems such as vulnerabilities [9]. Using a software bill of materials (SBOM) for such testing is well known.

4. Future perspectives

Data governance as introduced in this article specifies that data, in principle, can be placed at locations desired by the data owner and that data-processing methods can be specified, such as the sharing of data only with others in need of those data and only when needed and end-to-end data encryption, anonymization, etc. Looking to the future, data governance is expected to evolve toward more secure and flexible control of data and promote an even higher level of data sharing.

* PEC: Generic term for computation technology that fortifies privacy by enabling computations with data in encrypted form, making it impossible to identify the person associated with those data through anonymization, etc.

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Trusted Data Space Technology for Data Governance in the IOWN Era

Tomohiro Inoue and Tetsushi Morita

Abstract

We describe the components of the Trusted Data Space, the data-distribution infrastructure that will support society when the Innovative Optical and Wireless Network (IOWN) is widespread and all information is used by digital twins and artificial intelligence. We also describe a group of technologies (data sandbox technology, secure computation technology, secure matching technology) for achieving governance over data processing by conducting calculations in an encrypted state.

Keywords: data governance, secure computation, confidential computing

1. Background

As the Internet of Things and artificial intelligence (AI) technologies advance, the construction of digital twins that reproduce real-world systems in cyberspace and analyze and predict system behavior is progressing. The construction of digital twins for specific applications is leading the way, which will be interconnected, leading to increased data sharing and data analysis across organizational and industry barriers. For example, to enable various use cases expected in smart cities, such as disaster prevention, crime prevention, and attractive town development, data obtained from transportation operators, restaurants, and entertainment facilities need to be used in addition to public data by linking them with one another.

We are engaged in the research and development of the Trusted Data Space with the aim of creating a world in which a wide variety of data generated by various individuals and companies can be effectively used across the boundaries of organizations and industries and in which everyone can share data with one another, analyze them, and create data with a new purpose in a chain fashion to discover the value of one another's data and maximize the data's value for society as a whole.

The Trusted Data Space (**Fig. 1**) consists of various functionalities for interconnecting various data managed and shared by each data space*1 to enable data distribution across data spaces; virtual-secure-data-lake functionality for virtually integrating data managed by each data owner; functionality to support value creation through data distribution by matching between data owners and data users through data cataloging, credit evaluation, etc.; and functionality for managing agreements on terms of use in addition to data-access rights and limiting methods of data processing on the basis of those terms of use. This article details the last functionality, which restricts how data are processed.

2. Governance technologies for how data are processed

In a society envisioned by the Trusted Data Space, data are not managed by a centralized operator but assumed managed by each company, organization, or individual, who keeps their data under their control. Ideally, this means that data can be placed where the owner wants it (such as in a trusted device or datacenter), shared with others only when and to the extent necessary, and leveraged only under conditions

*1 Data space: A community with systems and mechanisms designed to enable highly secure data sharing. For details, see the article in this issue, "Data Governance for Achieving Data Sharing in the IOWN Era."

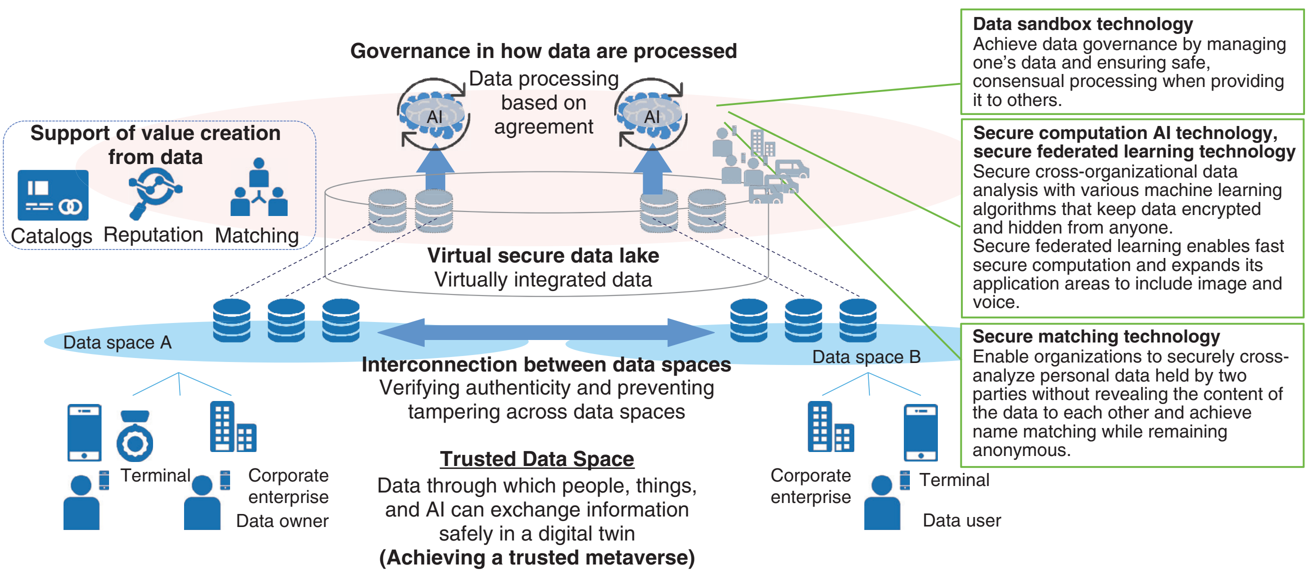

Fig. 1. Trusted Data Space.

prescribed by the parties involved. The virtual-secure-data-lake functionality of the Trusted Data Space enables data that remain under the control of the data owner to be virtually consolidated and retrieved as one huge data lake. Data owners share data-handling policies (e.g., period of use, permission to reproduce, feasible processing), and data users can use the data to the extent permitted by agreeing to the policies. We believe that by establishing such a system, we can create a world in which we can create value in a cascading manner by making it easier to use highly sensitive data that would otherwise be difficult for others to share and by promoting the secondary use of data.

Among the functions related to data governance, technology that uses cryptography to impose certain restrictions on how data are processed has been an area of remarkable development. Encryption technology has been primarily used to prevent theft from third parties when transferring and storing data. With the development of technology that can process data during the computation process while keeping them encrypted, the speed and practicality of computation have increased, making it possible to prevent data during the computation from being stolen and used for purposes other than their original purpose. Analysis operations using personal data and corporate trade secrets can be conducted without leaking data or "looking inside the data." This enables safer data processing, as well as new integrated analysis across companies and industries that share data that were previously difficult to disclose with other organizations.

We describe each of these governance technologies in the following sections.

3. Data sandbox technology

As mentioned above, the cascading creation of value through data utilization requires cross-organizational data collaboration. However, such utilization has not spread widely because in actual businesses, there is significant concern that data once shared by others may be replicated or used for purposes other than what was intended. To address this concern, we developed a technology (data sandbox technology: **Fig. 2**) that enables companies and organizations to hide the knowledge they manage (in this article, this means specific information, such as data or algorithms, that the organization wants to keep secret) from one another while leveraging the combined value. This technology can prevent duplication and abuse of shared knowledge by carrying out processing within a special trusted execution environment (TEE) provided by modern central processing units (CPUs).

With this technology, an isolated processing execution environment consisting of a TEE called a data sandbox (DSB) is created on the platform, and data processing is executed in it. (1) When data owners

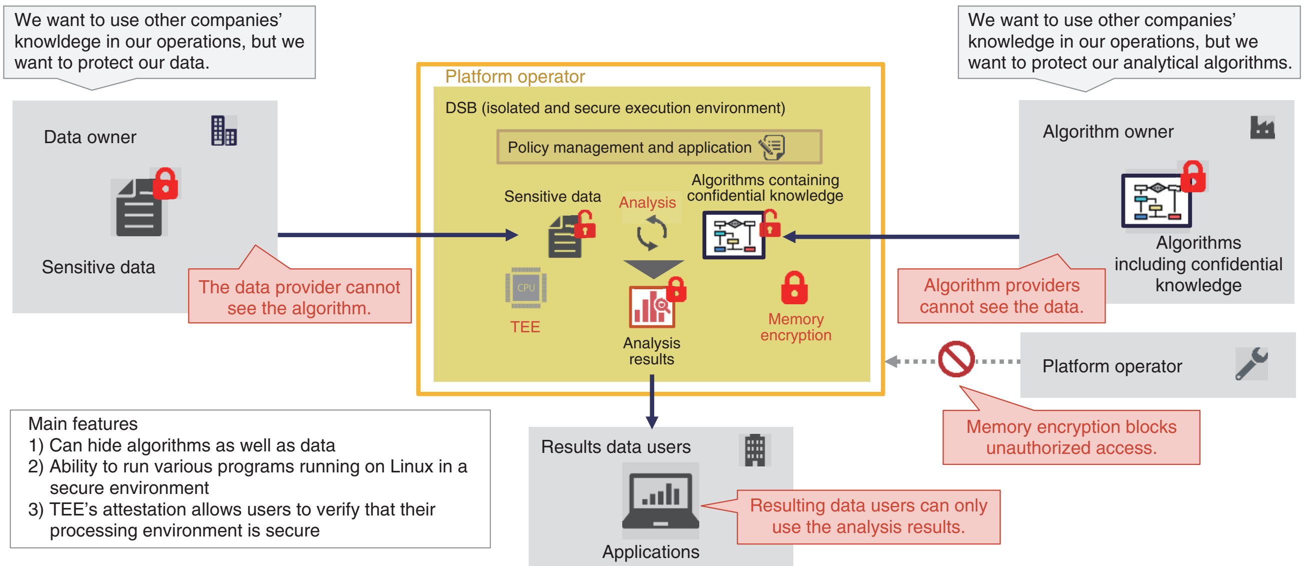

Fig. 2. Data sandbox technology.

and algorithm owners agree to share each other's knowledge and register policies on the platform, DSBs are generated. A DSB is restricted so that it cannot communicate with the outside world, the memory disk is encrypted, and neither the operating system nor the operator can see inside. (2) Each data owner and algorithm owner generates and shares a symmetric encryption key with the DSB and places data and algorithms encrypted with their key in the DSB. Each owner can verify whether the DSB was created in accordance with the policy agreed upon in advance, that is, whether it was not swapped with malicious data or algorithms, by referring to the attestation report*2 provided by the system. (3) The DSB uses a symmetric key between the data owner and algorithm owner to decrypt the data and the algorithm and execute the operation. (4) The DSB encrypts and returns the processing results with a symmetric key created and shared with the data user. (5) After processing, data and algorithms are deleted along with the DSB. With such a mechanism, the data sandbox technology makes it possible to use data without anyone having access to the processing process and result data as well as input data and algorithms.

4. Secure computation technology

Secure computation is a technology that allows data to be computed while remaining encrypted consistently even within the CPU. In addition to encryption during data communication and storage, secure computation can also be executed during data computation without ever decrypting the data, ensuring a high level of security.

NTT's secure computation uses a secret sharing scheme that conforms to the ISO (International Organization for Standardization) standards as its encryption mechanism and uses multiparty computation techniques based on the secret sharing scheme. Multiparty computation executes secure data processing while the data are encrypted by executing special cryptographic operations and exchanging encrypted data among multiple servers in accordance with preliminarily defined procedures. While performing these steps, the process is executed "without looking inside the data" because the data are always treated as encrypted pieces called a share in the context of a secret sharing scheme. Secure computation technology is currently available from NTT Communications in the form of the commercial secure computation cloud service SeCIHI (Secure Computation and Information Handling Interface). We are engaged in research and development of a technology that will advance secure computation and enable rapid learning and inference of AI.

*2 Attestation report: A function of TEE that certifies the state (e.g., binaries, settings, etc.) in the TEE based on the trustworthiness of the hardware security chip.

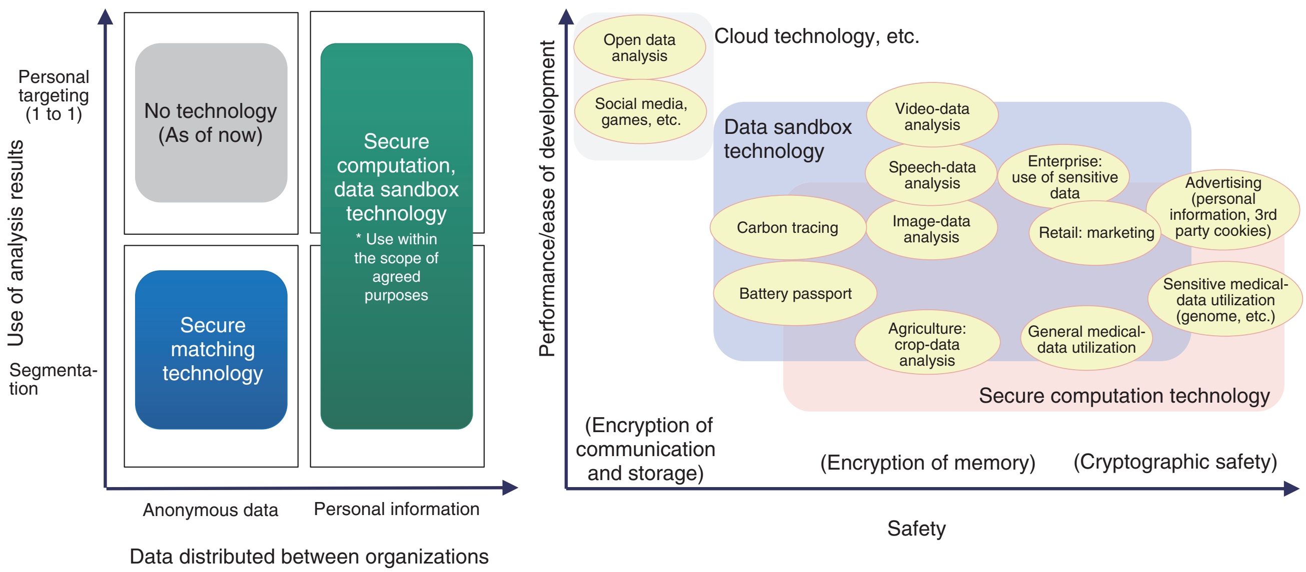

Fig. 3. Application areas of each technology.

5. Secure matching technology

Among the types of data utilization expected in the Trusted Data Space, sharing and analyzing data across industries and organizations for a common target is particularly important and desired. However, from the viewpoint of confidentiality and personal-information protection, data in an organization cannot be freely shared with others for statistical analysis. Secure matching technology enables secure cross-analysis of data by anonymously collating personal information and business data held by an organization between two parties without disclosing the content to the other party. Whereas the data sandbox technology and secure computation technology can execute arbitrary data processing, secure matching technology focuses on data exchange and aggregation processing between two parties, so that each data owner can safely conduct integrated analysis by introducing a simple system into their company and exchanging data.

There are two technological advances in secure matching. The first is a protocol for securely combining and totaling data while keeping them encrypted using advanced cryptography such as commutative hash functions and homomorphic encryption. The other is differential privacy, which adds noise at high speed while maintaining encryption to protect privacy so that the original data will not be known even from the aggregate results. We want to combine secure matching technology with other secure data-distribution technologies developed by NTT to create the Trusted Data Space for reliable data distribution. Secure matching technology is also being used in demonstration experiments at Japan Airlines (JAL), JAL Card, and NTT DOCOMO to improve customer experience and use data to solve social issues.

6. Technology selection for secure data utilization

There is much overlap in the use cases covered with the above technologies. Ultimately, if there were a technology that could theoretically process sensitive data securely and quickly and pass only the necessary results to those who need them, all use cases could be handled. However, no such technology currently exists. Therefore, better technologies need to be determined and applied as appropriate in accordance with the characteristics of the target data, requirements of the parties involved, and legal regulations. **Figure 3** illustrates the different uses of technology that we consider. Secure matching technology can be used when one wants to conduct statistical analysis on a dataset with identifiers (IDs) that can be collated and combined with data from other organizations. This is especially useful when conducting marketing analysis while maintaining the anonymity of personal information. While secure computation is highly secure because it executes operations on the basis of cryptographic theoretical security, data sandbox technology is characterized by its high processing speed and ability to execute algorithms almost without modification because it uses hardware-based memory encryption. Therefore, a processing method needs to be determined that balances safety and performance as required by the use case.

7. Future developments

To achieve the Trusted Data Space to distribute data in which new value is created in a cascading manner, progress must be made in not only the technologies introduced in this article but also various other areas such as searching and matching reliable data and analysts, standardizing data formats, promoting interconnection with existing data spaces, and creating value through AI. We will continue to promote these research and development efforts through collaboration and technical verification with a wide range of partners.

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Secure Optical-transport-network Technology in Anticipation of the Quantum Computer Era

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Abstract

In the January 2022 issue of NTT Technical Review, we introduced the *secure optical transport network* for enabling secure optical transport even in the era of quantum computers. In this article, two concepts, cryptographic agility and Multi-Factor Security, which are key factors in the transition from current cryptographic techniques to quantum-resistant cryptographic techniques and need to be considered in the era of quantum computers, are explained, and our efforts to incorporate these concepts into secure optical transport networks (i.e., elastic-key-control technology and disaggregation technology for cryptographic processing) are introduced.

Keywords: optical transport network, post-quantum cryptography, IOWN Global Forum

1. Background

The amount of data, such as video and voice data, flowing over the network is becoming ever larger. The need for low-latency communications is becoming ever more important in areas such as finance and telemedicine. On top of that, it is important to reduce power consumption while maintaining services.

The All-Photonics Network (APN), one of the three components of the Innovative Optical and Wireless Network (IOWN), which is being researched and developed by NTT, aims to provide services with three appealing features: low power consumption, large capacity and high quality, and low latency [1]. In addition to the above-described issues, financial and telemedicine applications require a high level of security due to the financial losses and risk to human lives in the event of a system attack. These features are also important from the perspective of data distribution.

Quantum computers are expected to be put to practical use in the 2030s in applications such as solving traffic congestion, analyzing risks concealed in financial data, and developing new drugs. However, current cryptosystems, such as RSA (Rivest–Shamir–Adleman algorithm) and elliptic curve cryptography, will be vulnerable.

NTT Social Informatics Laboratories and NTT Network Innovation Laboratories are working to add security to IOWN APN by sharing a common key between optical transponders—by using post-quantum cryptography (PQC) and quantum-key distribution (QKD)—and communicating by using that key, and also have been researching and developing a secure optical-transport-network technology that is safe even in the quantum-computer era by encrypting communications with the key [2] (**Fig. 1**). From the viewpoint of data distribution, in addition to encryption of transmission paths and stored data, end-to-end

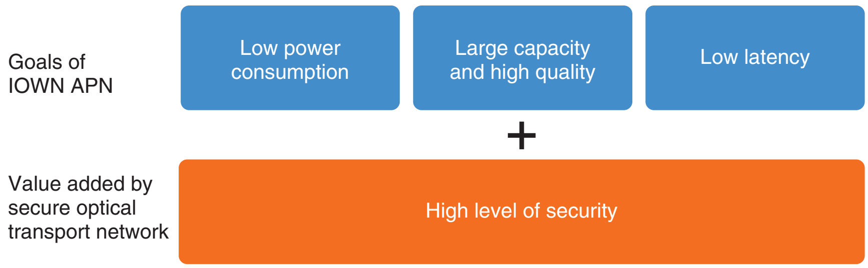

Fig. 1. Features of secure optical transport network.

security is required, and secure optical-transport-network technology is especially designed for transmission paths.

Furthermore, the IOWN Global Forum (IOWN GF) is currently discussing the ideal form of quantum-safe security*1 required of IOWN in the quantum-computer era.

2. Challenges

Conventional key sharing by the secure optical transport network [2] guarantees secure information communications—even if conventional public-key cryptography is compromised*2 by the development of quantum computers—by choosing either PQC or QKD depending on the application. PQC is a cryptographic scheme that uses a problem that even a quantum computer cannot solve efficiently as a basis for security. Although it has a shorter history than current cryptographic schemes, it is in the process of moving from the research stage to practical application. The National Institute of Standards and Technology (NIST) has begun standardization of key-exchange and signature schemes using PQC, which is expected to be implemented and widely used. On the contrary, research on the security of PQC is still in its developmental stage, and the possibility that it will suddenly be compromised is not zero. In fact, supersingular isogeny Diffie–Hellman key exchange (SIKE or SIDH), a key-sharing scheme that was being considered for standardization in Round 4 of NIST's competition to select PQC schemes, was found to be breakable during the competition by an attack method that can decrypt SIKE in just over an hour on a computer (as of July 2022) [3]. Accordingly, as we look ahead to the era of quantum computing, we need to satisfy the following requirements:

- Communications are not immediately threatened by the compromise of a single cryptographic algorithm.
- Flexibility to switch from one compromised cryptographic algorithm to another uncompromised one or to adopt a new algorithm must be assured.

3. Activities of IOWN GF

3.1 IOWN Security (IOWNsec)

IOWN GF discusses architectures and use cases of new communications and computation infrastructures that will implement IOWN. More than two years have passed since the establishment of IOWN GF. In that time, the technologies and use cases for implementing the IOWN have gradually materialized, and discussions on security in the IOWN era have recently begun.

In anticipation of the quantum-computer era, the security report "IOWN Security (IOWNsec)" specifies an architecture for maintaining end-to-end quantum-resistant security for data communications in IOWN use cases, and "Technology Outlook of Information Security" will be published by IOWN GF as a technical document in 2023.

3.2 Multi-Factor Security

IOWNsec is promoting the concept called Multi-Factor Security (MFS) to ensure end-to-end communications with quantum-resistant security. MFS combines multiple technologies to achieve a level of security that cannot be achieved with a single technology. For example, PQC, QKD, and pre-shared key (PSK) are technologies for assuring quantum-security

*1 Quantum-safe security: A security level that provides resistance to attacks by quantum computers.

*2 Compromise: A cryptographic compromise is a situation in which the level of security of a cryptographic scheme has been reduced (compromised). It may be caused by the algorithm or implementation problems.

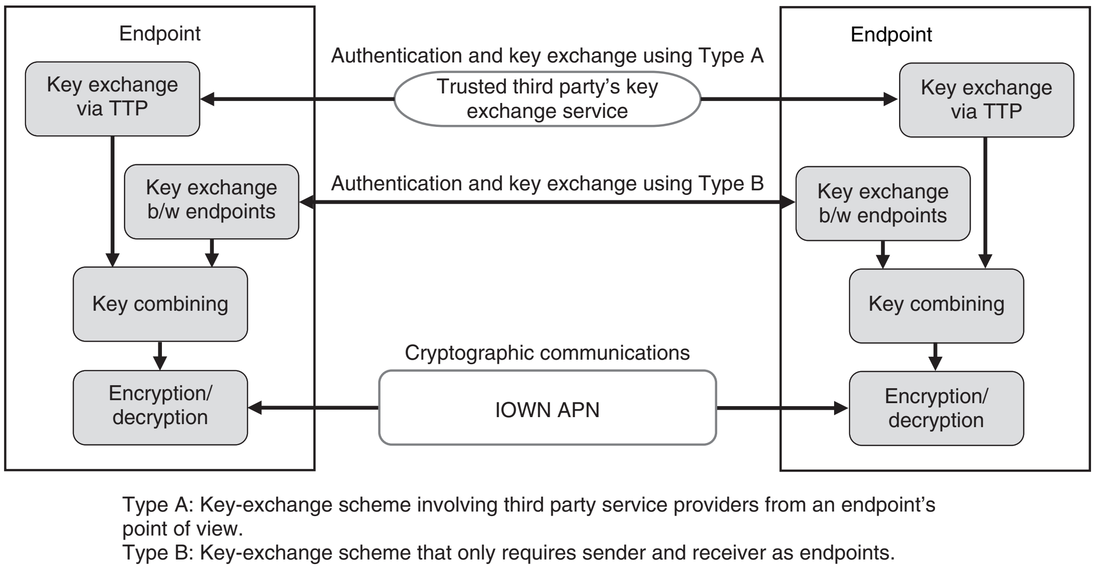

Fig. 2. Specific example of MFS.

resistance during key exchange for encrypting communications. However, each technology has advantages and disadvantages, and no single technology can provide perfect security. For example, QKD is a key-exchange technology with information-theoretic security*3, but long-distance key distribution requires a third-party network for relaying the key, and the risk of internal attacks cannot be avoided [4]. Moreover, the key-exchange scheme using PQC can be implemented using software, so it is possible to precisely exchange keys between endpoints, but its security is classified as computational security*4, which might be compromised in the future. Accordingly, IOWNsec uses MFS to combine multiple security technologies, such as PQC, QKD, and PSK, to compensate for their disadvantages and defines an architecture that can provide users with options that can respond to a wider range of threats (**Figs. 2** and **3**). As well as implementing MFS as an application on the main central processing unit for end-to-end communications, IOWN GF is also considering implementing MFS in gateways and network interface cards that forward data flows to optical paths. Thus, we hope that MFS can be used in a wider range of use cases.

4. Relevant external trends

4.1 Crypto-agility

Cryptographic agility (crypto-agility) is a concept proposed by NIST [5, 6] to quickly switch the cryptographic scheme to be used when the scheme used in a network or system is compromised or when a new cryptographic algorithm is introduced. Crypto-agility aims to (i) minimize the impact of the switch on existing networks and systems and (ii) shorten the time required for verification of security.

4.2 Hybrid scheme

In the context of cryptography, the term "hybrid" often refers to hybrid cryptography, which combines public-key cryptography and symmetric-key cryptography. However, the term "hybrid scheme" refers to a scheme with which key exchange and digital signature are executed by multiple public-key cryptographic schemes, and the results are combined to generate a single private key and signature. This hybrid scheme has recently been proposed to the IETF (Internet Engineering Task Force), a forum that defines Internet standards, and others [7]. The hybrid scheme enables multiple schemes to be selected from "conventional" cryptography (such as RSA and elliptic curve cryptography), PQC, and PSK (including shared-key using QKD) and combines the generated

*3 Information-theoretic security: Security against the most-powerful attacker imaginable, i.e., an attacker with unlimited computational power.

*4 Computational security: Security based on the assumption that the amount of computation required for decryption is so much larger than the available computing power that it cannot be executed in a realistic amount of time.

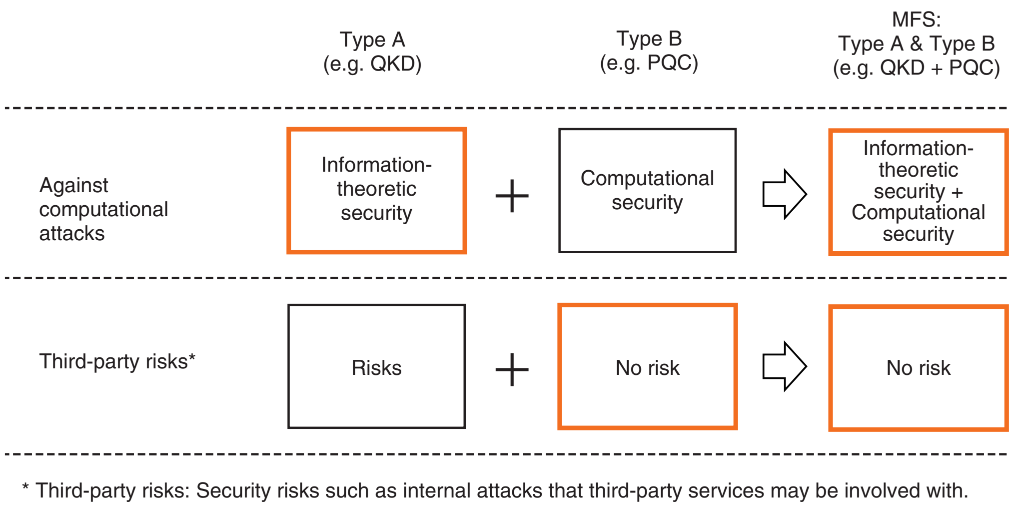

Fig. 3. Examples of MFS's effectiveness in key exchange.

results so that the system will not be immediately compromised even if one of the schemes is compromised. Using the hybrid scheme makes it possible to implement PQC in society while ensuring the security of conventional cryptography during the transition period to PQC. Even after the transition to PQC, it is effective to hybridize multiple PQC schemes to avoid rapid compromise.

5. Proposal

5.1 Elastic-key-control technology

The authors have proposed and developed elastic-key-control technology, which incorporates the hybrid scheme, as one way to implement the MFS concept stated in IOWNsec. With conventional secure optical-transport-network technology, either PQC or QKD can be selected as the key-exchange scheme according to the system requirements. Elastic-key control is a development of this technology. Elastic-key control allows flexible switching of the cryptographic algorithm used for key exchange according to user needs and the usage status of the cryptographic algorithm (**Fig. 4**). Available elastic-key-control algorithms include conventional ciphers, PQC, PSK alone, and any combination of hybrid scheme. The authors confirmed that a hybrid of conventional cryptography and PQC can be used for signatures for authenticating each server and their verification as well as for key exchange. ECDHE (Elliptic Curve Diffie–Hellman), CRYSTALS-Kyber, and NTRU have been implemented as key-exchange schemes, and ECDSA (Elliptic Curve Digital Signature Algorithm) and CRYSTALS-Dilithium have been implemented as signature methods; however, any algorithm that is implemented as a library can be added to the options. For example, it will be possible to combine conventional cryptography and PQC for practical use and, after accumulating a track record of social use of PQC, we can enter the quantum-computer era. Later, in the quantum-computer era, switching to a combination of multiple PQC algorithms will allow for the rapid implementation and use of future cryptographic algorithms while maintaining a secure situation as long as neither side is compromised. Elastic-key-control technology can thus increase crypto-agility.

5.2 Disaggregation technology for cryptographic processing

Conventionally, an optical transponder has been provided in the form of an integrated optical module. Thus, the open & disaggregated optical transponder has been investigated. This disaggregated architecture allows operators to choose a flexible configuration of various hardware and software. However, the cryptographic-processing module (hardware) is provided as an integrated module within the optical transponder, and the library (software) that controls the module is provided by the network operation system (NOS) of the optical transponder. From the viewpoint of crypto-agility, it is necessary to have a configuration that is rapidly applicable to new cryptographic algorithms. For an optical transport system,

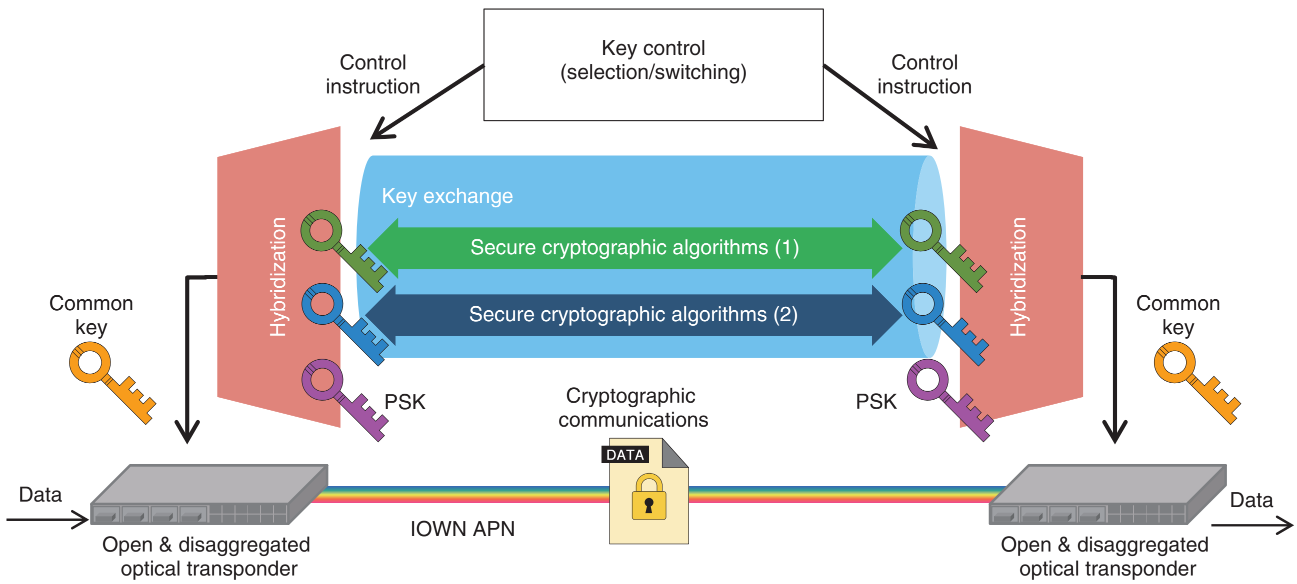

Fig. 4. Elastic-key-control technology.

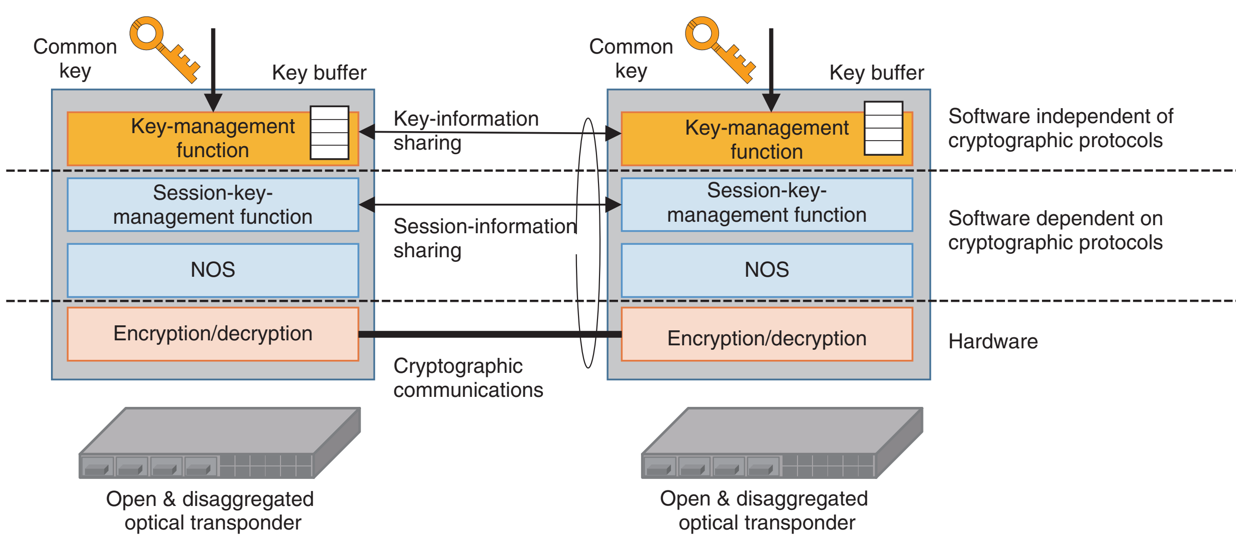

Fig. 5. Disaggregation architecture for cryptographic processing.

stable cryptographic communications must be possible even if the communication channel for exchanging the common key is interrupted.

The authors have also proposed and developed disaggregation architecture for cryptographic processing in the optical transponder as shown in **Fig. 5**. A key-management function receives a common key and manages the key in a way that does not depend on lower-level cryptographic protocols (MACsec (Media Access Control Security), OTN (Optical Transport Network) encryption, etc.) such as key-information sharing between optical transponders. A session-key-management function manages the key in a way that depends on lower-level cryptographic protocols such as session-information sharing between optical transponders. By implementing separate functions in cryptographic processing (executed with hardware) in this manner and loosely coupling the key-management and session-key-management functions, it is possible to implement cryptographic processing that does not depend on the NOS.

High-speed encryption and decryption is possible because it is executed in hardware as before. By standardizing the interface between the key-exchange, key-management, and session-key-management functions, it will be possible to accommodate differences in upper-level cryptographic-exchange methods and differences in lower-level cryptographic processing, making cryptographic processing possible on a variety of devices using the same key-supply method. Furthermore, by developing a redundant key feature that generates multiple shared keys from the shared key obtained through key-exchange communications and stores them in a buffer, cryptographic communications can continue even if certain shared keys cannot be obtained from certain key schemes due to communication failures or shortage of keys.

6. Future directions

In NTT's efforts to develop secure optical-transport-network technology, elastic-key-control technology and disaggregation technology for cryptographic processing were introduced. The authors are now preparing for trials of these technologies by implementing them into part of the network of NTT laboratories. We expect to improve these technologies and provide them as a general service for use in fields that require large capacity, low latency, and high security (such as telemedicine and finance).

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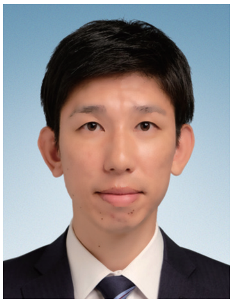

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Security Transparency Assurance Technology for Analysis and Visualization of Software Components

Takayuki Uehara, Yo Kanemoto, and Hiroto Nomura

Abstract

Cyberattacks targeting the software supply chain—the process of developing, providing, using, and updating software—has been increasing. This article discusses trends in supply chain security risks and research and development of security transparency assurance technology to identify information on software components to address such risks.

Keywords: security, supply chain, SBOM

1. Introduction

As economic activities and society evolve, the risks to devices and software are also changing. The most notable change is the increased security risk to the software supply chain. In the United States, an executive order was issued to address this risk, and it is necessary to understand the software component using a software bill of materials (SBOM). In this article, we discuss trends in supply chain security risks and the efforts at NTT laboratories to mitigate such risks.

The 2020 White Paper on Information and Communications in Japan reveals that information and communication technology (ICT) has reached the stage of "social and economic infrastructure." In the past, there were high expectations for ICT to enhance productivity and efficiency. We have transitioned from a long-term development style to a continuous integration approach, which involves releasing functions in rapid succession. To support this accelerated development, we use open source software (OSS) libraries for logging and web rendering as well as for databases and frameworks. The role of software has also become increasingly fragmented and complex, including tasks such as updates and plug-ins (**Fig. 1**).

2. Risk of software supply chain

The process of developing, providing, using, and updating software is known as the software supply chain. This supply chain has become a new target for cyberattacks. For instance, a vulnerability may be discovered in a software library, and an attack exploiting this vulnerability can result in an information leak. Malware may also be injected to a software component through a file updater. It is worth noting that the supply chain, which is responsible for maintaining the safety of the main software body, may paradoxically become a threat that causes significant incidents.

In response to numerous security incidents affecting the United States, the "Executive Order on Improving the Nation's Cybersecurity" was issued in May 2021. As a result, the US NTIA (National Telecommunications and Information Administration) mandates that vendors disclose the SBOM to purchasers.

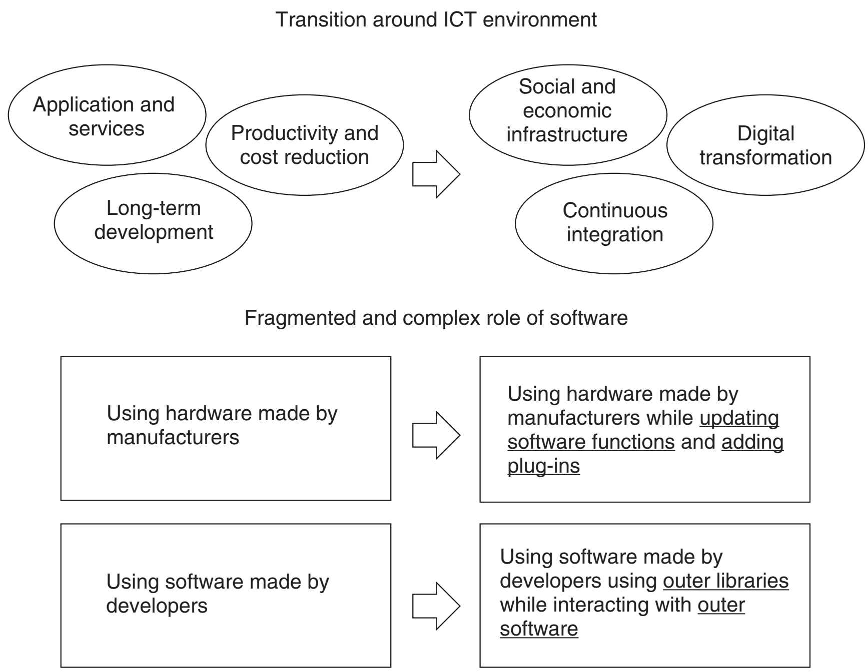

Fig. 1. ICT transition and role of software.

3. Risk countermeasure as key concept of transparency

An SBOM is an inventory of the software included in devices and systems, and data formats such as SPDX (Software Package Data Exchange) and CycloneDX have been proposed. By identifying software components, it becomes possible to promptly investigate the impact of a discovered vulnerability. Additionally, by generating SBOMs at each phase between procurement and use, it is possible to identify instances of unauthorized software infiltration.

In this manner, SBOM-induced transparency is a highly effective risk countermeasure, but there are several issues that must be addressed to further enhance its effectiveness, including:

(1) Software dependencies
(2) Undisclosed software
(3) Managing and using massive amounts of information

We introduce the following efforts of NTT laboratories to address these issues.

4. Software dependencies

Although an SBOM can list the software included in devices and systems, in many cases, only a portion of the software components can be clearly identified. Many pieces of software have dependencies, which reuse code libraries or packages. These dependencies are managed by a system called a package manager. Therefore, it is possible to determine which other software the software depends on from the management information of the package manager. For example, Python has a mechanism called Package Installer for Python (PIP), which manages information about packages to be used. By providing PIP management information from the developer, it becomes clear which software certain software depends on. Thus, while there are explicit dependencies indicated by management information, there are also implicit dependencies (**Fig. 2**).

The most well-known implicit dependency is code cloning. Code cloning refers to matching or similar software source code. A code clone is created by referencing the source code of other software to implement similar functions and copying the source code. In other words, software users may be using the same code as other software without realizing it. Similarly, some code examples are displayed on code question and answer (QA) sites, and some software may use them as is. In other words, it is possible to consider the software code to depend on the code examples on the QA site.

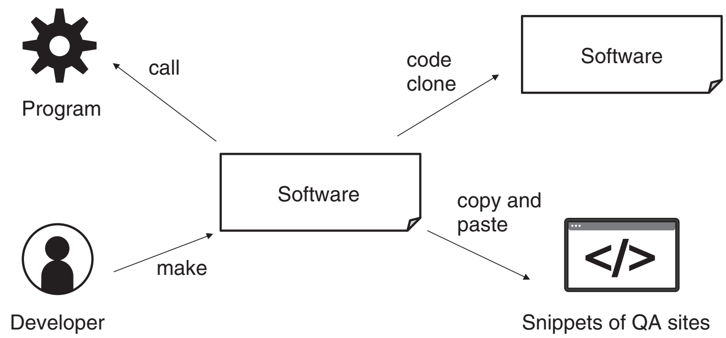

Fig. 2. Various implicit dependencies of software.

Hypothetically, what would happen if a vulnerability (security flaw) is found in the code of the software that the software depends on? Vulnerabilities may exist in all software that has code similar to the software in question. If the software is launched by another program, that program may also be impacted by the vulnerability, potentially affecting the operation of the system on which the software is running.

There may be dependency risks of software developers and their development environments. For an OSS, there are an indeterminate number of developers, and there may be malicious developers or developers among them who are using a development environment that has been compromised without realizing it. As a result, using software created by other developers without sufficient confirmation can pose a security risk.

In this manner, software may have implicit dependencies that are not depicted in the explicit dependencies depicted using an SBOM. We are engaged in research and development of technology to enhance the transparency of software and devices using software by understanding such implicit dependencies.

5. Undisclosed software

Disclosing software components may have drawbacks such as providing hints to attackers. As a result, some developers may want to conceal some or all of the component information. How can transparency be ensured in devices and systems even in such cases?

When a user purchases a device or system, they first verify that it operates as described in the catalog or manual. While using the device, they may detect communication that is not documented in the manual. For instance, some network devices obtain the latest versions of software and data via the Internet. In many cases, this communication is not documented in the manual but a specification for the device.

Therefore, we are conducting research and development focused on the potential for estimating the software components that contribute to operation by using such specifications and data observed from the outside of the device or system. For example, by using logs of communications and operations, it is possible to supplement the component information visualized using an SBOM. Our goal is to create a scenario in which the effectiveness of security risk countermeasures is maximized.

6. Managing and using massive amounts of information

Thus far, we have discussed efforts to increase the quantity of information related to software component information for addressing supply chain security risks. While the diversification of and increase in information increases the likelihood of its utilization for security measures, it may also make it challenging to identify the necessary information and use it appropriately. Additionally, the quantity of information related to component information (e.g., vulnerability information) will grow, and the amount of information to be managed and addressed will become enormous.

We are also researching the state of new security countermeasure work (security operation) and the technology to implement it after achieving security transparency through the enrichment of component information.

In the Cyber Security Framework (CSF) defined by the NIST (National Institute of Standards and Technology) in the United States, security measures are divided into five functions: identify, protect, detect, respond, and recover. Enriching component information to achieve security transparency will contribute to strengthening "identify." Therefore, by enhancing "identify," we are researching integrated management and utilization technology for visualization data that efficiently enhances the effectiveness of the other four functions in CSF (efficient vulnerability management using component information, rapid response, highly accurate anomaly detection/cause estimation, automatic countermeasures, etc.).

7. Conclusion

We introduced the research and development of supply chain security risk management based on the key concept of security transparency technology. This technology is an essential security technology for IOWN (the Innovative Optical and Wireless Network), where various players openly co-create, and we aim to support the core infrastructure of society and the economy.

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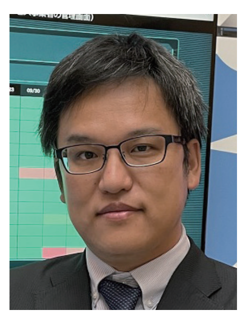

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Early Deployment and Popularization of IOWN Technologies as Targeted by IOWN Product Design Center

Takashi Utahara, Takuya Fukuhisa, Hideaki Midori, Noriaki Takeuchi, Shintaro Watanabe, and Yuichi Ikejiri

Abstract

The IOWN Product Design Center aims for early implementation and popularization of Innovative Optical and Wireless Network (IOWN) technologies. Through these activities, the center plans to experimentally demonstrate how IOWN will create new value in various industries by combining multiple IOWN and commercial technologies. The efforts of NTT laboratories to demonstrate a combination of IOWN technologies, including fundamental technologies that support data governance, are described in this article.

Keywords: IOWN, IOWN Product Design Center, data governance

1. The IOWN concept

The Innovative Optical and Wireless Network (IOWN) aims to transform existing information and communications systems and implement a new infrastructure that transcends the limitations of current information and communications technology (ICT) [1].

IOWN covers three major technical fields: (i) the All-Photonics Network (APN) provides end-to-end optical wavelength paths from terminals to networks via photonics-based technologies; (ii) Digital Twin Computing enables future prediction by combining the real and digital worlds; and (iii) the Cognitive Foundation® connects and controls all things/devices.

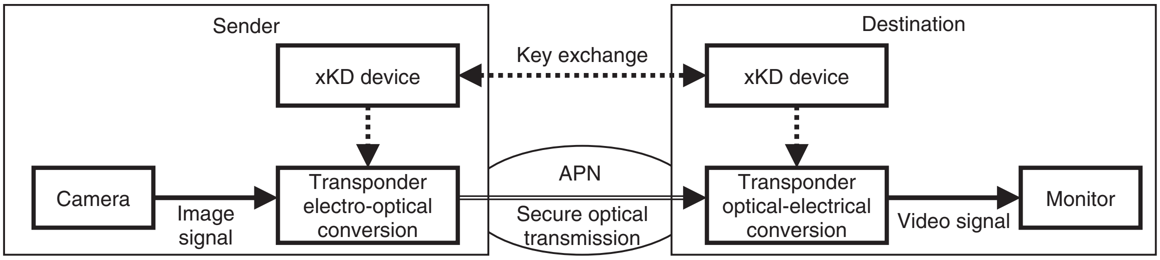
With the APN, light is transmitted from terminals to the network without electrical conversion, and such light-only end-to-end transmission results in unprecedented low power consumption, high quality, large capacity, and low latency, which are practically unachievable with current electronics-based technologies. Digital Twin Computing reproduces real-world objects as digital twins in a computer, enabling future prediction and optimization by combining digital twins with one another and with the real world. The Cognitive Foundation® harmonizes all ICT resources into a holistic optimum and optimally controls ICT resources, such as the cloud and edge, as well as networks and even terminals.

The goal is to create a more prosperous society by using these technologies to improve the quality of connections among people and between people and society through the real-time and fair distribution of information that encompasses a variety of values.

1.1 Initiatives of the IOWN Product Design Center

The IOWN Product Design Center aims to implement and popularize IOWN technologies as early as possible. To that end, we are formulating development and expansion strategies for IOWN technologies back-cast from market needs and societal demands and promoting activities such as technology development and demonstrations on the basis of those strategies [2].

Through these activities, we aim to (i) identify potential market needs through demonstrations with various companies, such as those participating in the IOWN Global Forum [3], government agencies, universities, telecommunications-equipment manufacturers,



xKD: Refers to quantum key distribution and post-quantum cryptography-based key distribution.

Fig. 1. Secure optical-transport-network technology.

the NTT Group, and other companies and (ii) improve IOWN technologies by repeatedly demonstrating their value. By combining multiple IOWN and commercial technologies, we aim to increase the value that meets market needs and social demands while promoting the early implementation and popularization of these IOWN technologies.

In the following sections, we introduce our demonstration plan for further expanding IOWN technologies by using the fundamental technology supporting data governance being developed by NTT laboratories and present examples of the new value created by IOWN.

2. The APN and secure optical-transport-network technology

2.1 Implementation of secure optical long-distance transmission

As mentioned above, the APN enables direct communications on the optical layer. Even in the case of conventional transmission networks, devices are connected by optical fibers. However, to cope with the attenuation of light over transmission distances and to switch light paths, it is often necessary to (i) convert the light into electrical signals in the transmission equipment at regular distance intervals and at each branching path and (ii) convert the electrical signals back into light and retransmit them.

In contrast, advances in digital coherent technology—which NTT laboratories have been researching and developing for many years—have enabled high-speed, long-distance, large-capacity transmission using optics, and the APN uses the technology to enable end-to-end optical transmission [4]. The APN is optical from end to end, and by greatly reducing the processing required to convert electrical signals to optical signals and vice versa, it helps reduce power consumption in the form of a low-delay, low-fluctuation network. Even when processing with light, it is necessary to take measures against security risks in the same way as when processing with electrical signals in the conventional manner. One way to meet that security requirement is through secure optical-transport-network technology*1 (see **Fig. 1**).

With this technology, keys are exchanged in a way that even a quantum computer cannot decipher. Keys are used for encryption to ensure secure communications. NTT has demonstrated that 8K60P uncompressed video can be transmitted securely at a data rate exceeding 40 Gbit/s with ultra-low latency [5].

2.2 Potential use cases for remote concerts, cloud gaming, and remote surgery

We are conducting various demonstration experiments using end-to-end optical transmission via the APN and secure optical-transport-network technology. One use case of the APN is remote concerts using uncompressed, bi-directional video communications that takes advantage of low latency. Two remote concert venues are connected with low latency that enables simultaneous enjoyment at both venues by real-time two-way transmission of musical performances and audience responses.

Another use case is cloud gaming. A communications environment with as little latency as possible is an important factor, and differences in the amount of latency between remotely located players can affect the outcome of the game. We are building an environment that uses technology to achieve low and uniform latency under such conditions and continuing to experimentally demonstrate comfortable and fair

*1 Secure optical-transport-network technology: Technology that (i) shares a common key between optical-transmission devices (by using post-quantum cryptography and quantum-key distribution) and (ii) encrypts communications with the key.

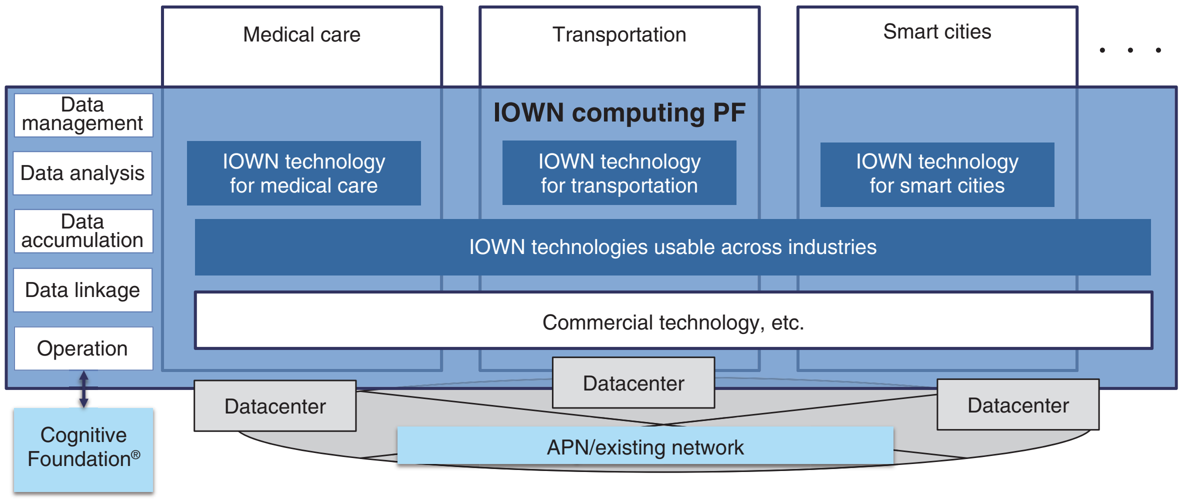


Fig. 2. IOWN computing PF.

cloud gaming.

The final use case is in the field of medical care, specifically, remote surgery. Remote surgery requires that the manipulations of the surgeon be transmitted quickly and reliably to a remote robotic arm. Satisfying that requirement necessitates not only low latency but also a low-fluctuation communications environment with ensured tight security. We have started demonstrations to establish such an environment by applying the characteristics of the APN and secure optical-network-transport technology.

2.3 Potential use case for an inter-datacenter network

The APN is also being used to connect datacenters by taking advantage of their high-speed, wide-bandwidth, and low-latency characteristics. Computing resources are expected to be distributed over a wide area [6], so we are also considering the use of long-distance remote direct memory access (RDMA)*2 for the data plane. While RDMA was developed for short distances (up to 10 m) within a datacenter, long-distance RDMA enables data transfer over long distances by connecting datacenters via the APN; thus, it will be possible to use the computing resources of multiple remote datacenters as if they were a single datacenter. However, data communications that were previously closed within a datacenter—thus protected from external security threats—must now pass through external paths due to the application of long-distance RDMA, so it has become necessary to ensure secure data communications on those paths. We plan to apply the secure optical-transport-network technology to meet this need and have started experimentally demonstrating this technology application.

3. IOWN computing platform and the Trusted Data Space

3.1 IOWN computing PF for Digital Twin Computing

Digital twin refers to a technology that uses data collected from the real world to create the same world (a twin) in cyberspace. As part of IOWN, Digital Twin Computing—based on such digital twins—has been proposed. Digital Twin Computing enables simulations by freely combining, in cyberspace, data concerning objects and people in various industries. It also makes it possible to predict the future by using highly accurate data concerning objects and people. This prediction requires an environment in which data can be appropriately processed and advanced calculations possible, and the IOWN computing platform (PF) enables such an environment (**Fig. 2**).

The IOWN computing PF implements each IOWN technology to contribute to the creation of new value in various businesses by making it possible to collect and analyze data across multiple industries. In the following sections, issues related to handling of data—from collection to analysis—are described, and potential use cases of new-value creation via the

*2 RDMA: Technology for copying data from the memory on the source server to the memory on the destination server on the network-device side without involving the central processing unit.

IOWN computing PF are presented.

3.2 Data handling for creating new value

The IOWN computing PF will handle large amounts of data in a variety of industries. Some of the data are unique to individuals or companies, and the confidentiality of the data must be guaranteed. Data are unevenly distributed across industry boundaries and stored in various locations; thus, it is necessary to integrate them for efficient handling. Implementing IOWN will make it possible to implement the technologies that can address such issues concerning data handling.

When personal or company-specific data are being handled, the data must be analyzed in a confidential manner. To meet this need, we developed the Trusted Data Space [7], which integrates multiple IOWN technologies, i.e., secure computation technology*3 [8], secure matching technology*4, and data sandbox technology*5, to ensure data confidentiality. The Trusted Data Space will be implemented on the IOWN computing PF in a manner that ensures safe and secure data handling. For handling data unevenly distributed across various locations, it is necessary to enable both (i) sending and receiving of large amounts of data and (ii) integration and analysis of unevenly distributed data. To meet these requirements, we are developing a next-generation data hub [9] by integrating two IOWN technologies, i.e., data broker*6 (enabling efficient data transmission and reception among multiple locations) and virtual data lake*7 (enabling efficient data retrieval and acquisition by virtually integrating data from multiple locations), and implementing them on the IOWN computing PF. We will solve various problems facing data handling by combining IOWN technologies and commercial technologies as necessary and contribute to creating new value by implementing advanced data handling on the IOWN computing PF.

3.3 Potential use case 1: Creation of new value in the medical industry

In the medical industry, the handling of personal medical and behavioral data is expected to create new value such as predicting health risks and changing people's behavior to improve their health. To create such value, it is necessary to increase the accuracy of forecasts and analysis; however, meeting this need requires a large amount of sample data. The data to be handled are sensitive, so there is a high psychological barrier for individuals to grant permission to use such data, and it is difficult to collect and use the data for analysis. Such data are ubiquitously accumulated in the data-management environment of each data owner, so comprehensive analysis of the data is also an issue.

The IOWN computing PF solves various issues by enabling analysis and processing of data under the control of the data owner in a manner that does not disclose sensitive data to third parties. IOWN technologies include the Trusted Data Space, which enables analysis of data while keeping the data confidential, and virtual data lake, which integrates and handles ubiquitous data. These technologies make it possible to handle large amounts of sensitive data, improve prediction and analysis accuracy, and contribute to building a prosperous society in which people can live in good health.

3.4 Potential use case 2: Creation of new value in the transportation industry

In the transportation industry, we expect to create new value from a wide variety of data by (i) reproducing and analyzing ever-changing location information, such as vehicle sensor data and personal GPS (Global Positioning System) data, in a digital space and (ii) encouraging individuals to change their behavior to reduce traffic congestion. To create value in this manner, it is necessary to reproduce and analyze movement data managed by each individual or multiple companies in real time. However, it is generally difficult to process the wide variety of data generated from moment to moment in a practical time frame. Data that are the source of competitiveness for the owners are also practically challenging to share across several companies.

The IOWN computing PF solves the above problems by handling a wide variety of data in real time without disclosing competitive data managed across

*3 Secure computation technology: Technology that ensures secure data analysis across organizations by using various machine-learning algorithms that encrypt data without revealing them to anyone.

*4 Secure matching technology: Technology that enables safe cross-analysis of data collation of accounts between two parties without revealing each other's data.

*5 Data sandbox technology: Technology that ensures secure processing on the basis of on-demand agreements when providing data to others while maintaining control over one's data. It prevents anyone other than the rightful owner from viewing confidential information (data, programs, and execution results).

*6 Data broker: Technology that enables low latency and reliable transmission and reception of high-frequency data to and from a vast number of devices.

*7 Virtual data lake: Technology that enables data to be integrated virtually and handled centrally without having to be consolidated at a single location.

multiple companies to third parties. In addition to the Trusted Data Space and virtual data lake, IOWN uses data broker for efficient transmission and reception of data from multiple locations. These technologies enable data sharing among multiple companies and efficient handling of ubiquitous data that change from moment to moment and contribute to solving social issues such as mitigation of traffic congestion.

4. Future developments

The first step in actualizing IOWN is to collaborate with companies participating in the IOWN Global Forum, government offices, universities, communications-equipment manufacturers, the NTT Group, and various other companies in conducting demonstration experiments using IOWN technologies. Through this collaboration, we will steadily create new value by breaking down the boundaries among industries. The IOWN Product Design Center will continue to promote various activities for gaining knowledge and feedback to improve IOWN technologies and create new value.

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He was active in the standardization of multiprotocol label switching technology in the Internet Engineering Task Force. He is a co-author of RFC 4736, 5088, 5089, 5298, and 5886. He was also active in the Internet community in Japan. He was chair of the Japan Network Operators' Group from 2007–2012, which consisted of about 6000 engineer members from various Internet services providers mainly in Japan.

A Concept of Introducing Magnetic Attraction Structure into Optical-fiber Connector

Kota Shikama, Norio Sato, Yoshiyuki Doi, Satoshi Tsunashima, and Yuzo Ishii

Abstract

High-density on-board optical connectors are necessary for next-generation optical interconnects such as co-packaged optics in datacenter networks. To break through the size limitation of current optical connectors, we proposed the concept of introducing a magnetic attraction structure into an optical-fiber connector. We previously developed simplex and multi-fiber connectors on the basis of this concept. This article reviews the design and fabrication results of our developed multi-fiber magnetic connector, which provided low-insertion losses comparable to those of conventional multi-fiber push-on connectors while achieving space-saving connection.

Keywords: optical connector, magnet, optical fiber

1. Introduction

As information technology services, such as cloud services, fifth-generation mobile communications applications, and artificial intelligence, continue to evolve, datacenter networks will demand higher-capacity data transmission. High-bandwidth optical interconnects based on high-speed optical transceivers are widely used to accommodate the growing traffic in such datacenter networks. New optical interconnects based on co-packaged optics (CPO) have been attracting attention to break through the capacity limit of conventional interconnects based on pluggable transceivers. NTT has been developing such interconnects on the basis of our co-package type optical engine as a target example of the All-Photonics Network in the Innovative Optical and Wireless Network (IOWN) [1, 2]. **Figure 1** shows an example image of CPO applications in which a large-scale integration chip and multiple optical engines with fiber pigtails are placed on a board. Since several fiber pigtails should be connected efficiently to other single-mode fibers (SMFs), a high-density multi-fiber connector is necessary.

Figure 2 shows the configuration of a typical multi-fiber push-on (MPO) connector [3], which was developed by NTT and the most widely used multi-fiber optical connector. The MPO connector plug consists of a mechanically transferable (MT) ferrule into which optical fibers are precisely aligned and fixed, two guide-pins in the male plug (two guide-holes in the female plug), spring, and housing parts. When we connect these connectors via an adaptor, multiple optical fibers can be connected simultaneously with high precision by fitting the two guide pins and guide holes. Each ferrule end is obliquely polished and pressed with the spring from the rear end of the ferrule to achieve angled physical-contact (PC) connection. The connector can yield good optical characteristics with a push-pull connection but is not ideal for such applications because it is too large for on-board connections. Further size reduction of MPO connectors is limited because they require a spring and related housing parts, which are essential for applying enough compression force needed for the angled PC connection [3].

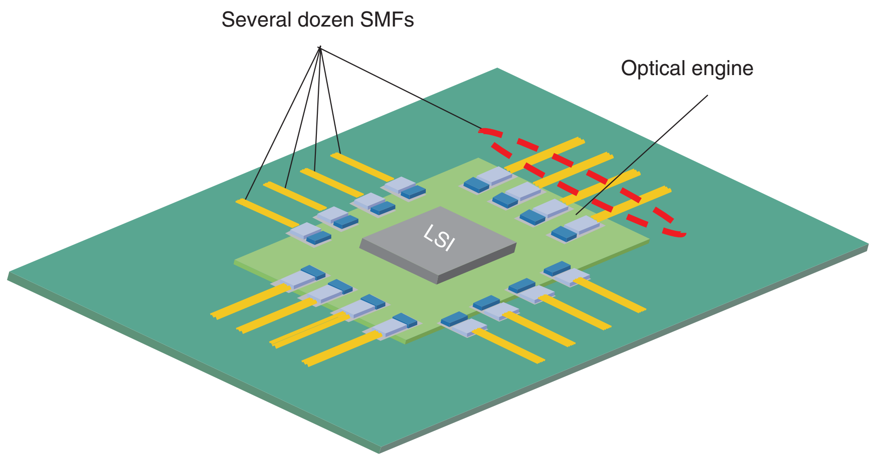


Fig. 1. Example of CPO applications.

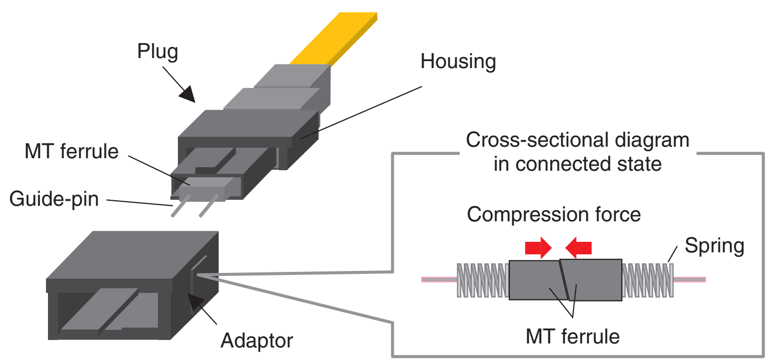


Fig. 2. Structure of MPO connector.

In light of the above issues, we proposed the concept of introducing a magnetic attraction structure into an optical-fiber connector to provide enough compression force by magnetic force. Our concept enables us to eliminate the need of spring and related housing parts; thus, the connector size can be miniaturized. This article introduces this concept and reviews the design and fabrication results of our developed multi-fiber magnetic connector [4], enabling an angled PC connection.

2. Concept of magnetic connector

Our concept is to use magnetic attraction as compression force applied between mated plug facets while following the conventional fiber alignment mechanism with conventional high-precision ferrules. We previously applied this concept to our simplex connector [5] and multi-fiber connector [4]. **Figure 3** shows the relationships among this simplex magnetic connector prototype, our multi-fiber magnetic connector prototype, and conventional single fiber coupling (SC) and MPO connectors. To suppress Fresnel reflection at the mated facets, both conventional connectors provide a PC connection, which is achieved by the elastic deformation of the mated connector ends through the axial compression force supplied by a spring. In our magnetic connector prototype, a magnet or magnetic metal is placed around the ferrule instead of the spring, and sufficient compression force for PC is provided by the magnetic attraction force between them.

Figures 4(a) and **(b)** respectively show a perspective view of the first prototype of our multi-fiber magnetic connector [4] in the connected state and its cross-sectional diagram. At one side of the connector,

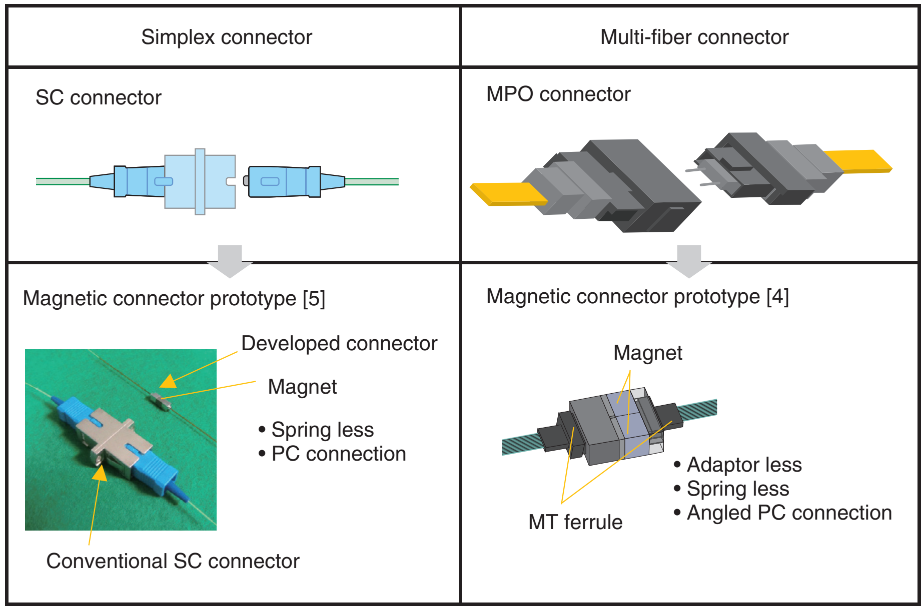


Fig. 3. Relationships among magnetic connector prototypes and conventional connectors.

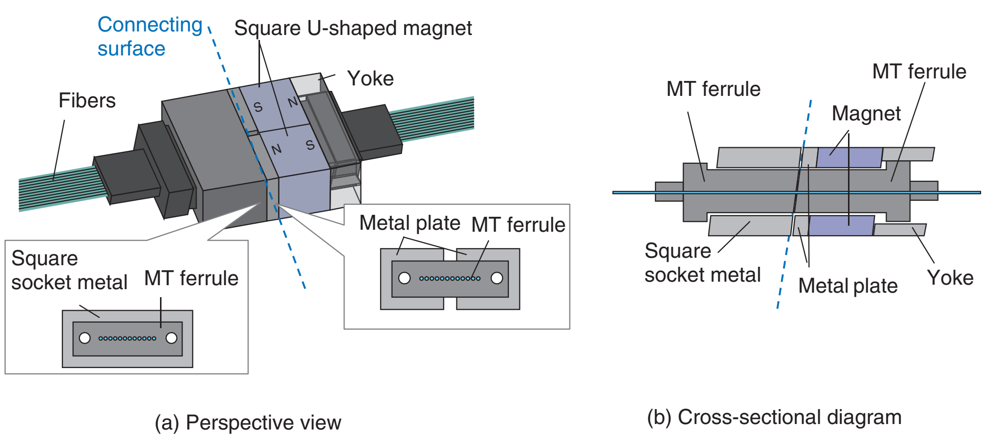


Fig. 4. Basic structure of developed multi-fiber magnetic connector.

a square magnetic-metal part with a square socket is fixed to a conventional MT ferrule (6.4 mm in width and 2.5 mm in height). At the other side, two square U-shaped magnetic-metal plates are fixed around the other MT ferrule, behind which are placed two square U-shaped magnets and magnetic-metal parts that serve as magnetic yokes. The two magnets have opposite magnetization directions, both of which are parallel to the lengthwise fiber direction. Each facet of the components is angled to be parallel to the ferrules. In this configuration, compression force between the two connectors is applied vertically to their angled facet through the magnetic force between the square-socket part and magnetic-metal plates with the two magnets.

3. Magnetic simulation and mechanical design

To provide sufficient magnetic force with our magnetic multi-fiber connector while keeping the connector size as small as possible, detailed magnetic simulation is necessary since the magnetic force depends on the

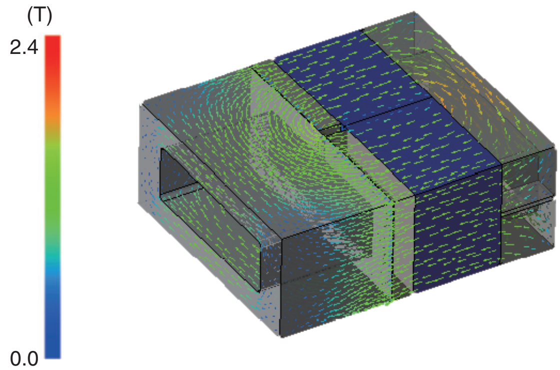


Fig. 5. Simulated magnetic-flux density line.

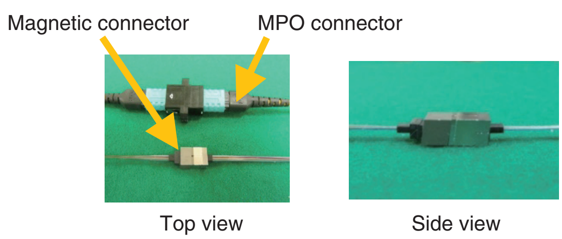


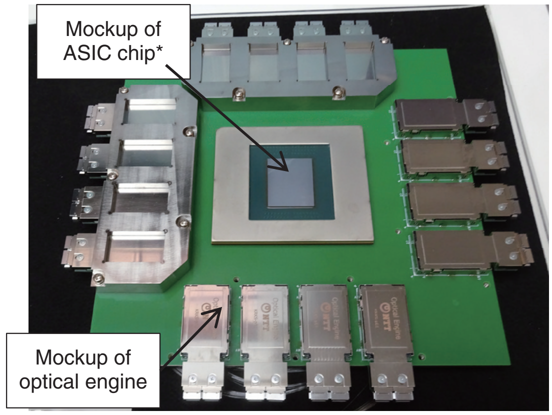
Fig. 6. Photographs of prototype of fabricated connector.

size, material, arrangement, and shape of the mated magnets and magnetic-metals. The ferrules should also slightly protrude from each facet of each magnetic part to ensure that the ferrule ends touch each other; thus, there should be a gap between the mated magnetic-metals. Since magnetic force is also dependent on the gap, it is necessary to design the amount of protrusion by taking the component tolerance of each part and assembly precision into account.

Figure 5 shows an example of a simulated magnetic-flux density line under the basic configuration of our multi-fiber magnetic connector prototype shown in Fig. 4. In simulation, we used neodymium-based magnets and SUS430 as a magnetic-metal. As shown in the figure, the magnetic circuit is effectively confined by the yoke, and magnetic flux passes densely through the connecting surface, which indicates that magnetic attraction force is effectively applied between two mated connectors. We found that the gap should be less than about 0.09 mm if we set the target magnet force to more than 10 N, which is a standard value for conventional spring force in MPO connectors.

4. Fabrication results

As a case study, we fabricated our multi-fiber magnetic connector with a standard 12-MT ferrule in which twelve SMFs were fixed with an adhesive and the connector-end was appropriately polished to an angle of 8 degrees. We then fixed the SUS430 square-socket part to one of the ferrules and the SUS430 plates to the other so that the gap value meets the gap requirement mentioned in the previous section (0.09 mm). **Figure 6** shows photographs of this connector. The connected size is sufficiently small (about $9.3 \times 5 \times 16$ mm^3), which is drastically smaller than that of MPO connectors. The insertion losses were acceptably low, less than 0.6 dB, and the average loss was 0.16 dB. The return losses of the mated connectors were also acceptably high, more than 65 dB, and confirmed angled PC connection was successfully achieved due to the magnetic force. These results indicate that the performance of our multi-fiber magnetic connector is comparable to conventional MPO connectors while enabling drastic miniaturization.



*By courtesy of Broadcom Inc.

ASIC: application-specific integrated circuit

Fig. 7. Photograph of mockup of our optical engines with ASIC chip.

5. Conclusion and future work

We presented the concept of introducing a magnetic attraction structure into an optical-fiber connector and our developed multi-fiber magnetic connector with an angled PC connection. We will continue to develop compact optical connectors suitable for future optical interconnects with our optical engine, a mockup of which is shown in **Figure 7**, and contribute to the actualization of IOWN.

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ITU-T Study Group 16 Meeting Report and Recent Development in Standardization of Immersive Live Experience Technologies

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Abstract

The recent meeting of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) Study Group (SG) 16 was held in October 2022, with the new management members. An SG vice-chairman and two Working Party chairmen were appointed from Japan. Regarding immersive live experience, four draft documents including one new work item were discussed, and the definition of the descriptor of haptic information was added to one of the documents during the meeting. In the meeting, a Correspondence Group on Metaverse was held and sent a liaison statement to the Telecommunication Standardization Advisory Group (TSAG) asking for TSAG's decision on whether to start a Focus Group on Metaverse. With the newly appointed director of the Telecommunication Standardization Bureau, Mr. Seizo Onoe, a positive cycle of technology development and dissemination is expected by incorporating industry into the standardization activities of ITU-T.

Keywords: ITU-T, Study Group (SG) 16, immersive live experience (ILE)

1. New Study Group 16 administration

The administrations of Study Groups (SGs) of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) are renewed every four years. The Plenipotentiary Conference (PP)[*1] decides the general policy for the whole ITU and World Telecommunication Standards Assembly (WTSA)[*2] for ITU-T, including appointments of SG chairmen and vice-chairmen. The recent ITU-T SG16 meeting was held between October 17 and 28, 2022. The new SG16 administration under the chairman (re-appointed) was formed as it was the first meeting after WTSA. The chairman and vice-chairmen of SG16 are listed in **Table 1**. Mr. Yamamoto (OKI) from Japan was appointed as a vice-chairman.

The rapporteurs and associate rapporteurs who lead Questions (Q) and Working Party (WP) chairmen were also appointed during the SG16 meeting. **Table 2** lists the WP chairmen. Mr. Yamamoto and Mr. Imanaka (National Institute of Information and Communications Technology (NICT)) from Japan were appointed as WP2 and WP3 co-chairmen, respectively. The rapporteurs and associate rapporteurs are listed in **Table 3**. Three rapporteurs (Q8 Mr. Imanaka, Q27 Mr. Yamamoto, Q26 and Q28 Mr. Kawamori (Keio University)) and two associate rapporteurs (Q8 the author, Q27 Mr. Shimizu (Mitsubishi Electric)) from Japan were appointed.

*1 PP: The highest policy-making body of ITU. It is held every four years. Delegates from about 190 member states gather.

*2 WTSA: WTSA is held every four years and defines the next period of study for ITU-T.

Table 1. Chairman and vice-chairmen of SG16.

	Name	Country
Chairman	Mr Zhong (Noah) LUO	China
Vice-chairman	Mr Ashok KUMAR	India
Vice-chairman	Mr Hideki YAMAMOTO	Japan
Vice-chairman	Mr Shin-Gak KANG	Korea (Rep. of)
Vice-chairman	Ms Sarra REBHI	Tunisia
Vice-chairman	Mr Charles Zoé BANGA	Central African Republic
Vice-chairman	Mr Per FRÖJDH	Sweden
Vice-chairman	Mr Justin RIDGE	United States
Vice-chairman	Mr Akmal SAVURBAEV	Uzbekistan

Table 2. WP chairmen (co-chairmen) of SG16.

WP	WP title	Chairmen (Country)	Questions
WP1	Infrastructure for multimedia systems	Shin-Gak KANG (Rep. of Korea) Marcelo MORENO (Brazil)	11, 13, 21, 22, 27
WP2	Multimedia digital services and human aspects	Mohannad EL-MEGHARBEL (Egypt) Hideki YAMAMOTO (Japan)	23, 24, 26, 28
WP3	Audiovisual technologies and intelligent immersive applications	Hideo IMANAKA (Japan) Yuan ZHANG (China)	5, 6, 8, 12

2. SG16 meeting topics

2.1 Immersive live experience

The Q8 of SG16 studies immersive live experience (ILE). NTT has been contributing actively to Q8 since the beginning of the Question. Five Recommendations (From ITU-T H.430.1 to H.430.5) have been published thus far. Study on interactive immersive services (IIS) started recently, and NTT proposed to start the draft Recommendation H.ILE-Haptic. Other topics are described below.

(1) H.430.3 V2 (Service scenario of ILE)

This draft Recommendation explains service scenarios and use cases of ILE. Transport of haptic information and IIS are considered to be added to the document. Descriptions of the relevant service scenarios were revised, and information on the related technologies provided by SG13 was added to the draft Recommendation during the meeting.

(2) H.IIS-Reqts (Requirements of IIS)

This document defines the requirements of IIS. Consent of the draft was proposed, but it was postponed because a relatively large revision was made to the draft including elaboration and change of sections.

(3) H.ILE-Haptic (Media transport protocols, signalling information of haptic transmission for ILE systems)

NTT proposed to start this draft Recommendation to add haptic transmission technology to ILE. The current Recommendations on ILE describe transport of video, audio, location, etc., but the draft aims to add the transmission technology of haptic information to achieve even higher sense of immersiveness. Stiffness and other information have been added to the draft along with the definition of the descriptor of haptic information during the meeting.

(4) H.IIS-FA (Functional architecture of IIS system)

This is a new work item consented to start during the meeting. High-level architecture of IIS and functional architecture are expected to be studied. Details will be discussed in future meetings.

2.2 Metaverse

Correspondence Group (CG) on Metaverse had been held in the previous SG16 meeting (January 2022). Focus Group (FG)[*3] on Metaverse was proposed from Japan in this meeting (October 2022).

*3 FG: A group created by ITU-T to augment the SG work program or when the issue is not covered within an existing SG. Non-ITU member can join FGs.

Table 3. Questions, rapporteurs and associate rapporteurs (* indicate rapporteurs).

Question (WP), Question title	Name	Country
Q1 (SG16 Plenary) Multimedia and digital services coordination	*Sarra REBHI	Tunisia
Q5 (WP3) Artificial intelligence-enabled multimedia applications	*Yuntao WANG	China
	Qing LIU	China
	Yuwei WANG	China
Q6 (WP3) Visual, audio and signal coding	*Gary SULLIVAN	USA
	Thomas WIEGAND	Germany
	Yan YE	China
Q8 (WP3) Immersive live experience systems and services	*Hideo IMANAKA	Japan
	Hoerim CHOI	Korea (Rep. of)
	Jiro NAGAO	Japan
Q11 (WP1) Multimedia systems, terminals, gateways and data conferencing	*Patrick LUTHI	Switzerland
Q12 (WP3) Intelligent visual systems and services	*Yuan ZHANG	China
	Haitao ZHANG	China
Q13 (WP1) Content delivery, multimedia application platforms and end systems for IP-based television services including digital signage	*Marcelo MORENO	Brazil
	Chuanyang MIAO	China
Q21 (WP1) Multimedia framework, applications and services	*Liang WANG	China
	Nijingnan ZHANG	China
Q22 (WP1) Multimedia aspects of distributed ledger technologies and e-services	*Kai WEI	China
	Liangliang ZHANG	China
Q23 (WP2) Digital culture-related systems and services	*Hong (Norman) CHEN	China
	Shizhong XU	China
Q24 (WP2) Human factors for intelligent user interfaces and services	*Miran CHOI	Korea (Rep. of)
	Done-Sik YOO	Korea (Rep. of)
Q26 (WP2) Accessibility to multimedia systems and services	*Masahito KAWAMORI	Japan
	Mohannad EL-MEGHARBEL	Egypt
Q27 (WP1) Vehicular multimedia communications, systems, networks, and applications	*Hideki YAMAMOTO	Japan
	Hongki CHA	Korea (Rep. of)
	Naoki SHIMIZU	Japan
Q28 (WP2) Multimedia framework for digital health applications	*Masahito KAWAMORI	Japan

The CG was also held in this meeting, and issues, such as whether to start the FG, the parent group of the FG, name of the FG, were sent to the Telecommunication Standardization Advisory Group (TSAG)*4.

3. Future prospect

In PP-22 [1] held from 26 September to 14 October 2022, Mr. Onoe from Japan (then NTT chief standardization strategy officer) was elected as the next director of the Telecommunication Standardization Bureau at ITU-T. He started his post in January 2023. This appointment is expected to stimulate the telecommunication standardization activities in Japan, resulting in more active discussion in SG16. NTT plans to continue contributing to the work items such as H.ILE-Haptic. Not only the standardization communities but also the market is interested in the metaverse. Collaboration between the industry, who implements technologies, and ITU-T, who deploys technology standards worldwide, is expected to create a positive cycle of technology development and dissemination.

Reference

[1] PP-22, https://pp22.itu.int/en/

*4 TSAG: The advisory body to SGs in administration and operation of ITU-T. TSAG meets during the years when WTSA is not held.

Jiro Nagao

Senior Manager, Standardization Office, Research and Development Planning Department, NTT Corporation.

He received a Ph.D. in information science from Nagoya University, Aichi, in 2007. He joined NTT the same year. From 2007 to 2011, he was engaged in research and development of image processing and content distribution technology. From 2012 to 2017, he worked for NTT Communications, serving as the technical leader of commercial video streaming services. From 2017 to 2021, he was engaged in research and development of immersive media and presentation technology at NTT Service Evolution Laboratories. Since 2019, he has contributed to the international standardization efforts on ILE of ITU-T SG16. He served as an editor of ITU-T H.430.4 (ex H.ILE-MMT) and H.430.5 (ex H.ILE-PE) from 2019 to 2020. He received the ITU Association of Japan Encouragement Award in 2021. He is currently an associate rapporteur of ITU-T SG16 Q8 (Immersive Live Experience, since 2022) and the leader of ILE Sub Working Group of the Telecommunication Technology Committee (since 2020). He is a member of the Institute of Electrical and Electronics Engineers (IEEE), the Institute of Electronics, Information and Communication Engineers (IEICE), and the Japanese Society of Medical Imaging Technology (JAMIT).

Case Study of Malfunctions of Outdoor Security Cameras Caused by Lightning Surge

Technical Assistance and Support Center, NTT EAST

Abstract

This article introduces the malfunctions of outdoor security cameras caused by lightning strikes. The path of the lightning-surge current and countermeasures against the malfunctions are also explained. This is the seventy-fifth article in a series on telecommunication technologies.

Keywords: lightning strike, outdoor security camera, surge protective device

1. Introduction

Security cameras have become widely used for crime prevention and safety management. The network configuration, the management function of which is centralized in one location, is suitable for monitoring a wide area with multiple cameras. To monitor a wide area, security cameras are often installed in places offering good visibility; however, such places are likely to be damaged by lightning strikes, which can cause problems such as equipment malfunction. To prevent such problems, it is necessary to configure equipment by taking countermeasures against lightning damage. An example of malfunctions of outdoor security cameras caused by lightning strikes is introduced in this article.

2. Malfunctions of outdoor security cameras

A customer who used multiple outdoor security cameras on the premises of a temple reported that after a thunderstorm, the video images from three out of five security cameras were interrupted, and the images could not be displayed. We investigated the cause of the malfunctions and provided technical support concerning lightning-damage countermeasures for the customer's planned upgrading of the security equipment.

2.1 Network and equipment configuration

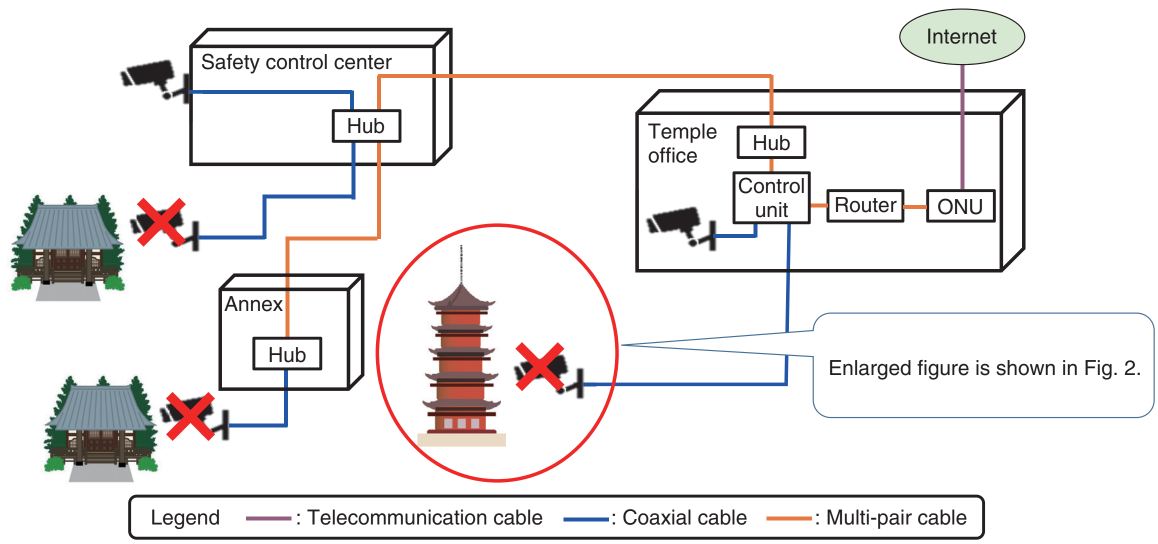
The configuration of the security network when the malfunctions occurred is shown in **Fig. 1**.

The five security cameras (four outdoor and one indoor) are controlled and managed by a control unit located in the temple office, and the cameras and control unit are connected using coaxial cables. The three cameras that malfunctioned were all outdoor types, and other equipment did not malfunction.

2.2 Equipment conditions and results of on-site investigations

The equipment conditions at a malfunction location and results of the on-site investigations are shown in **Fig. 2**.

A lightning rod is installed on the temple building and connected to a ground electrode buried around the building. The outdoor security cameras are installed on metal camera poles, and the distance between the building and security cameras is 10 to 20 meters. The power supply for the outdoor security cameras is fed from a power cable wired underground.



ONU: optical network unit

Fig. 1. Network and equipment configuration.

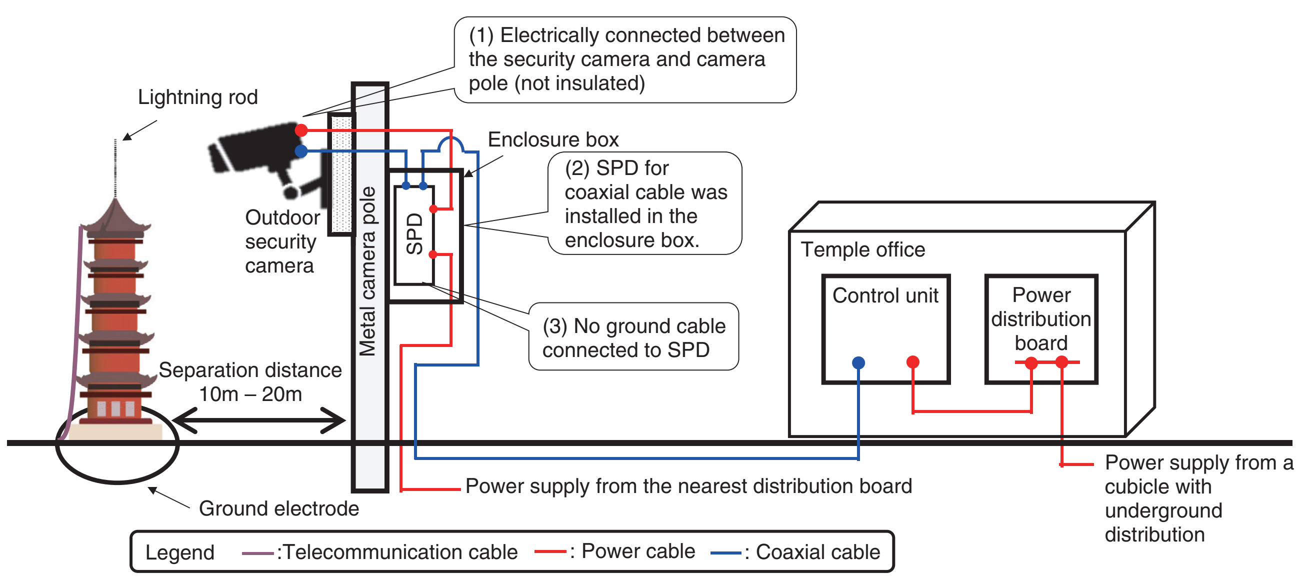


Fig. 2. Equipment conditions when the malfunctions occurred.

We conducted an on-site investigation to check the installation conditions of the outdoor security cameras at the three locations where the malfunctions occurred and the equipment conditions connected to the cameras. The results of the on-site investigation were (1) the outdoor security cameras and camera pole were not insulated; (2) a surge protective device (SPD) for a coaxial cable was installed in an enclosure box near the camera, and the coaxial cable and power cable went through the SPD; and (3) the ground cable was not connected to this SPD.

2.3 Estimation of cause of malfunctions and lightning-surge path

Considering the equipment conditions at the locations of the malfunctions and the results of the on-site

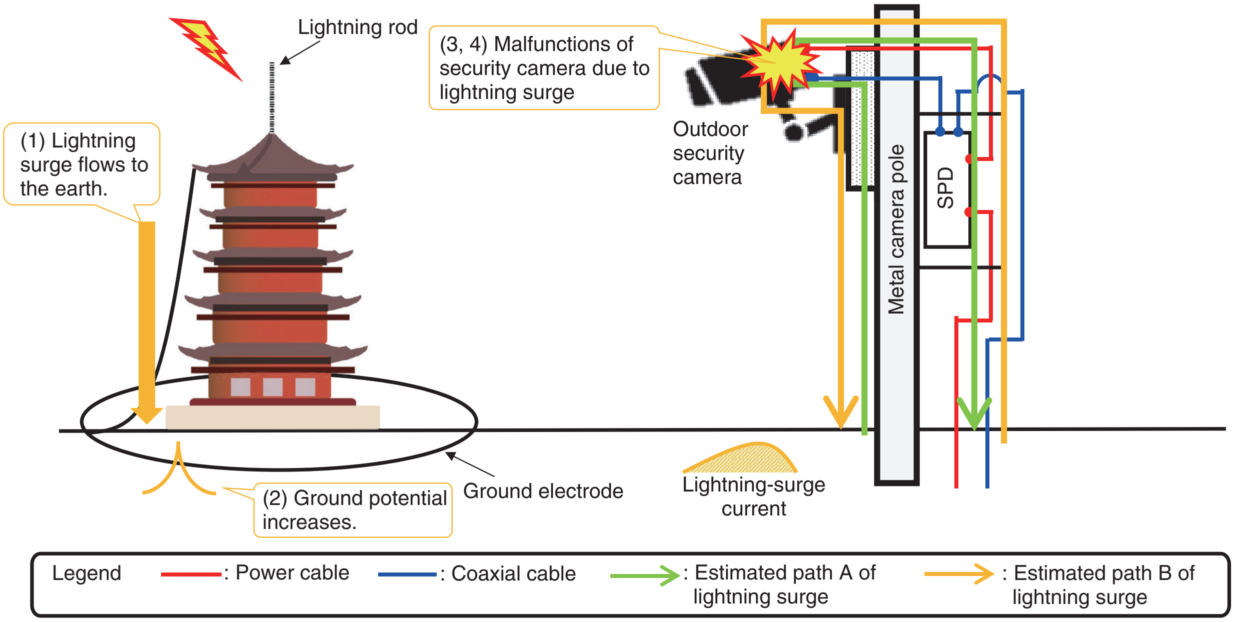


Fig. 3. Estimated lightning-surge path.

investigation, we estimated the path of the lightning surge that caused the malfunctions (**Fig. 3**).

(1) Due to a lightning strike to the lightning rod, the lightning surge flowed to the earth from the ground electrode.

(2) Flow of the lightning surge into the earth caused an increase in the ground potential.

(3) The increase in the ground potential caused the lightning surge to flow into the nearby camera pole (estimated path A) or into the coaxial-cable shield and power cable laid underground (estimated path B).

(4) The lightning surges flowed through the camera pole and into the security camera (estimated path A) or flowed into the camera from the shield of the coaxial cable or power cable (estimated path B).

2.4 Countermeasures against malfunctions caused by lightning strikes

The basic countermeasures against malfunctions caused by lightning strikes are based on (i) preventing the lightning-surge current from flowing to the equipment, (ii) bypassing the lightning-surge current, and (iii) suppressing the potential difference between the equipment and installation site.

Considering the equipment conditions and on-site investigation results discussed in Section 2.2 and the estimated causes of the malfunctions described in Section 2.3, we proposed the following basic countermeasures against lightning surge:

- To prevent lightning surges from entering the security camera via the camera pole, insulate the camera from the camera pole.
- To prevent lightning surges from entering the security camera via the cable, insert an SPD in the cable to be connected to the security camera and securely connect it to earth.

This temple is scheduled for equipment renewal, and the configuration of the new equipment is shown in **Fig. 4** and summarized as follows:

- Change the security cameras to power over Ethernet (PoE) type.
- Install a PoE hub for connecting the security cameras with a Layer 3 switch (L3SW) that has both router and switching-hub functions.
- Connect L3SW and a PoE hub with optical cable and the hub and security camera with a local area network (LAN) cable that supports PoE.
- Use a DC-power-supply media converter (MC) powered from the hub.

Considering these modifications, we proposed the following lightning-damage countermeasures, which are also illustrated in **Fig. 5**.

(1) To prevent lightning surges flowing into security cameras, insulate the security cameras

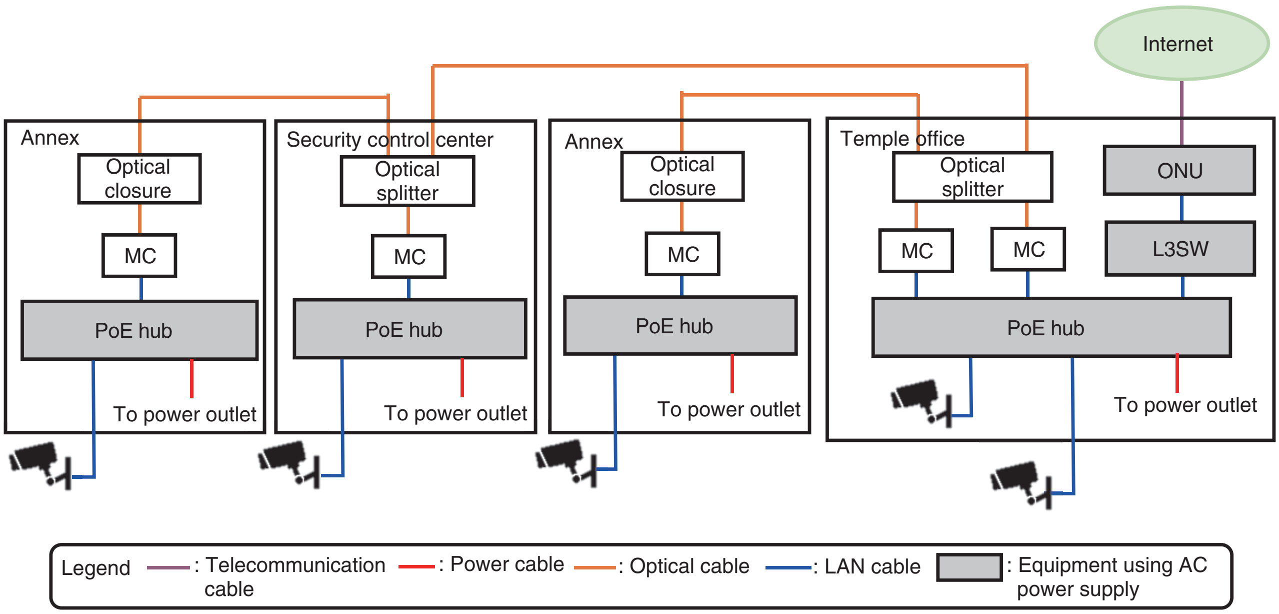


Fig. 4. Renewed configuration of equipment.

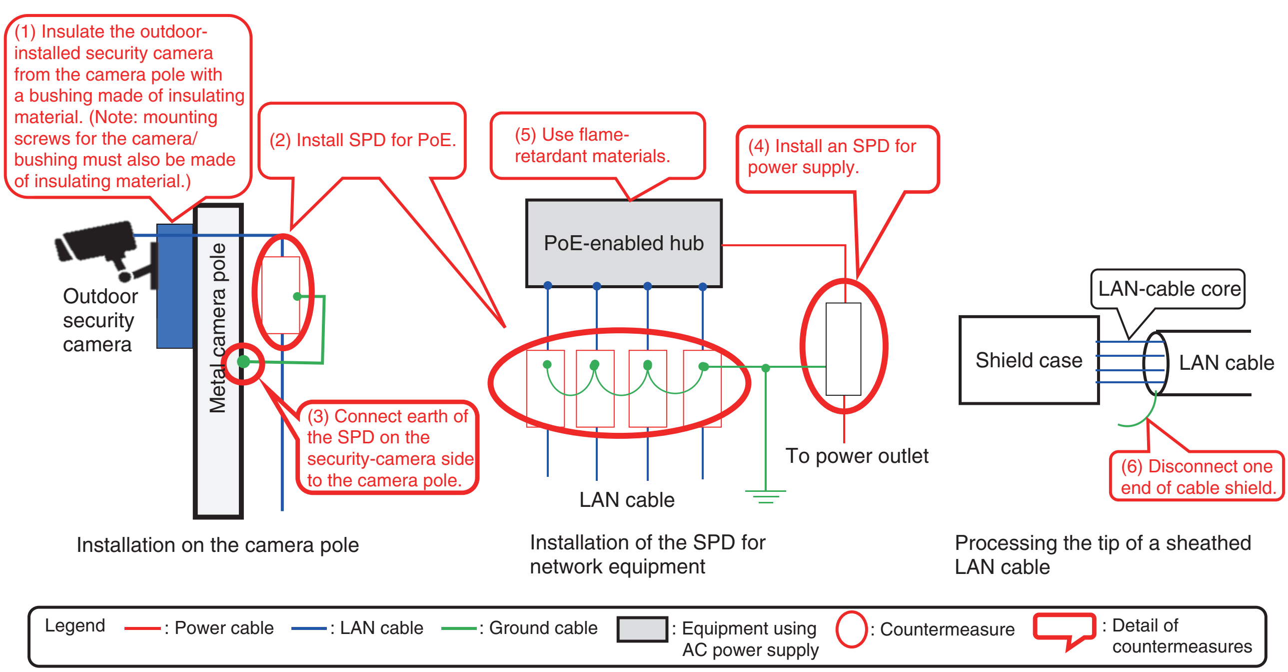


Fig. 5. Proposed countermeasures.

from the camera poles with bushing made of insulating material.

(2) To prevent the inflow of lightning surges from the LAN cables, fit PoE-compatible SPDs to the security cameras and hubs.

(3) Connect SPD's earth on the security-camera side to the camera pole.

(4) To prevent the inflow of lightning surges from

the power-supply system, insert an SPD into the power cable for equipment that uses AC power supply.

(5) Select the equipment that uses flame-retardant materials.

(6) When a LAN cable with a Cat6 or other PoE-compatible sheath is used, cut off one end of the cable shield (so that end is left open) to prevent breakdown of the insulation of the cable cores if a lightning surge enters the sheath.

From the viewpoint of fire prevention, taking countermeasures against tracking for the power outlet is also recommended.

3. Conclusion

This article introduced the malfunctions of outdoor security cameras caused by lightning strikes and countermeasures against those malfunctions. Equipment installed outdoors is at a higher risk of malfunction due to lightning, so it is necessary to configure equipment more reliably. At the Technical Assistance and Support Center (TASC), we will continue to play a role in reducing the operational load of maintenance by providing the knowledge we have accumulated. To reduce malfunctions caused by electromagnetic noise, radio, induction, lightning and improve the reliability of telecommunication services, the EMC Engineering Group of TASC will continue to engage in technical cooperation, development, and dissemination of technology through technical seminars and other activities.

External Awards

Excellence Award at Digital Signage Award 2022

Winner: NTT Human Informatics Laboratories
Date: June 15, 2022
Organization: Digital Signage Consortium

For creating a new spectator experience for the Tokyo 2020 Olympic Games.

IPSJ Computer Science Research Award for Young Scientists

Winner: Shigeo Hakkaku, NTT Computer and Data Science Laboratories
Date: June 30, 2022
Organization: Information Processing Society of Japan (IPSJ)

For "Sampling-based Quasi-probability Simulation for Fault-tolerant Quantum Error Correction on the Surface Codes under Coherent Noise."
Published as: S. Hakkaku, K. Mitarai, and K. Fujii, "Sampling-based Quasi-probability Simulation for Fault-tolerant Quantum Error Correction on the Surface Codes under Coherent Noise," SIG Technical Reports, Vol. 2021-QS-4, No. 10, Oct. 2021.

JSAI Annual Conference Award

Winners: Mana Ihori, NTT Computer and Data Science Laboratories; Ryo Masumura, NTT Computer and Data Science Laboratories
Date: July 26, 2022
Organization: The Japanese Society for Artificial Intelligence (JSAI)

For "Sequence-to-Sequence Document Revision Models Using Switching Tokens to Handle Multiple Perspectives Simultaneously."
Published as: M. Ihori, H. Sato, T. Tanaka, and R. Masumura, "Sequence-to-Sequence Document Revision Models Using Switching Tokens to Handle Multiple Perspectives Simultaneously," Proc. of the 36th Annual Conference of JSAI, 1P4-GS-6-05, Kyoto, Japan, June 2022.

Quantum Software Research Conference Presentation Award

Winner: Yasunari Suzuki, NTT Computer and Data Science Laboratories
Date: August 29, 2022
Organization: IPSJ Special Interest Group on Quantum Software

For "Parallelization and Optimization of SELECT Operations in Fault-tolerant Quantum Computing."
Published as: Y. Suzuki and R. Tokami, "Parallelization and Optimization of SELECT Operations in Fault-tolerant Quantum Computing," SIG Technical Reports, Vol. 2022-QS-6, No. 18, June 2022.

Award of Excellence at the 6th Annual HAGURA Award

Winner: NTT Human Informatics Laboratories
Date: November 18, 2022
Organization: The State of the Art Technologies Expression Association

For creating a new spectator experience using the ultra-realistic communication technology Kirari! for the Tokyo 2020 Olympic Games.

SCAT Chairman's Award 2022

Winner: Toshimori Honjo, NTT Basic Research Laboratories
Date: January 13, 2023
Organization: Support Center for Advanced Telecommunications Technology Research (SCAT)

For research and development of quantum key distribution over optical fiber.

Top Reviewer Award

Winner: Yoichi Chikahara, NTT Communication Science Laboratories
Date: February 6, 2023
Organization: The 26th International Conference on Artificial Intelligence and Statistics (AISTATS 2023)

He was selected as one of the top 10% of reviewers for AISTATS 2023, which will be held in Spain April 25–27, 2023.