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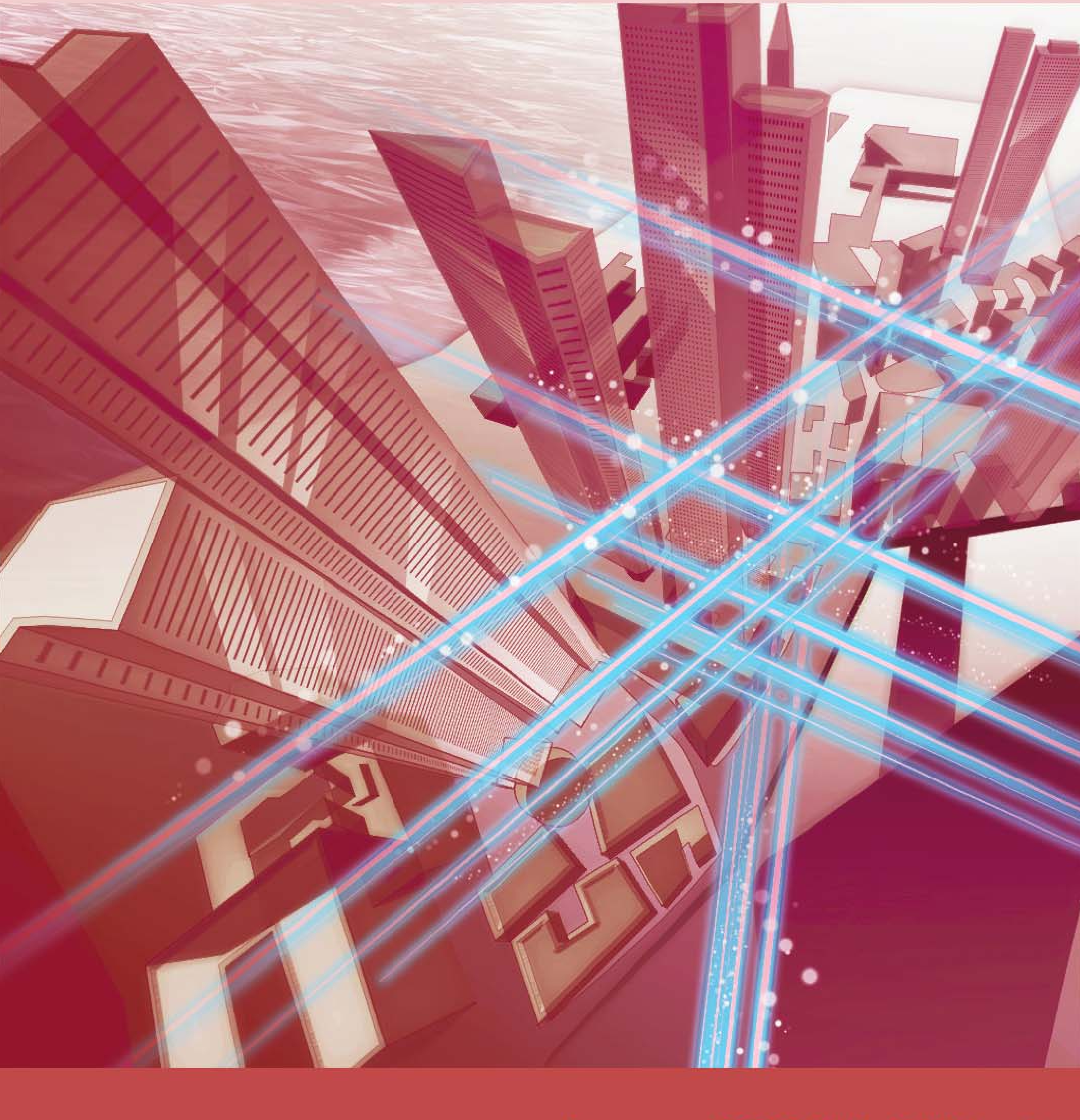

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If We Pursue Research Properly and Correctly, We Will Accumulate Knowledge That Will Make a Valuable Contribution to Academia

Shigeto Furukawa
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Abstract

According to the World Report on Hearing issued by the World Health Organization, it is estimated that by 2050, approximately 2.5-billion people (one in four people) in the world will suffer hearing loss, which is considered a major risk factor in developing dementia. Hearing is an indispensable information-processing mechanism for understanding the environment and communicating with people and an important component of the sensory world that is directly linked to emotions. We interviewed Shigeto Furukawa, a senior distinguished researcher at NTT Communication Science Laboratories investigating the auditory mechanism, about the progress of his research activities and his attitude as a researcher.

Keywords: auditory mechanism, artificial neural network, hearing loss

Investigating intermediate processing in the brainstem to elucidate the auditory mechanism

—It has been two years since our last interview. Could you give us an overview of the research you are currently working on and how it is progressing?

Two years is a very short time regarding basic research activities, and I don't have much to tell you in terms of progress that I have made in solving research problems all at once over the last two years. Therefore, I'll report on any progress I've have made and new collaborative research I've started.

I'm researching the mechanisms of sensory perception that support comfortable communication, focusing on the psychophysics and neurophysiology of hearing. I'm involved in (i) measuring, evaluating, and modeling the mechanism and physiological functions of auditory-scene analysis; (ii) determining and evaluating the mechanism of hearing difficulties; and (iii) clarifying neural mechanisms related to sensory perception and mental states. I'm also interested in variations in hearing, namely, how different people hear the same sound differently or how the same person hears the same sound differently according to the situation. The findings of this research will provide

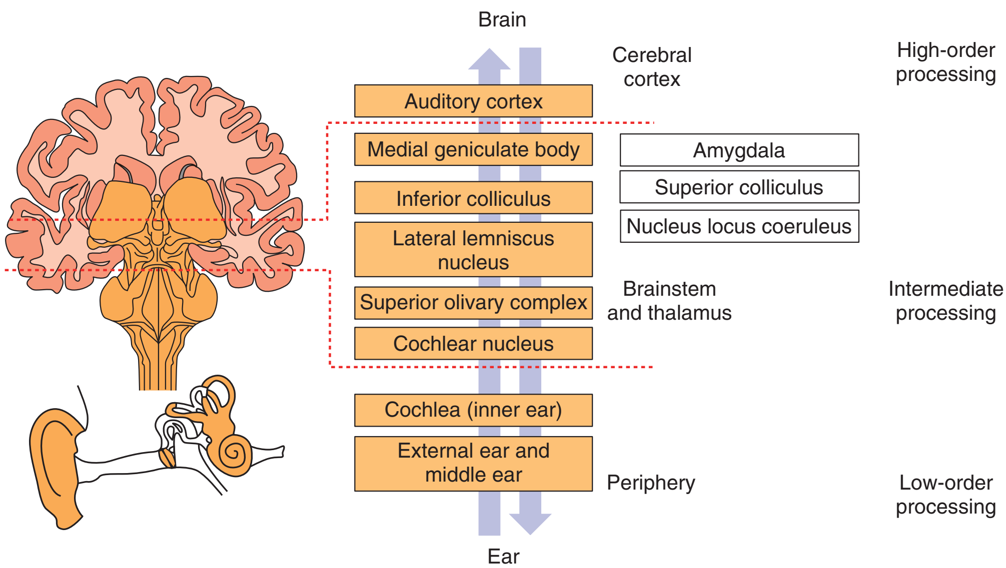


Fig. 1. Flow of processing auditory information.

the basis for technologies that connect people with others, society, and the environment in a harmonious manner.

The mechanism of hearing is often thought of as follows: sound, which is the vibration of the air, is converted into nerve signals by the eardrum and inner ear (i.e., lower-order processing), which are transmitted to the brain, where they are recognized, understood, and interpreted (i.e., higher-order processing), especially in the cerebral cortex. As shown in **Fig. 1**, the signals received from the ear pass through the brainstem on the way to the cerebral cortex, and in the brainstem, they are subjected to multistage processing (i.e., intermediate processing). For example, it is thought that the brainstem is responsible for extracting basic information, such as the pitch of a sound, and for selecting information that reflects the level of importance of the sound.

Focusing on the intermediate processing in the brainstem, I'm analyzing brain and auditory mechanisms indirectly by using biometric measurements, such as electroencephalograms and eye movements, and computer-based modeling. For example, when I measured the brain waves of a person who is played a sound, I found the frequency components of a pattern similar to that of the sound played. Since these components are thought to originate in the brainstem, it is possible to investigate activities related to frequency analysis in the brainstem by analyzing them. It is also known that the activity of neuronal groups related to arousal level and attention in the brainstem is linked to the size of the pupil. These measurements and analyses enable us to access the workings of the brainstem without having to insert electrodes into the brain. I expect that combining various measurement methods and modeling will make it possible to confirm from the outside of the body what is happening naturally in the auditory system that we are not consciously aware of.

—The topic you mentioned in the previous interview, "attention and hearing," is unique.

Let's consider a situation in which you are listening to music. Whether one likes a song or not depends on the individual, and the enjoyment of a song may change from time to time, even if the same person listens to it. When we are enjoying music, some phrases may catch our attention with surprising sound/rhythm tricks, and other phrases may attract us without any notable features even though the music appears to be playing smoothly. By measuring biological reactions of a person listening to a song, I want to be able to observe how each person feels at any given moment. There are many ways to perform this task. One would be to measure the pupil to determine which sounds the person is paying attention to. Previous studies revealed that the size of the pupil changes in accordance with the physical brightness in the direction of attention even if the person is not

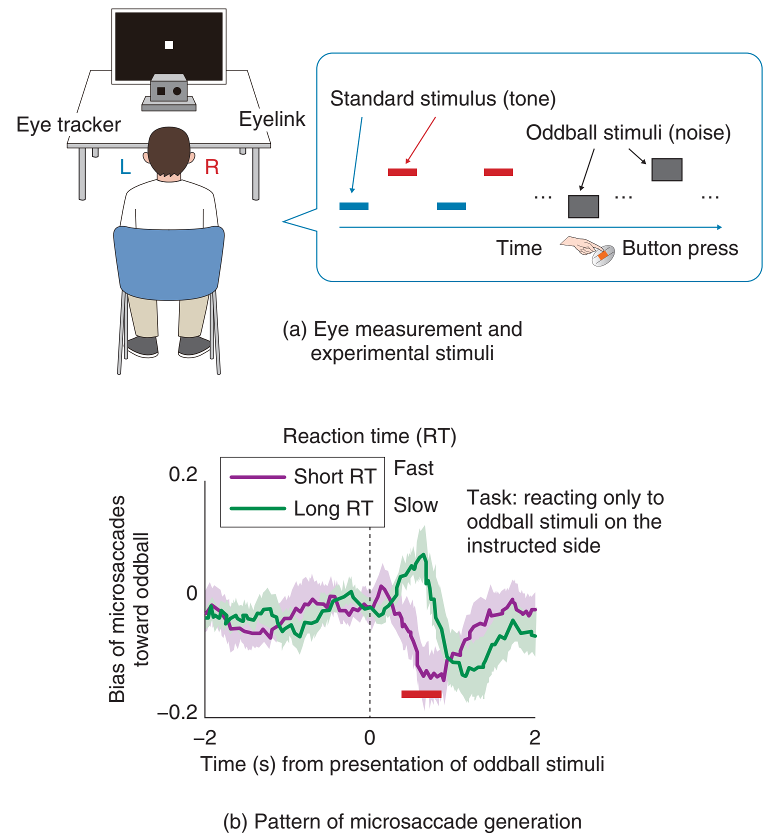


Fig. 2. Microsaccades and auditory attention.

actually looking at the subject. We have found that this phenomenon can be applied to auditory attention as well.

It is also known that in addition to the pupil, small and involuntary eye movements called microsaccades also respond to visual and auditory stimuli in a way that is related to attention. We experimentally investigated the relationship between microsaccades and auditory spatial attention and found that (i) the pattern of generation of microsaccades varies with the direction of auditory attention and (ii) this directional characteristic also correlates with performance in an auditory task (**Fig. 2**). Although many studies have shown a correlation between microsaccades and visual attention, our study also showed a correlation between microsaccades and the direction of auditory attention and information processing in the auditory system.

One of our future research directions is to develop a technology for estimating the attentional state of a person by external observation. It may be possible to visually read information such as which voice a person is paying attention to when many people are having a conversation, such as at a party. We also hope to understand the mechanism by which people allocate their attention in accordance with the situation and to develop technology that uses that mechanism to present appropriate information in a timely manner.

Artificial neural networks trained to recognize sounds acquire a brain-like representation of sound

—I understand that you are also embarking on new research that will have a significant impact on academia.

As I mentioned earlier, in the mammalian brain, features of sound are analyzed in a multistage process—even between the brainstem and the cerebral cortex—from the time a sound reaches the ear until it is recognized (Fig. 1). For example, a relatively slow change in amplitude (amplitude modulation) is an important cue for recognizing a sound. In neurophysiology, researchers have clarified "how" neurons express amplitude modulation in many brain regions in the auditory nervous system.

However, for "why" neurons have come to express amplitude modulation in such a way (namely, is it a natural consequence?), we cannot answer that no matter how many times similar experiments are repeated. In principle, it is difficult to ascertain the relationship between the properties of neurons and the evolutionary process by using a general experimental approach. I have studied the properties of neurons in the cortex and brainstem (although focusing on a property other than amplitude modulation), but I was frustrated that no matter how hard I tried, I could only get a glimpse of the answer to the "how" and not the "why."

It has recently become possible to use artificial neural networks to recognize categories of sounds directly from natural and complex sound waveforms. Fortunately, I was able to team up with motivated researchers in the field of neurophysiology, and with this artificial-neural-network technology in hand, we approached the aforementioned "why" question. Among artificial neural networks, deep neural networks (DNNs) have a structure like that of the auditory nervous system (Fig. 1); that is, DNNs consist of many layers of elements, which correspond to neurons in living organisms, arranged in columns. Other than that similarity, however, DNNs do not simulate the specific neural circuits of the auditory system.

We trained a DNN on a certain task, namely, classifying natural sounds. We then inputted sounds with various modulation frequencies into the trained DNN and examined the output from each individual element composing the DNN. That is, we applied the paradigm used in neurophysiological experiments on animal brains to DNNs as is. The results of the examination revealed that the DNN exhibits similar characteristics to those reported in previous studies on the auditory nervous system in animals. For example, some elements respond strongly only to specific modulation frequencies, and the response characteristics change regularly as the processing progresses from stage to stage.

We also found that (i) the DNN gradually acquires similarity to the brain during the training process; (ii) the more accurately the DNN recognizes sounds, the more similar it becomes; and (iii) untrained DNNs show no similarity to the brain in recognizing natural sounds. These findings suggest that the expression of amplitude modulation observed in animal brains may have been rationally acquired during the evolution of properties suitable for sound recognition. I believe that these results will encourage physiologists who have been steadily studying the properties of the nervous system. For now, we are only seeing the response of the auditory nervous system to amplitude modulation; however, this approach is general enough that we expect it to develop in many directions in the future.

—It is wonderful to hear that you have made progress in a field that has been researched for a long time. I also heard that you are conducting collaborative research that has social significance.

In 2021, we began joint research with Shizuoka General Hospital on speech and language perception in people with hearing loss and cochlear implants. The purpose of this research project is to understand the mechanism behind individual differences in speech perception and language development by clarifying the nature of the auditory mechanism in people with hearing loss.

Digital hearing aids and cochlear implants have recently become popular. It has been demonstrated that children with congenital hearing impairment who receive cochlear implants in early infancy can acquire spoken language just like children with normal hearing do. However, many unknowns concerning the process of sound perception and word recognition have yet to be explained, and the brain mechanisms and developmental processes involved in information processing—from the electrical signals provided by the cochlear implant to word recognition—and vocalization and singing ability have not been understood. Accordingly, there is a great deal of room for research on what should and can be done to maximize the effectiveness of hearing-aid technology, and researchers from both medicine and brain science are expected to collaborate to enhance that research. I believe that it is significant that this medical institution, which has made pioneering efforts regarding newborn hearing screening tests and support for children with hearing loss and has a variety of data on children with hearing loss and experience in dealing with them, has joined forces with NTT laboratories, which are researching the auditory mechanism and the process of language development in infants. The research on pupil and eye movements and modeling that I mentioned earlier could also be useful in this collaborative research. I expect that such multidisciplinary and multifaceted joint research will help explain the essential nature of the human auditory mechanism. On the basis of the scientific evidence acquired from this research, I want to offer support to many people with hearing loss.

I want to contribute findings that will be included in textbooks

—Please tell us what you have realized through your research activities over the past 30 years, including your post-doctoral period.

In the previous interview, I mentioned that when I was a child, I wanted to be a doctor (who has a Ph.D.) when I grew up. At the time, I thought a doctor could answer any questions and resolve problems, but now I realize that is not the case. For example, since human cognition and behavior are based on the accumulation of various mechanisms, hearing-related knowledge alone does not necessarily cover all the problems faced by the hearing impaired. Even if I have some knowledge and can identify the problem, it does not mean that I can immediately solve the problem of the person who is suffering from hearing loss. Truly solving the problems of the real world involves many elements including politics and education. In that sense, I learned that a broad perspective is necessary. That is why I need to have a horizontal network of researchers in various fields as well as the perspectives and knowledge I can gain from them. Of course, I want to contribute to the network if my expertise is useful.

Research is a never-ending process. You may be able to see that each aspect “might” be explained this way or that, but it is unlikely that you will be able to understand everything. Naturally, we pursue it to know the unknown but rarely find the answer immediately. I realize that I am not so naive as to believe that a little bit of research can truly clarify anything. Therefore, I believe that research requires steady and constant effort.

Sometimes I feel limited and try to change my focus toward different research. Sometimes changing focus is a step in the right direction, but at other times, I feel that it takes us away from the essential problem. To be honest, even now, I’m researching while worrying about that outcome.

Despite this constant sense of inadequacy, as a basic researcher, I have a desire to conduct research that has a long-term impact. “Long-term impact” can take many forms, but in a nutshell, I want to do research that will be written up in textbooks. Although I want to deliver surprising discoveries, I also think that research that builds a single system over a long period is just as important.

—Your strong conviction as a researcher is there for all to see. What do you always keep in mind during your research activities? And what would you like to say to the younger generation of researchers?

As for my research activities, I don’t think we have to dramatically win from behind. Even if people say to you, “He’s still doing the same thing…,” if you pursue your research properly in a manner that answers essential questions, the knowledge you accumulate will be a valuable academic contribution. Research that is published in textbooks and cited in papers for a long time might be the result of such steady work, and I respect researchers who can do it.

I believe that an essential question has more than one form, that is, it differs in accordance with one’s position and background. When I am not sure which is better or worse, I sometimes change my point of view by thinking, for example, “If I pursue this, who would be pleased?” This “who” could be a fellow researcher by your side, an outstanding professor at an academic conference, a great person in history, or even a person in need in society.

I previously had two positions: a researcher as a senior distinguished researcher and a manager as the head of Human Information Science Laboratory. I was sometimes asked if it was difficult to reconcile my position as a researcher with that as a manager. There is certainly a conflict between the researcher, whose ideas are the standard, and the manager, who thinks about how others behave and how the organization is run. However, some research themes came to light through my management position, and those themes enabled me to expand my world. As a result, a synergy between my two roles was created, so it was a good opportunity to expand my research.

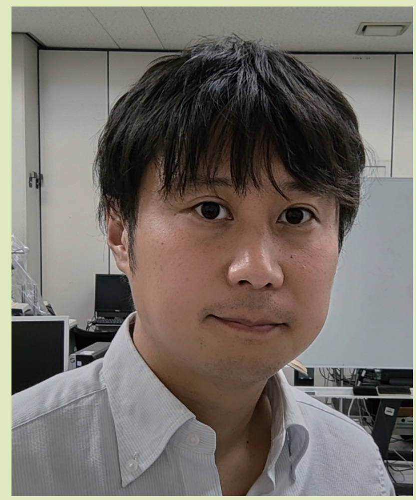
Finally, let me say some words to the younger generation of researchers. Make good use of your seniors. I hope that rather than simply treating your superiors as mentors or simply receiving guidance from them, you will use the knowledge, experience, and connections of your seniors as a means of improving yourself and your team.

■ **Interviewee profile**

Shigeto Furukawa received a B.E. and M.E. in environmental and sanitary engineering from Kyoto University in 1991 and 1993, and Ph.D. in auditory perception from University of Cambridge, UK, in 1996. He conducted postdoctoral studies in the USA between 1996 and 2001. As a postdoctoral associate at Kresge Hearing Research Institute at the University of Michigan, USA, he conducted electrophysiological studies on sound localization, specifically the representation of auditory space in the auditory cortex. He joined NTT Communication Science Laboratories in 2001. Since then, he has been involved in studies on auditory-space representation in the brainstem, assessing basic hearing functions, and the salience of auditory objects or events. As the group leader of the Sensory Resonance Research Group, he is managing various projects exploring mechanisms that underlie explicit and implicit communication between individuals. He is a member of the Acoustical Society of America, the Acoustic Society of Japan, the Association for Research in Otolaryngology, the Japanese Psychonomic Society, the Japan Audiological Society, the Japan Neuroscience Society, and the Japanese Society for Artificial Intelligence.

“Tunable Light Source by Electric-field Control” Technology for High-quality, Low-latency Communications

Yuta Ueda
Distinguished Researcher, NTT Device Innovation Center



Abstract

The Innovative Optical and Wireless Network (IOWN) proposed by NTT envisions a future of low-latency, high-quality, and high-speed communications, but making this vision a reality will require a rapid evolution of optical communication devices. In particular, given the increase in network connection devices driven by recent advances in the Internet of Things and the emergence of communication applications with high real-time characteristics, the power consumption and latency of the communications infrastructure have become major issues throughout the world. We talked with NTT Distinguished Researcher Yuta Ueda about “tunable light source by electric-field control” technology as a solution to these issues.

Keywords: tunable light source, electric-field control, optical sensing

Creating a totally new optical system through wavelength control by an electric field

—Dr. Ueda, what type of technology is “tunable light source by electric-field control”?

Simply speaking, “tunable light source by electric-field control” is a technology for controlling the color of light by voltage for use in optical communications. The wavelength of light corresponds to color when talking about visible light, and various types of colors can be used in optical communications. For example, if we assign signal A to the color red and signal B to the color green, different signals can be carried on lasers of different colors and input into a single optical fiber. In this way, communication capacity can be increased by many times on the basis of color, which is one advantage of optical communications. In the past, the requirement placed on wavelength-tunable light sources was that preferred colors be output from only one type of semiconductor chip. In this way, the laser chips prepared by telecom operators could be commoditized, thereby reducing inventory and lowering the cost of communication operations. Furthermore, in addition to meeting this inventory-reducing objective, an increase in network connection devices due to the expansion of Internet of Things systems has been making the power consumed for controlling optical wavelengths a problem as well. Here, while the means of decreasing power has fundamentally not been on the physical level, it has nevertheless been an issue of concern in this field.

In recent years, moreover, attempts have been made to not only increase the types of optical wavelengths in a tunable light source but also to express new functions by dynamically switching wavelengths in the middle of optical communications. For example, if sunlight, which includes a variety of wavelengths (colors), is passed through a prism, the path that light takes will differ for each color. From this fact, the switching of optical communication paths by dynamically changing wavelengths can be imagined. Simply passing light through a prism completely negates the need for complicated electrical control. In other words, making wavelengths correspond to optical paths will enable high-speed, low-power path control. This phenomenon of driving wavelengths at high speed is not limited to communications—it can also be applied to sensing. For example, the keyword LiDAR (light detection and ranging) has been appearing frequently in newspapers and other media of late as a new optical system having many possibilities. However, semiconductor lasers suffer from high laser noise when driving wavelengths at high speed, and achieving both high-speed and low-noise characteristics as demanded of new optical systems has historically been difficult in either communication or non-communication applications.

"Tunable light source by electric-field control" is technology that can resolve these issues. The main point of this technology is to control optical wavelengths by using voltage instead of current when applying an electrical signal. There are various advantages to controlling optical wavelengths by voltage, one being very small power consumption. As learned in middle-school science courses, electrical power is the product of voltage and current, but voltage-based control, to put it another way, means that current is unnecessary (zero). So, simply speaking, it means that the power used for controlling wavelengths can be made very close to zero. In addition, voltage has the property of acting very fast upon a semiconductor so that voltage-based control can be expected to enable high-speed wavelength control. Moreover, it also means no generation of current—frequently the source of noise in semiconductor devices—so that deterioration due to laser noise accompanying wavelength control is small. As a result, voltage-based control can be said to be superior to existing technology in terms of power consumption, high-speed control, and noise, so research has been focusing on whether it can truly solve the various issues that have so far affected optical systems.

A tunable light source by electric-field control has many advantages as described above, but it has been considered to be impossible in practice. The reason for this is that a tunable light source based on voltage control has an extremely narrow range in which wavelengths can be changed, which means that a practical wavelength-tunable function cannot be achieved. In response to this problem, we combined optical semiconductor technology researched by NTT over many years with an original semiconductor optical filter circuit that I invented, enabling us to get as far as a proof-of-principle test for a low-power, high-speed, and low-noise tunable light source using the advantages of electric-field control while achieving a practical wavelength-tunable range.

—Specifically, what kind of method do you use to operate a tunable light source by electric-field control?

At NTT laboratories, I originally belonged to a team in the technical field of modulated light sources, and I feel that I am still applying the experiences and ideas from that time to my present research. A modulated light source is a semiconductor chip that integrates a laser light source with a modulator that places a signal on the laser output from that light source. In this team, we took up wavelength multiplexer technology for combining the light from multiple modulated light sources of different laser wavelengths. As I mentioned earlier, inputting optical signals of multiple wavelengths into a single optical fiber can increase communication capacity. However, from a different perspective, a wavelength multiplexer can also be used to extract a single wavelength from multiple wavelengths. That is to say, a wavelength multiplexer also has the property of being used as a wavelength filter. There are many types of wavelength multiplexers, but in the type of wavelength multiplexer that we were researching at that time, we noticed that wavelength-selection rules were highly sensitive to electrical signals and that a practical wavelength filter could be achieved even for signals not suitable for wavelength control such as voltage signals. "Tunable light source by electric-field control" technology that applies this characteristic generates light of different wavelengths by applying voltage to the original semiconductor filter circuit that I invented and changing that wavelength-selection rule.

Of course, technology that changes the wavelength-selection rule by applying an electrical signal to a

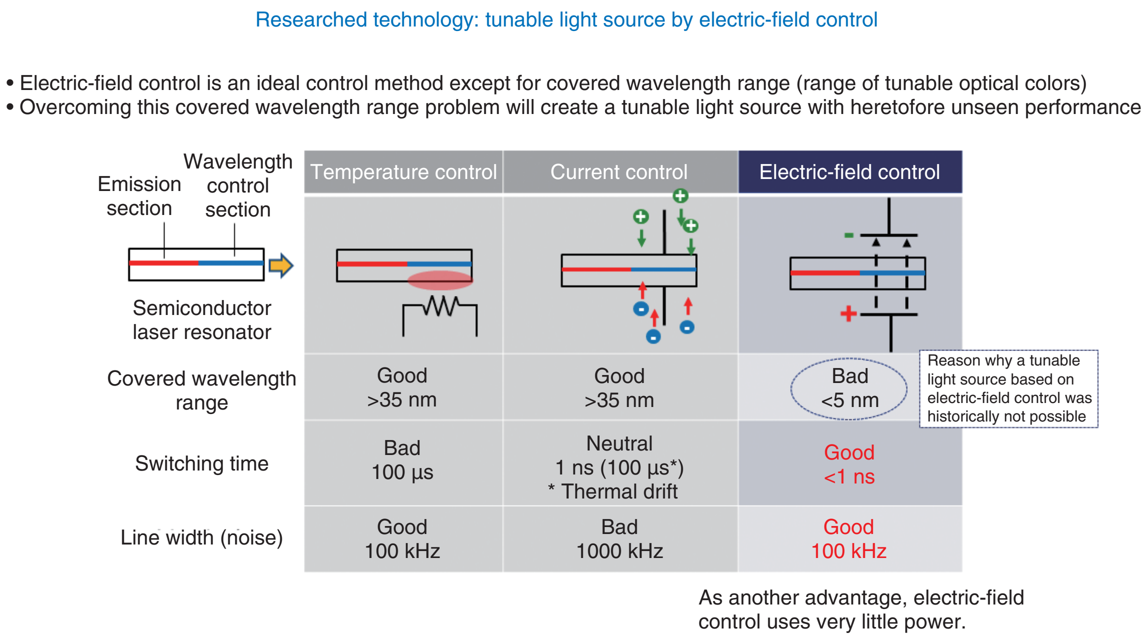


Fig. 1. Comparison of tunable light source by electric-field control and conventional technologies.

filter already exists. For example, there are techniques that warm the semiconductor or make current flow. These techniques, however, consume much power in wavelength selection and suffer from the problem that achieving both high-speed wavelength changing and low-noise laser operation is difficult in principle. Electric-field control can solve the above problems all at once, but as I described earlier, there was the problem of obtaining a practical wavelength-tunable range, so achieving a practical device was not yet attainable. With this being the case, we took up the challenge of achieving a tunable light source having a practical wavelength-tunable range even when using electric-field control by applying the ideas that arose in the modulated light source project.

As a result, our prototyped tunable light source is able to keep laser noise (line width) sufficiently low in actual use compared with conventional control-by-temperature technology while increasing the speed of wavelength control by as much as one million times. This prototype also exhibits a practical wavelength-tunable range, which suggests this technology can greatly contribute to high-performance optical communications and optical sensing in the future. Moreover, the power used for changing wavelengths is less than 1/10 the conventional value, which means that further power savings can be expected when considering the reduced burden on external circuits. This can solve the present energy problem in communications and contribute to a significant decrease in communication costs (**Fig. 1**).

Solving many social problems and creating the IOWN future

—Please tell us your outlook for the future using tunable light sources by electric-field control.

One objective of the All-Photonics Network (APN) within the Innovative Optical and Wireless Network (IOWN) vision proposed by NTT is to increase power efficiency by 100 times to achieve low power consumption. There is consequently the prospect of using tunable light sources by electric-field control as the platform technology of APN from the viewpoint of achieving a low-power optical network. The idea here is that controlling wavelength tuning by an electric field can reduce the power and costs involved in optical communications and help expand the potential of an information-processing platform in no small way. Additionally, from the viewpoint of low noise and short switching time, achieving other APN objectives, namely, low latency, large capacity, and high quality, is also an outlook for the future.

Application to non-communication fields such as optical sensing can also be envisioned. For example,

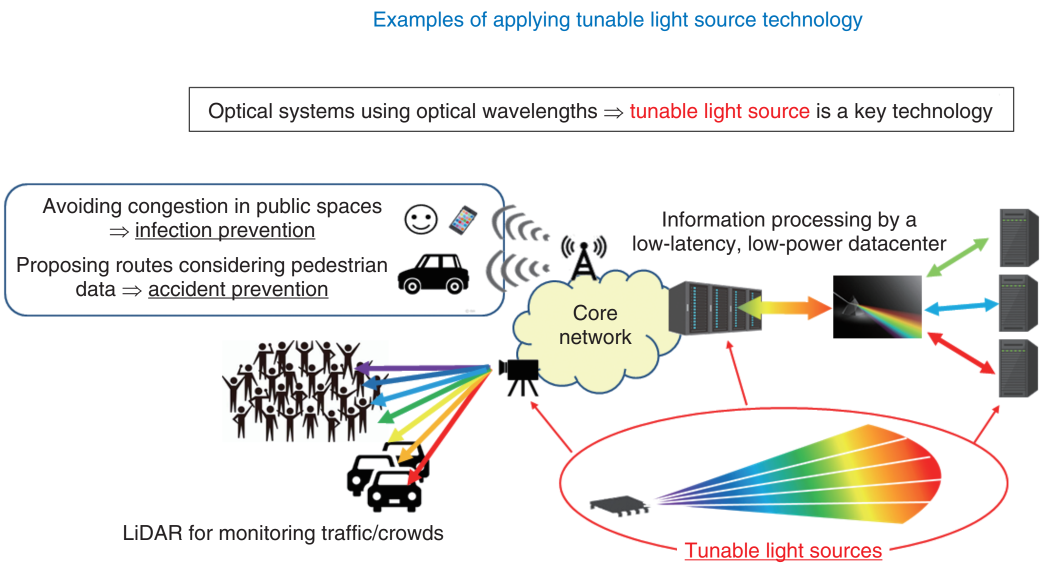


Fig. 2. Solving diverse social problems by applying tunable light source technology.

Digital Twin Computing within the IOWN vision converts the real world into a computer society for the sake of data processing with the aim of disseminating beneficial information for society. This process could contribute, for example, to infection prevention and accident prevention in public spaces. Here, "converting the real world into a computer society" is surely the domain of sensing technology. We can therefore expect "tunable light source by electric-field control" technology to serve as an "eye" of the digital world on the real world. In this way, we are aiming for technology that can solve a wide variety of social problems in both communication and non-communication fields and help enhance the lives of many people (**Fig. 2**).

—Dr. Ueda, can you leave us with a message for researchers and students?

At NTT, you can do your work based on the concept of "Wouldn't the world change if we had this technology?" On top of that, I feel that doing research at NTT can be quite interesting. This is because it's a place where we ourselves can add finishing touches to our research results up to the practical level and even engage in the device business by selling devices, receiving feedback, and continuing with device development. In short, NTT enables researchers to be widely involved in research, development, and business. I should mention here that all of these schemes are not necessarily carried out within NTT laboratories—the ability to collaborate with outside partners as needed is a key strength of NTT. Of course, writing papers and spreading the word on NTT's technical capabilities is important work, but in the field of optical semiconductors that I am involved in within NTT laboratories, it is particularly important to perform research repeatedly and make results practical to create new social value all under the idea of "for the world and for people." I feel that if someone has a need for a certain type of technology and is willing to pay for it, then I have a very worthwhile role to play in this world. From here on, in addition to my research on "tunable light source by electric-field control" technology that I introduced here, I would like to make good use of a wide array of technologies and ideas in all sorts of scenarios and contribute to the creation of a society filled with people leading happy lives.

At present, I am conducting device research in the field of optical semiconductors, but in this field, many researchers come together each with a set of specialized skills to conduct research on a daily basis with the aim of creating a single device. Of course, this research and partners too includes overseas institutions. In this process, I feel strongly that "team power" is vitally important for making research proceed smoothly. There is no way that a single individual can perform device research, so it is essential that research be performed in a cooperative manner while respecting people with specialized skills and learning many things from others. In this regard, diversity has recently become an important theme in society, and I too recognize its importance, but in a research project, and particularly in a project that assumes development of a practical product, there are many times in which a single decision is finally made out of necessity, which can easily generate some conflict. In such a situation, it is very difficult to achieve both "decision-making as a project" and "diversity for deepening research discussions," but I feel that an approach that attempts mutual understanding while seeking compromise among people with different ways of thinking is very important.

Of course, a major premise here is that it is exactly a group of individual researchers having their own opinions and interests that constitutes team power. I don't think that a researcher who does not have ideas on one's own field of specialty can actually be called a researcher. When I was a student in a master's program, I was told by an academic advisor, "When you investigate something thoroughly when young, you come to have a different view of things from then on." Then, with this advice in hand, I went on to a doctor's program. I would like young researchers who are reading this to place importance on one's own gut feelings and to pursue one's research in an all-out, devoted manner. I think that it is more fitting to think of research as one's consuming interest than simply work. If you truly like something, you can continue to do it with all-out passion and devotion. For this reason, I would like researchers, while still young and highly sensitive, to place importance on what they feel gives them great pleasure. Today, there is much activity in semiconductor research around the world, but in Japan, where fierce competition makes conditions severe and less than optimistic, it is NTT laboratories that provide a blessed environment for research. To young researchers who will take on the burden of future challenges, I say, "Let's work together as colleagues in creating the future of communications."

■ Interviewee profile

Yuta Ueda received his Ph.D. in electrical engineering from the Graduate School of Waseda University in 2011. He served as a research fellow of the Japan Society for the Promotion of Science during his doctoral course. He joined NTT in 2011 becoming a member of NTT Photonics Laboratories. He has been an NTT Distinguished Researcher at NTT Device Innovation Center and NTT Device Technology Laboratories since 2022 engaged in the research of semiconductor tunable light sources. He received the Institute of Electronics, Information and Communication Engineers (IEICE) Young Researcher's Award in 2012 and the IEICE Best Paper Award in 2022. He has been a visiting associate professor at Kyushu University since 2020.

Optical Transmission Technology for Practical Implementation of the All-Photonics Network

Sachio Suda, Kenichi Aoyagi, Yasutaka Sugano, Hiroto Takechi, Fumikazu Inuzuka, Hiroki Date, and Soichiroh Usui

Abstract

NTT Network Innovation Center is developing technologies and systems for the practical implementation of an optical transmission network, the key element for implementing the All-Photonics Network (APN), which in turn will support IOWN (the Innovative Optical and Wireless Network). With our next-generation optical transmission network, which is an advance release of the APN, we are working to increase speed and capacity to handle growing communication traffic as well as provide open optical interfaces for connecting various systems and devices without photoelectric conversion to enhance the added value provided by optical networks and develop operations and maintenance technologies for these networks.

Keywords: optical transmission, open optical interface, latency management

1. Introduction

By introducing photonics-based technologies to the All-Photonics Network (APN) [1], which forms the foundation of the Innovative Optical and Wireless Network (IOWN), we are aiming to significantly enhance the potential of the information processing infrastructure. We also aim to achieve low-power-consumption, high-quality, high-capacity, and low-latency transmission by disaggregating and reconfiguring various functional parts of the APN using open interfaces. Our three performance targets are to increase transmission capacity by a factor of 125, electric power efficiency by a factor of 100, and reduce end-to-end latency by a factor of 200. Building the practical APN requires advanced engineering, which involves integration of state-of-the-art elemental devices and the latest technologies—under various conditions and constraints—such as open interfaces.

As part of our effort toward the early social implementation of the APN, we are developing and engineering a next-generation optical transmission network, which will serve as an advance release of the APN. In developing this network, we are focusing on (1) studying a system configuration in which the most advanced optical communication devices and latest technologies and expertise are used to increase transmission capacity by a factor of 10, and in which the reconfigurable optical add/drop multiplexer (ROADM) function is separated from the optical transceiver function using an open optical interface to reduce photoelectric conversions, thus significantly reducing system power consumption; (2) developing a photonic transceiver that suppresses end-to-end latency and delay jitter in the Internet and a Layer 2 virtual private network by managing the absolute delay for applications that are sensitive to transmission delay and delay variation, an ability that constitutes one of the added values to be provided by the APN; and (3) studying maintenance and control

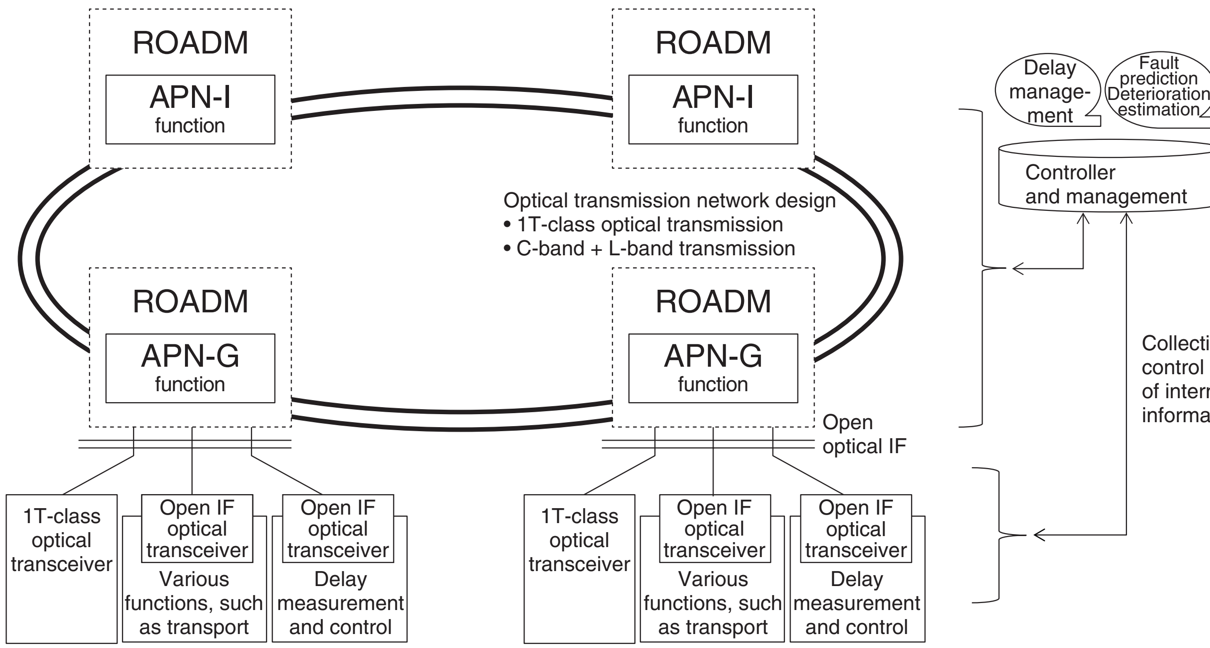


Fig.1. Next-generation optical transmission network.

subsystems for overall operation of these systems.

2. Achieving high-speed, wide-bandwidth, and open optical interfaces

While the next-generation optical transmission network (**Fig. 1**) is based on dense wavelength division multiplexing and digital coherent technology, its transmission capacity will be increased by multiplexing optical signals of approximately 1 Tbit/s per wavelength across multiple wavelength bands. By disaggregating the ROADM function and optical transceiver function and specifying an open optical interface between them, we aim to enable connections to be established to remote locations using various optical transceivers without photoelectric conversions.

2.1 1-Tbit/s-per-wavelength-class optical signal transmission

To boost the transmission capacity per wavelength (800 Gbit/s/wavelength for long-distance transmission and 1 Tbit/s/wavelength for short-distance transmission), the optical transceivers in the next-generation optical transmission network will use world-leading digital signal processors (DSPs)*1, which increase both the optical signal modulation rate and number of modulation levels. The optical design of the ROADM function component will also be revised to appropriately control optical noise and optical signal distortion to allow stable transmission of high-speed optical signals.

2.2 Multiplexing using multiple wavelength bands

Traditionally, NTT's optical transmission networks have used dispersion shifted fiber (DSF) [2], which is considered suitable for long-distance transmission. However, DSF inherently involves zero-dispersion wavelengths, which cause large waveform distortions in high-speed optical transmission. Consequently, the C-band cannot be used for optical transmission, leaving only the L-band usable. Now that cut-off shifted fiber (CSF) [3] is available, the next-generation optical transmission network will adopt an optical and system design suitable for CSF. This will make both the C-band and L-band usable, doubling transmission capacity.

2.3 Open optical interface

The Open ROADM Multi-Source Agreement (MSA)*2 defines interfaces for multi-vendor connectivity and interoperability between functional parts of

*1 DSP: NTT laboratories developed a state-of-the-art DSP capable of 1-Tbit/s-class signal processing in 2022. https://group.ntt/en/newsrelease/2022/09/05/220905a.html

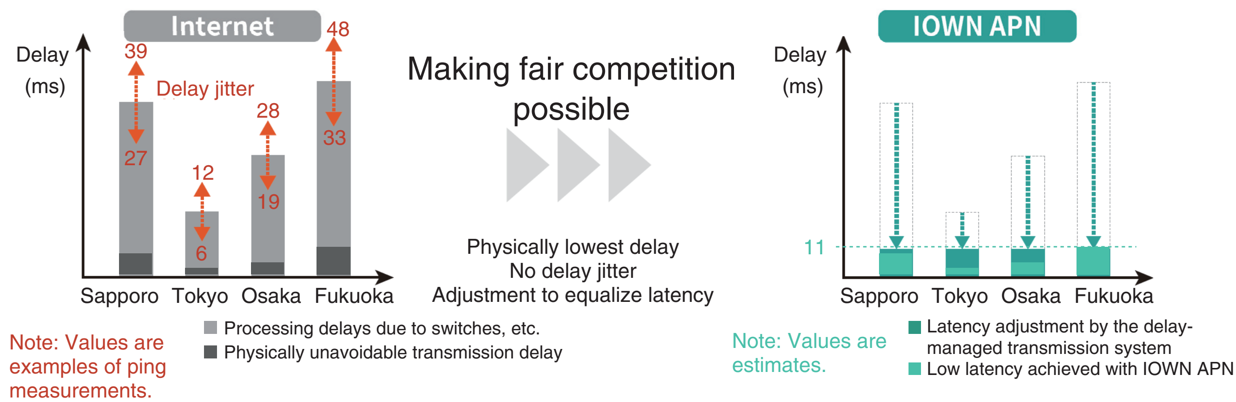


Fig. 2. Example of application to e-sports competitions.

optical transmission networks. It is being extended to cover 400G-capable nodes [4]. Technical Specification 2.0 was also released [5] for Open ZR+ MSA, which defines interoperability specifications between pluggable optical modules such as quad small form-factor pluggable-double density (QSFP-DD)*3. Therefore, telecommunication carriers, hyperscalers, and optical module vendors are working together to accelerate the shift toward open and disaggregated optical transmission systems. These MSA standards will be adopted in the next-generation optical transmission network to achieve open optical interfaces and provide optical end-to-end connectivity for various systems and services targeted with the APN.

3. Optical transmission system capable of latency management

We are developing a delay-managed transmission system. With increased sophistication in communication network usage and the COVID-19 pandemic, there has been a rapid increase in remote work and other remote activities. For activities that require coordination and synchronization among multiple locations, communication delays and delay jitters have significant impact on the user experience (UX).

For example, in an e-sports tournament with players located at different sites, a fair match may not be possible if there are noticeable communication delays or delay jitters. If an e-sports server is located in Tokyo, there will be a time difference of approximately 30 milliseconds between Tokyo and Fukuoka (**Fig. 2**, left) due to transmission delays caused by the difference in physical distance (dark gray) as well as processing delays caused by routers and other devices in networks run by Internet service providers (ISPs) (light gray). Furthermore, the processing delay within ISP networks is not constant but varies with time (the length of the orange arrow) because it is affected by other non-e-sports traffic. Users with lower latency connections are generally able to react faster, giving a clear advantage to players in locations closer to Tokyo, where the server is located.

Our delay-managed transmission system will minimize delay by providing a communication environment that does not involve the Internet (Fig. 2, right, light green) and maintain fairness among users by assigning delays to lines in such a way that the delay of every line will be equal to that of the line with the largest delay (Fig. 2, right, dark green). This eliminates delay differences between users. This stable communication environment, characterized by ultra-low latency, no latency differences, and no delay jitters, makes fair competition possible.

3.1 Communication control using the OTN protocol

The delay-managed transmission system will use the Optical Transport Network (OTN)*4 protocol at Layer 1, which is the physical layer of the Open Systems Interconnection (OSI) reference model*5, to achieve low latency that is close to the physical

*2 MSA: An agreement for companies to develop and commercialize compatible products based on common specifications with the aim of increasing user convenience and expanding market size through the standardization of product specifications.
*3 QSFP-DD: An optical module standard.
*4 OTN: A communication standard for optical transmission networks specified by International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), an international standardization organization.

minimum limit. Layer 1 communication is circuit-switched communication. Once a connection is established with the other end, the communication constantly occupies the bandwidth. Therefore, in principle, the bandwidth is fixed and no delay jitter occurs. In addition, when communication control is executed only at Layer 1, packet retransmission and packet queuing processes, such as those used in Layers 2 and 3, are not required, achieving low latency close to the physical minimum limit.

To implement latency management, a device in the delay-managed transmission system measures end-to-end delay time using the delay measurement information specified in ITU-T G.709 and stores the OTN signal data in the first-in-first-out memory within the device, adjusting the delay time to that desired between the users concerned.

3.2 Demonstration for application to e-sports competitions

We demonstrated an e-sports tournament involving fighting games at NTT R&D Forum - Road to IOWN 2021 held in November 2021 and docomo Open House ’22 held in January 2022. Two e-sports players belonging to a professional team competed in a communication environment that simulated the conventional Internet with a latency difference of 50 milliseconds and in a communication environment with zero latency difference between the players. In the unfair communication environment that simulated Internet connections, the win rate of the player who was subjected to delay was clearly low at 10.9%. In the fair communication environment in which the latency was adjusted to be the same for the two players, the win rate of the same player was 54.3%.

We believe that delay-managed transmission systems can bring about a UX revolution in latency-sensitive applications, ranging from e-sports to other entertainment such as arts and culture, remote working, education, telemedicine, and telecollaboration.

4. Activities to upgrade operations and maintenance

As the capacity of optical transmission networks soars, the impact of optical transmission device failures increases. Even when optical signal quality degradation occurs, causing communication errors in the optical transceivers at both ends of the optical path, ROADM may not be able to detect anomalies if the anomaly exists in an optical amplifier or one of the wavelength-selective switches that constitute the ROADM in the relay section of the optical path. In such cases, the system component that caused the quality degradation may not be promptly pinpointed from a wide range of suspect components, and it may take a long time to restore the network.

Therefore, we are seeking to detect failure signs and identify a suspect component with a high level of accuracy by collecting and analyzing detailed information about optical signal characteristics, which has not been fully used in conventional operations and maintenance. We are focusing on the following three types of optical signal characteristics:

(1) Optical input/output power: Conventionally, optical power could be monitored only at 15-minute intervals. We will measure this information at shorter intervals and collect it in real time for use in failure analysis.

(2) DSP internal state: We will start to collect and analyze data from DSPs—which compensate for optical signal degradation in the optical transceiver and execute demodulation—regarding optical signal intensity, noise level, and waveform distortion.

(3) Optical spectrum: We will also start to collect and analyze optical signal-to-noise ratios inside the ROADM at each relay section.

We are studying how to link such characteristic information with the optical transmission network configuration information, including the accommodation of optical paths. The aim is to accurately identify signal-degrading components that may lead to failure (**Fig. 3**) and, based on the time-series variation in the characteristics of the signal-degrading component, predict when the degradation will begin to impact the service [6].

5. Conclusion

This article introduced research and development efforts toward early practical implementation of the APN, focusing on the next-generation optical transmission network, which will serve as an advance release of the APN. With the aim of delivering low-power, high-quality, high-capacity, and low-latency optical transmission networks, we will continue our efforts to incorporate and engineer the APN’s elemental technologies, perfected at our laboratories, for system integration at the appropriate time.

*5 OSI reference model: A model that divides communication device functions into a hierarchical structure adopted by the International Organization for Standardization.

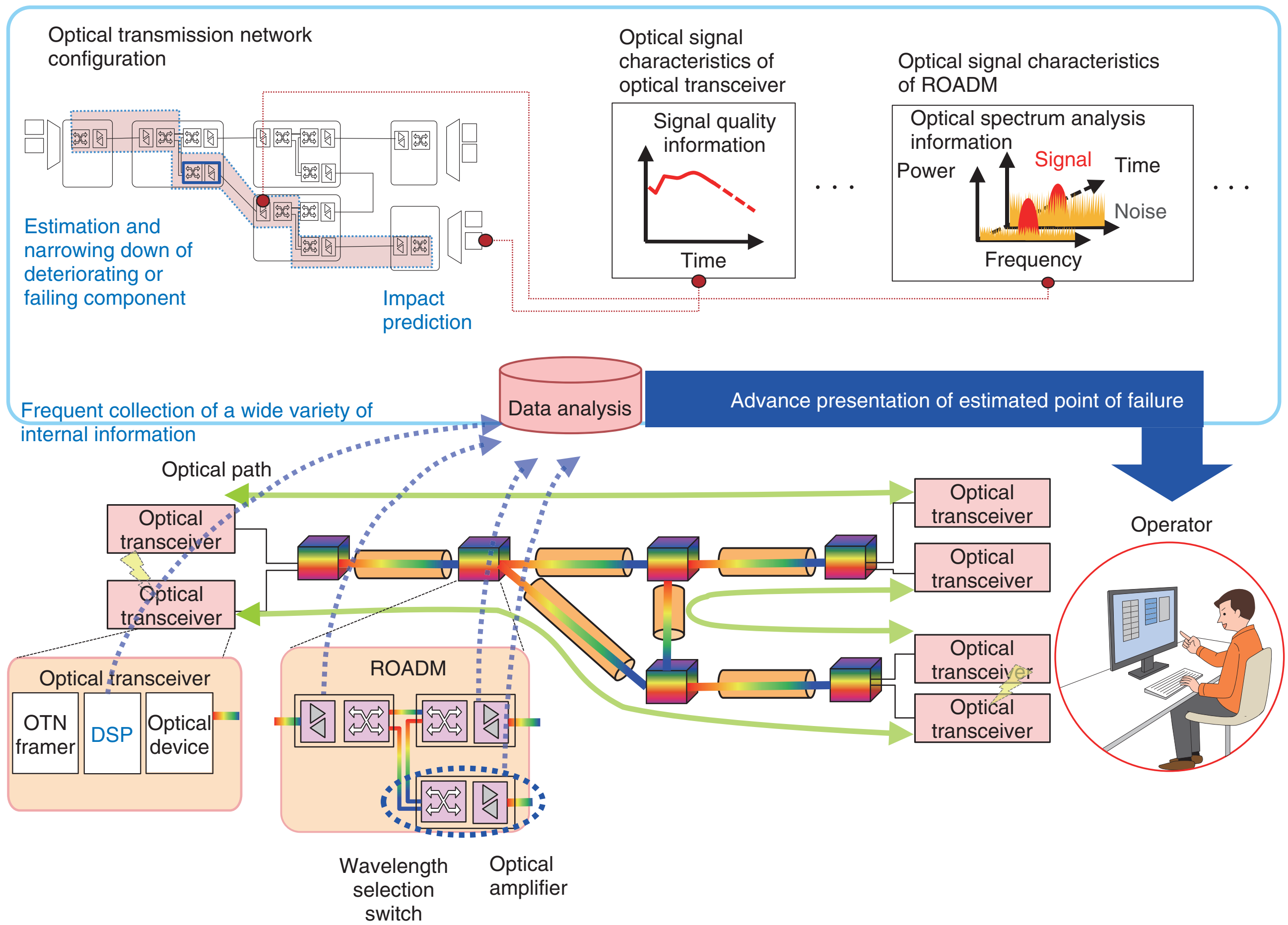


Fig. 3. Deterioration estimation and failure prediction.

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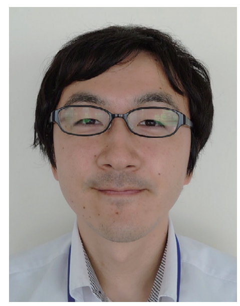

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Service Node Architecture Technology for Disaggregated Network Service Functions and Fixed-mobile Convergence Networks

Toshihiro Yokoi, Konomi Mochizuki, Takayuki Nakamura, Satoshi Nishiyama, Kensuke Takahashi, and Takeshi Osaka

Abstract

With the goal of increasing the variety of network requirements and desired value added in the Innovative Optical and Wireless Network (IOWN), our goal is to provide quick network services by providing in-house network functions by using software. This article introduces Beluganos®, a network operating system for white box switches, and the Value-added Pluggable Network Platform Technology to achieve this goal.

Keywords: network OS, fixed-mobile convergence, one-stop operation

1. Introduction

The Innovative Optical and Wireless Network (IOWN) is intended to be commonly used for information communications technology infrastructure services in various industries, and one of its applications is as a fixed-mobile convergence network that seamlessly accommodates fixed and mobile networks and enables end-to-end cloud and Internet connectivity.

Fixed-mobile convergence networks require the on-demand provision of network services that meet a wide variety of requirements in any location, including Internet of Things (IoT) terminals, which will become increasingly important as social infrastructure in the future; drones and other robots; and e-sports and other services that require high-speed and low-latency communication.

To meet these requirements and provide network services quickly, we are developing integrated service-node-configuration technologies using white box hardware and network control software in the cloud to make it possible to softwareize the functions of traditional hardware-centric carrier networks and assemble networks flexibly.

This article introduces Beluganos®, a network operating system (OS) for white box switches, as shown in **Fig. 1**, and the Value-added Pluggable Network Platform Technology.

2. Overview of NTT's in-house network OS (Beluganos®)

Beluganos® is being developed to target a wide range of white box network equipment including datacenter switches, carrier routers, and transmission equipment.

There are two main advantages to using white box network equipment. One is that hardware and software can be separated, so we can use hardware and software freely. For example, even if the hardware is no longer manufactured, the OS software can continue

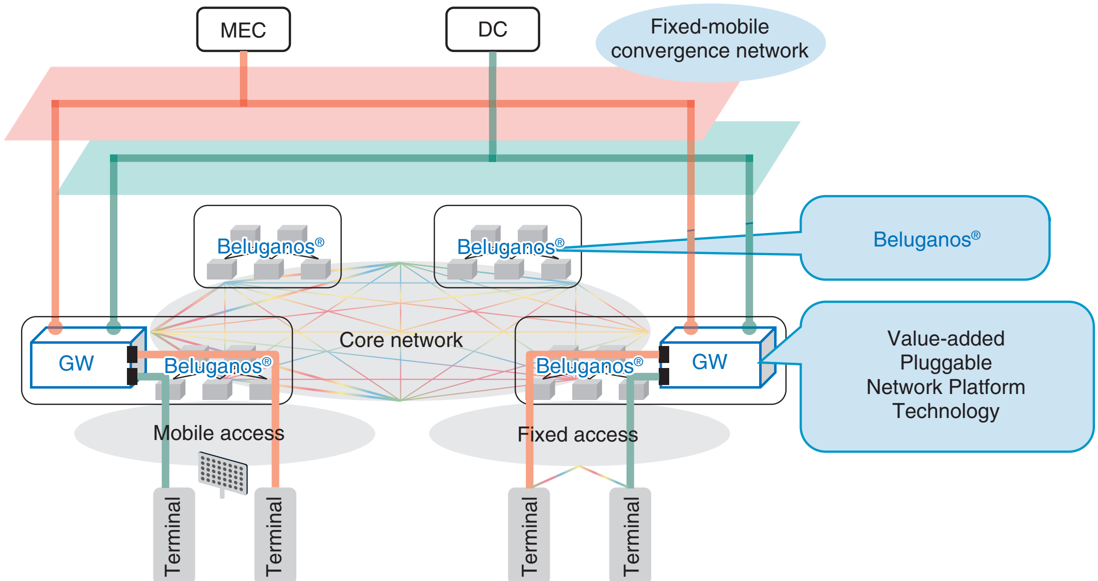

Fig. 1. Overview of fixed-mobile convergence network architecture.

to be used, so changes to the monitoring system and maintenance of manuals can be reduced. The other is that with the freedom to select hardware, we can purchase components, including transceivers, for a long time at low cost. These features reduce the total cost of development, installation, and operation.

There are two issues when using a commercial network OS as software. The first issue is that, as with conventional network equipment, new functions are added or problems are fixed at the vendor's convenience, so the carrier, which is the user, is not always able to use it when necessary. The second issue is the lack of operational capabilities. White box network equipment typically has different hardware and software vendors. Commercially available network OSs have the necessary functions, but they lack the implementation of operational functions such as monitoring and path visualization that carriers require in their operations.

To solve these problems, NTT is developing Beluganos® as an in-house network OS. This enables NTT to add and modify functions at the right time while implementing the operational functions required by carriers. The following sections describe the operational features that are enabled when applying Beluganos® to the switches that make up the Internet protocol (IP) fabric in a datacenter.

3. Beluganos® features (operational)

The IP fabric uses a generic routing protocol to build multipath Layer 3 (L3) networks over Clos network topologies. The overlay's virtual network is also configured using the EVPN/VXLAN (Ethernet virtual private network/virtual extensible local area network) protocol to create an L2 flat network, improving operability and addressing the mobility issue of virtual machines.

However, in such an overlay network, two issues occur.

- Unknown underlay network through which traffic is passing.
- No fast fault-detection function per overlay tunnel.

To address these issues, we implement the loopback, pathtrace, and continuity-check functions as the overlay network operations, administration, maintenance (OAM) functions (**Fig. 2**).

The loopback function pings the overlay tunnel, and the pathtrace function traces the overlay tunnel. This enables us to see which underlay link traffic is passing through. We also implemented a function to simulate load-balancing results by inserting information simulating real traffic into packets. This enables us to see through which underlay link a packet

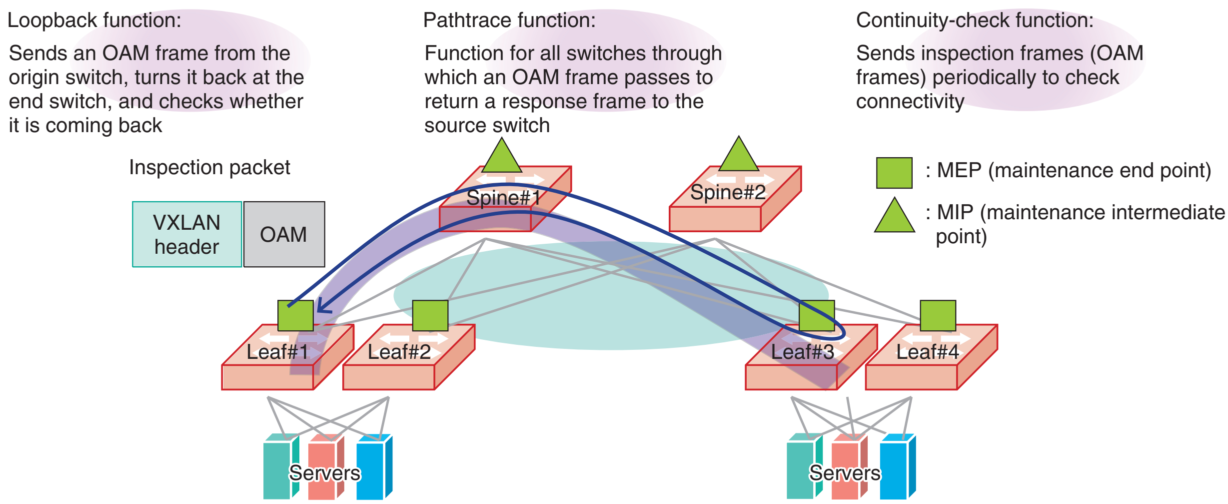

Fig. 2. Overlay network OAM functions.

traversing the tunnel goes.

The continuity-check function sends packets back and forth to periodically monitor the health of the overlay tunnel by specifying the endpoint of the overlay tunnel. It also detects a failure if these packets do not arrive for a certain amount of time. Previously, we needed a health-monitoring function to operate independently on all multiple underlay links. This continuity-check function, however, enables monitoring of all underlay links between them by specifying an overlay tunnel. Thus, unexpected failures can be rapidly detected regardless of the underlay configuration and service impact can be minimized.

4. Technology roadmap for Beluganos®

Toward the future use of open hardware control in IOWN, development will proceed on two axes: expanding the number of controllable devices and developing operational technology.

The first is the expansion of controllable devices. With an eye on future control of optical and photoelectric conversion devices, this development will accumulate expertise by developing a network OS that can control switch application specific integrated circuits (ASICs) as well as high-function router ASICs.

Regarding operating technology, we will advance cooperation with controllers. We developed a technology to enhance the operational sophistication of a single node but aim to achieve more efficient end-to-end wavelength utilization by applying it to network orchestration and transmission equipment.

5. Value-added Pluggable Network Platform Technology

To provide communication environments for IoT services, self-driving cars, smart factories, etc., the quality and functional requirements for carrier networks are expected to diversify. To provide networks in a timely manner to service providers offering diversified services, conventional carrier networks face the following challenges.

- Since individual network devices were used in accordance with requirements, the number of device types increased as requirements diversified, and network operations became more complex.
- The lead time is difficult to shorten because network-equipment settings are designed and configured individually on the basis of the requests of the operators and businesses.

We are developing the Value-added Pluggable Network Platform Technology that provides a variety of network functions on demand to address these issues.

6. Components of Value-added Pluggable Network Platform Technology

This section introduces the four components of the Value-added Pluggable Network Platform Technology shown in **Fig. 3**.

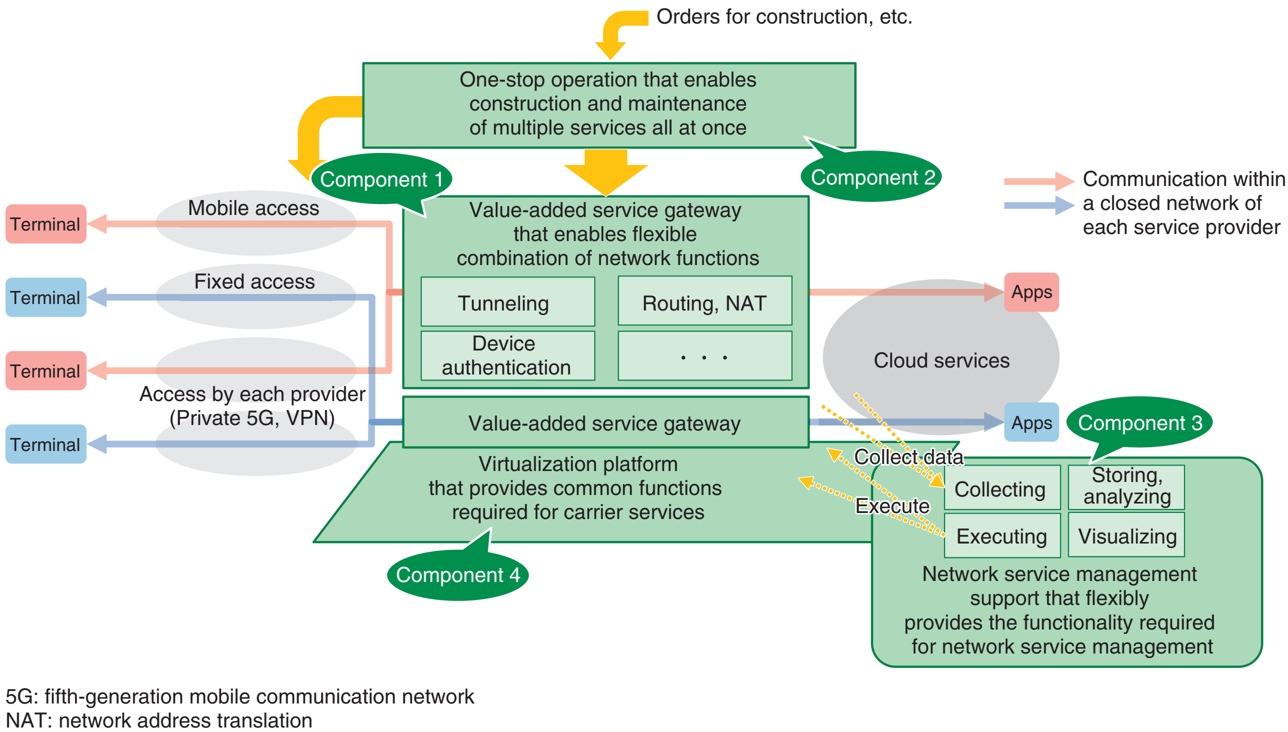

Fig. 3. Four components of Value-added Pluggable Network Platform Technology.

6.1 Value-added service gateway

The first component is a value-added service gateway that enables a flexible combination of network functions. This component is provided as a virtual gateway for each service provider that is built on-demand on a commodity server. By combining functional elements divided into containers to form the network functions of this virtual gateway, functionality can be added flexibly and rapidly. For service providers who require a secure closed network, for example, a virtual gateway with containers equipped with tunnel termination and device authentication necessary to configure a closed network can be built on-demand at the start of network use. The virtual gateway also enables network service control such as route assignment and quality-of-service control on the basis of authentication results, etc., to meet the needs of a variety of service providers.

Lifecycle management, such as creation, deletion, and configuration changes of virtual gateways, can be executed via the controller. The controller provides a RESTful (representational state transferful) application programming interface (API), which is widely used in web-based application development. In developing the controller, we incorporated web-based technologies such as Swagger and Flask to reduce development and maintenance costs.

6.2 One-stop operation

The second component is a one-stop operation that enables service providers to build and maintain multiple services, such as networks, clouds, and applications, all at once. This component exposes APIs compliant with the TM Forum (TMF) APIs as northbound APIs and provides service providers with abstracted APIs necessary for setting up each service to be coordinated. When there is an increase in the number of services to be coordinated, this component can support such services by simply adding a conversion adapter to the TMF API for the APIs provided by the coordinating services. This component also has maintenance functions through closed-loop control such as monitoring, analysis, decision, and action. By developing and combining operation functions appropriate for each service as microservices, for example, it will be possible to implement autonomous recovery measures in the event of a failure of a service to be managed.

In the Value-added Pluggable Network Platform Technology, one-stop operation automatically creates the virtual gateway settings to match the virtualization platform to which they are deployed. This enables service providers to build the desired network without having to be aware of differences in virtualization platforms.

6.3 Network service management support

The third component is the management support required to provide network services, such as analysis, reporting, and visualization of logs and metrics collected and stored from the virtualization platform and each machine and automatic execution of software updates and operational procedures. To support various virtualization platforms, this component can flexibly respond to changing requirements by enabling the combination and replacement of tools suitable for each OS, hypervisor, container, and application.

6.4 Virtualization platform

The fourth component is a platform for load balancing, state management, failure recovery, and health monitoring, which are commonly required to ensure reliability, operability, and performance as a carrier service for applications deployed in a virtualized environment. This platform makes it easy to expand network functions.

7. Future prospects for Value-added Pluggable Network Platform Technology

The goal with the Value-added Pluggable Network Platform Technology is to achieve higher speeds to cope with increasing communication traffic and more advanced maintenance and operations to further improve the efficiency of network operations. Specifically, we are investigating the use of hardware accelerators, such as field-programmable gate arrays, that can process high-speed traffic and developing operational technologies that can adapt to changes in the environment by analyzing collected data through artificial intelligence.

Trademark notes

All company names or names of products, software, and services appearing in this article are trademarks or registered trademarks of their respective owners.

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Network Control System Configuration Technologies for Advanced Network Operation

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Abstract

To provide services on the All-Photonics Network, which handles traffic with much higher capacity and lower latency than what is currently possible, it is necessary to further improve the quality management of a carrier network. This article describes two technologies being developed at NTT Network Innovation Center. One is the Network Information Collection and Analysis Platform Technology for efficiently collecting traffic-flow statistical information, telemetry, and communication delay for network operation. The other is the Network Control Platform Technology for automating and optimizing network operation and network control.

Keywords: real-timed information collection and analysis, operation and control automation, transport network

1. Introduction

The All-Photonics Network (APN), one of the three core technologies for the Innovative Optical and Wireless Network (IOWN) advocated by NTT, will introduce optical technology in everything from networks to terminals [1]. Compared with the conventional network infrastructure, the APN will have an overwhelmingly broad bandwidth and lower communication latency for handling a dramatically large amount of traffic, and the required communication quality will also be at a level far higher than what is currently possible. To provide services to users on these networks, more efficient and higher-level network quality management and network operation are required.

2. Network Information Collection and Analysis Platform Technology and Network Control Platform Technology for advanced network operation

For advanced network quality management and operation, it is necessary to keep track of the network status and take appropriate actions (e.g., route control). For example, we collect and analyze network information such as communication delay and traffic amount, and if signs of network-communication-quality degradation are observed, we switch user traffic to other routes that will not affect network-communication quality. In the APN, sensitive network control will be required because there is a large amount of user traffic that must be managed with strict network-quality requirements.

This article describes two technologies, as shown in **Fig. 1**: the Network Information Collection and Analysis Platform Technology for efficiently collecting and analyzing traffic-flow statistics, telemetry, and communication delay for network operation and

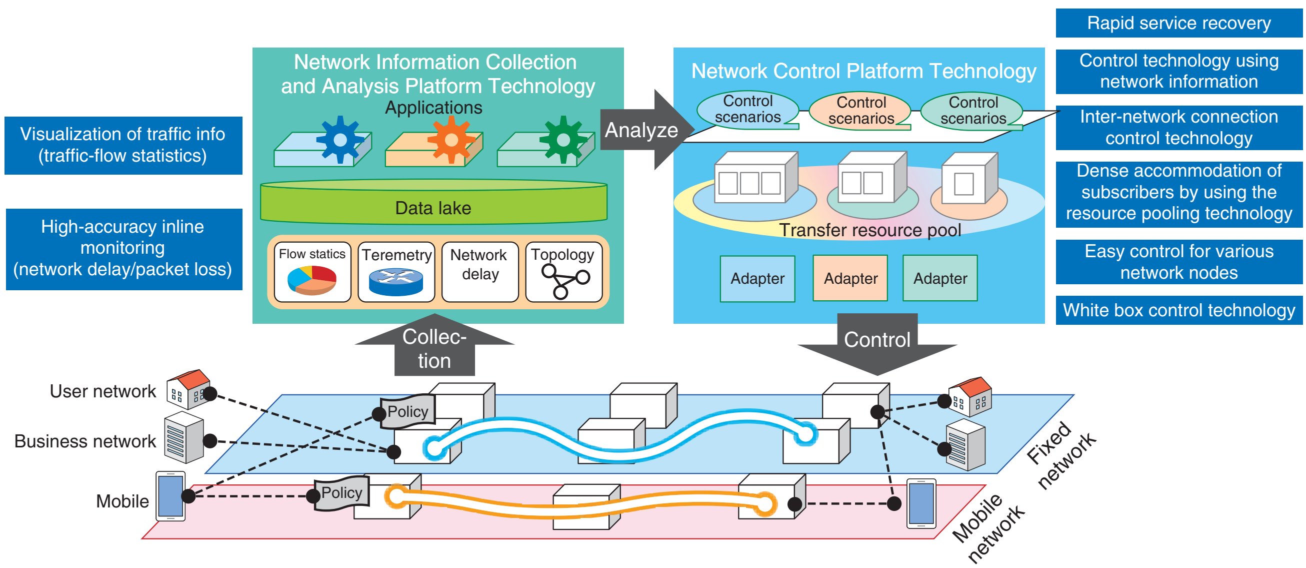

Fig. 1. Network Information Collection and Analysis Platform and Network Control Platform Technologies.

Network Control Platform Technology for automating and optimizing network operation and network control.

3. Network Information Collection and Analysis Platform Technology

To collect various types of network information in the APN, we are developing the Network Information Collection and Analysis Platform Technology shown in **Fig. 2**. This technology can be used by easily combining multiple elemental technologies that contribute to collecting and analyzing network information. For example, by installing and combining elemental technologies that support traffic-flow statistics and communication delay, it will be possible to use it for virtual private network (VPN) service monitoring or use only a part of it, such as analyzing only traffic-flow statistics. By adding elemental technologies, it will be possible to easily expand the items to be collected.

We plan to use this technology to collect various types of network information, but in this article we focus on the collection and analysis of communication delay, packet loss, and traffic-flow statistics.

3.1 Communication delay and packet loss

Communication delay for most of the services specified in 5G (5th-generation mobile communication system) is in the millisecond range, and the APN is expected to have stricter delay requirements in the microsecond range. Therefore, even higher accuracy is required in delay measurement. Scalability will also be necessary for network-quality management of carrier networks.

To solve these problems, we are researching and developing high-accuracy inline monitoring technology, which uses segment routing (SR) to generate monitoring packets. By connecting a monitoring system that is based on our technology to a carrier network, it will be able to immediately calculate all monitoring routes, generate monitoring packets, and send them. By using the Data Plane Development Kit (DPDK), delay measurement in microseconds (nanosecond precision as resolution) can be achieved. Unlike peer-to-peer probe measurement, which is a common method of measuring delay, it is possible to achieve network-carrier scale by only connecting to a single location on the network (**Fig. 3**) (without installing measurement equipment at multiple locations in the network).

The high-accuracy inline monitoring technology can be applied to monitoring VPN services because it can measure the communication delay of the desired route (e.g., user communication route).

3.2 Traffic-flow statistics

In current carrier networks, many user communications with different bandwidth requirements are transported in the network. Therefore, it is becoming

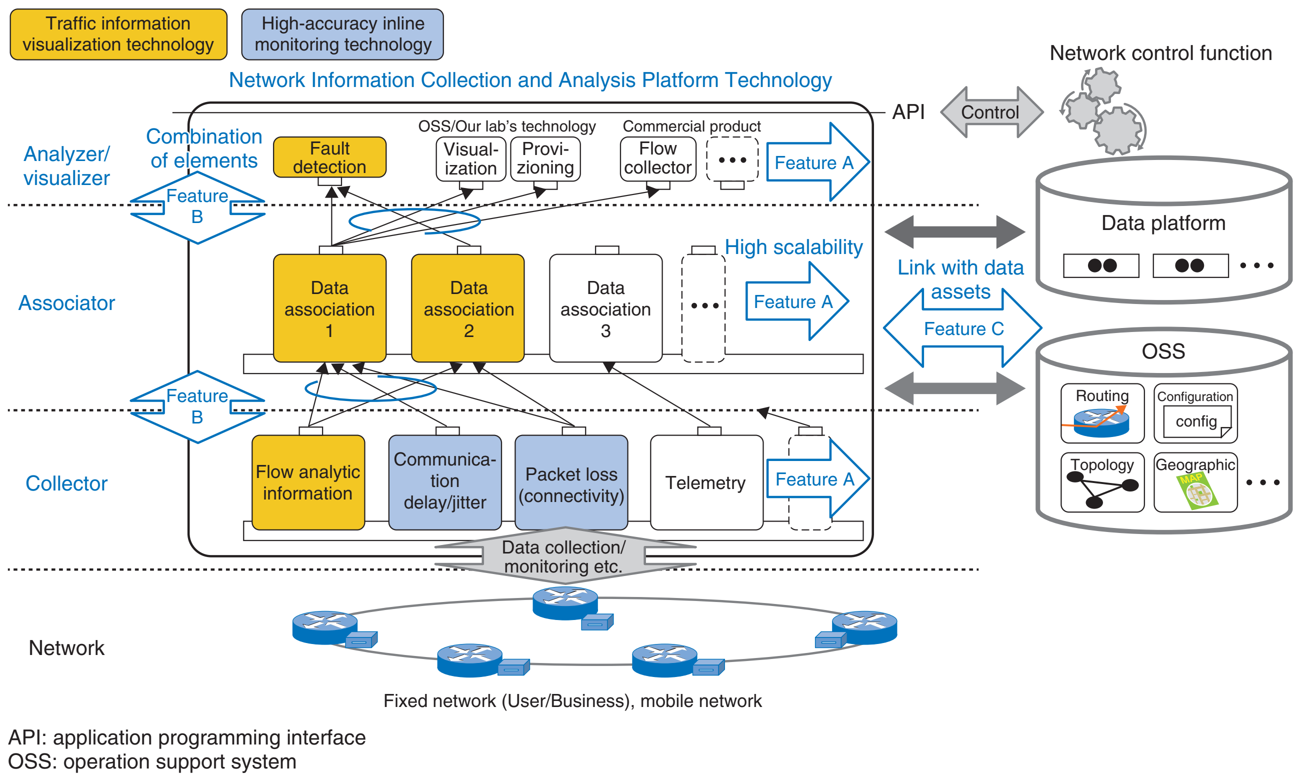

Fig. 2. Overview of Network Information Collection and Analysis Platform Technology.

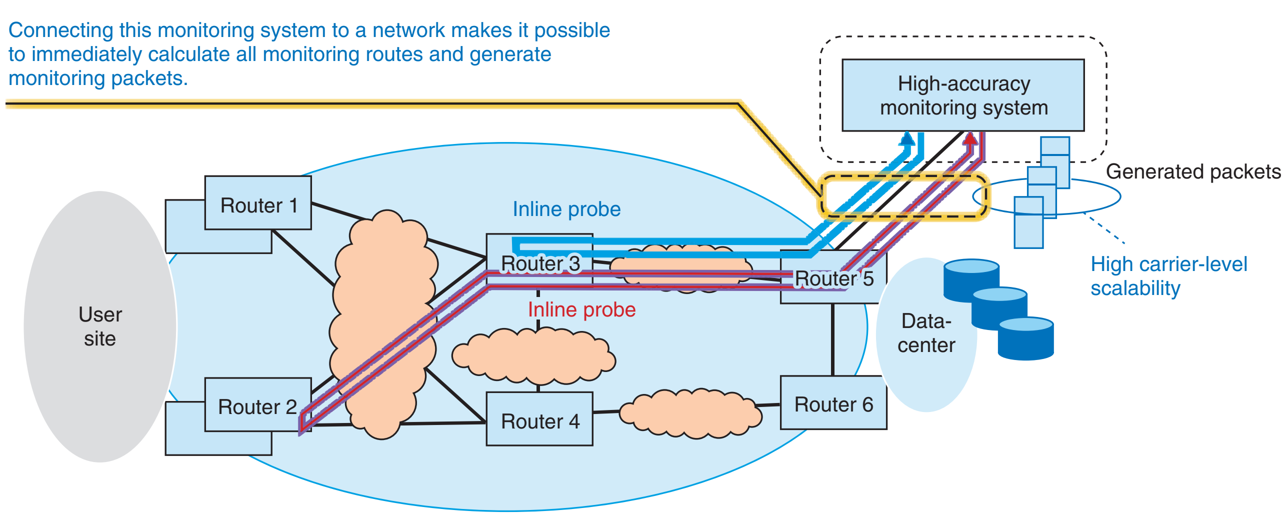

Fig. 3. Overview of high-accuracy inline monitoring technology.

increasingly important for network operation to confirm whether user communication can be transported as requested within the network.

We therefore developed a technology called Fast xFlow Proxy [2], which collects header samples and raw packets from routers and executes protocol analysis, grouping, header removal, and traffic measurement. Various flow analyses are possible by using

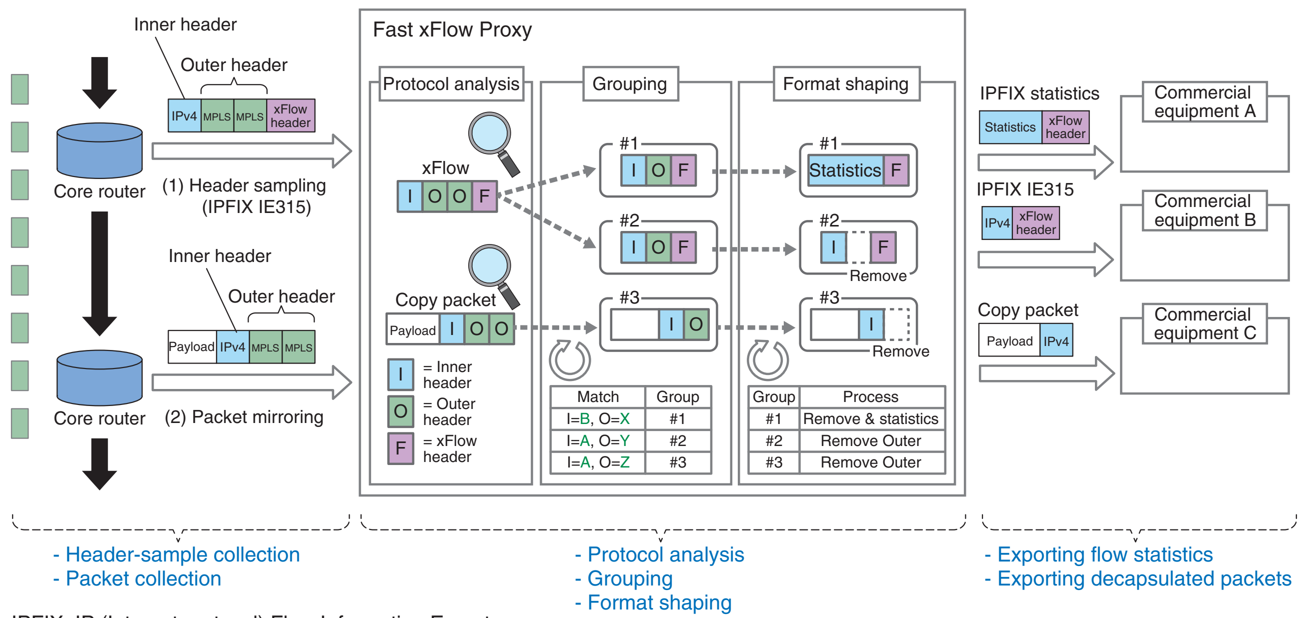

Fig. 4. Outline of flow-statistics collection (Fast xFlow Proxy).

the results as traffic-flow statistics as input for commercial analysis technologies (**Fig. 4**). The advantage of this technology is that these processes are accelerated using a field-programmable gate array (FPGA) and DPDK. The monitoring of carrier-level large-capacity communications will be achieved by deploying appropriate functions in both hardware and software, passing metadata from hardware to software, and providing load balancing functions to improve scalability.

By using this technology, it is possible to monitor the bandwidth of user communication and the route actually passed through, for example, in a network that provides a VPN to users on SR-MPLS (multiprotocol label switching). By comparing the current and past traffic volume of a certain user's communication and by comparing the traffic volume between users, it will be possible to identify the cause of a communication failure, i.e., the user network or carrier network.

4. Network Control Platform Technology

For practical application of the APN, NTT Network Innovation Center is researching and developing the Network Control Platform Technology. This technology controls networks efficiently in cooperation with the Network Information Collection and Analysis Platform Technology.

NTT Network Innovation Center is researching this technology on the basis of the following three requirements.

1. Dense accommodation of subscribers by using the resource pooling technology
2. Rapid service recovery
3. Easy control for various network nodes

4.1 Dense accommodation of subscribers by using the resource pooling technology

In a current commercial network, network providers consistently use the identifier of physical assignment from the subscriber-management and network-resource management systems to the network nodes. It achieves accurate accommodation with millions of subscribers. However, the consistent use of the physical identifier is a problem in that the use of the subscriber accommodation resource is not efficient, which leads to increased capital expenditure. The Network Control Platform Technology pools the resources of the network nodes and executes centralized management. The subscriber-management systems use the identifier of the virtual assignment, and this technology determines the physical assignment for efficient accommodation and translates the identifier of the virtual assignment to that of the physical assignment in accordance with the accommodation information.

4.2 Rapid service recovery

In the event of a large-scale failure such as a building-affected disaster, service provision may be suspended due to the network-node restriction in current services. The Network Control Platform Technology enables rapid service recovery by controlling network changes to other network nodes within an available resource in the pooled resources.

4.3 Easy control for various network nodes

The subscriber accommodation in the network of multi-vendor nodes has the problem that the interface implementation and configuration format of each network node differs, which requires individual configuration. The Network Control Platform Technology enables multi-vendor control by consistent configuration with a plug-in module and by flexible translation of the virtual and physical assignment identifiers.

5. Extension of control technology and target network

We are developing the following control technologies with the aim of advancing the Network Control Platform Technology and expanding its use.

5.1 Control technology using network information

Network control requires fast and appropriate recovery from sudden network failures. Therefore, we are investigating the automation of network control using real-time data from the Network Information Collection and Analysis Platform Technology. For example, when allocating traffic to optimal routes to minimize quality degradation in a real network, it is necessary to consider the reduction in route-calculation time as well as the impact on uncontrolled communications. Therefore, we implemented logic to optimize network utilization per application and minimize the communication impact of route variations. In addition to this traffic engineering, we are also considering active processing for specific traffic. This technology will automate the process from information collection and analysis to network control, which will drastically reduce operational costs.

5.2 Inter-network connection control technology

To extend the target network for control, we are investigating interconnecting different networks. Current networks are independent of fixed and mobile networks or cost-efficient networks that accommodate multiple users and quality-guaranteed networks for business, making it difficult to provide a flexible combination to meet user needs. Therefore, we are developing technology to control the connection points between networks that guarantees independence among users and technology to integrate and manage each network resource across different networks to determine the optimal interconnection point locations such as low latency routes. With these technologies, we aim to provide a secure, one-stop service for network interconnection.

5.3 White box control technology

This control technology will extend network-construction automation and network functionality for white box switches. It will enable automation of user VPN construction by managing topology information and dispatchable resource status. It will also enable the deployment of information-collection agents at arbitrary locations to extend network testing and information collection.

6. Future work

Regarding the Network Information Collection and Analysis Platform Technology, we are currently implementing the function of collecting network information, such as communication delay, packet loss, and traffic-flow statistics, for transport networks consisting of routers and switches. We will apply our elemental technologies to delay-managed transmission systems through the collection of communication delay in optical networks and integrate various types of performance-monitoring information collected from optical networks with information collected from transport networks for visualizing both network layers.

Regarding the Network Control Platform Technology, we are aiming to contribute to the actualization of IOWN by expanding the control technology of the optical layer such as cooperation with delay-managed transmission systems.

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Understanding Desire to Touch Using Large-scale Twitter Data

Yusuke Ujitoko

Abstract

I and research colleagues investigated people's desire to touch by collecting and analyzing a large amount of text data that contain phrases such as "want to touch" on Twitter. We revealed the relationship between the body part that people want to touch and the touch gesture. We also revealed the effects of the COVID-19 pandemic on the desire to touch. Specifically, we observed "skin hunger," i.e., the strong desire for physical communication, and variation of touch avoidance toward objects such as doorknobs. Our results will be beneficial for understanding human behavior as well as for the further development of haptic technology.

Keywords: desire to touch, Twitter, haptics

1. Background

People physically touch many targets throughout the day. For instance, people may make physical contact with familiar people or animals to communicate with them, touch targets to evaluate their texture, or use equipment such as pliers to determine their condition. There are targets that people desire to touch and others that they do not. From the perspective of understanding human behavior, it is crucial to comprehend what people want to touch. Recognizing the desire to touch is also beneficial for the development of consumer applications that satisfy such desire using haptic displays.

The COVID-19 pandemic required a sudden cessation of physical contact, and the extended lockdown had left many people in isolation. This unprecedented dissociation from touch has affected people's mental and physical well-being. Some people may experience "skin hunger," i.e., the strong desire for physical communication, and a public health crisis has been addressed in the major mass-media outlets [1] as a result of a life without touch. For the scientific study of human behavior as well as the development of technology that enables social touch at a distance, it is crucial to comprehend how people's desire for touch changed as a result of the COVID-19 pandemic [2].

Previous research [3] examined the desire to touch through laboratory experiments in which participants saw or touched specific objects that are rarely touched in the course of a day then responded to questions on the degree to which they felt a desire to touch. Therefore, the desire to touch was not addressed. The methods for investigating the desire of people to touch targets placed in front of them do not enable investigation of the desire to touch that people may had felt in the past.

We chose Twitter for our analysis to aggregate the self-reporting of what people desire to touch. Twitter accumulates a large amount of users' spontaneous reports (tweets) about their intention at various times throughout the day. By analyzing tweet texts, we aimed to understand people's desire to touch and how it changed due to the COVID-19 pandemic.

2. Desire to touch in daily lives

We analyzed the text data posted on Twitter containing each of the seven phrases such as "want to touch" (as shown in leftmost column in **Table 1**). The phrases were defined by referring to exploratory procedures [4]. Each phrase corresponded to different touch gestures. We then conducted preprocessing, such as noise reduction, on the text data and syntax

Table 1. The relationship between popular targets of touch desire and touch gesture.

Phrases corresponding to touch gesture	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
want to touch	breast	hair	buttocks	cat	abdomen	cheek	dog	body	ear	hand
want to statically contact	you	people	skin	cat	hand	warmth	animal	human skin	object	lip
want to stroke	head	cat	dog	abdomen	buttocks	hair	me	back	child	cheek
want to grab	waist	hand	buttocks	tail	arm	hair	ankle	breast	tongue	leg
want to push	button	stamp	cart	abdomen	card	whorl	key	everyone	mole	chair
want to hit/tap	drum	buttocks	keyboard	head	hand	shoulder	something	iron	them	cheek
want to trace	line	abdominal muscle	eyebrow	muscle	back	clavicle	blood vessel	crack	tooth	ditch

analysis using a machine-learning model to extract the targets that people expressed a desire to touch.

We determined the popular targets for each touch gesture, as shown in Table 1, showing the relationship between targets of touch desire and touch gesture.

We found that body parts were more popular than objects. We visualized the geometric relationships between touch gesture and body part by mapping them into a whole-body illustration (see **Fig. 1**). In this illustration, each touch gesture (e.g., “grab”) is mapped to body parts where occurrence probability of the touch gesture (e.g., corresponding to “want to grab” in the first row of Table 1) is higher than that in the gesture of general “touch” (corresponding to “want to touch” in the table). We also mapped the gesture of general “touch” when occurrence probability of the body part was higher than that for other touch gestures.

In accordance with this visualization, for example, we see that the head is the desired target of stroking. This might be due to multiple factors such as people feeling pleasure by stroking hair. It might be also due to communicative and cultural aspects because in Japan, people stroke the child’s head as an expression of affection.

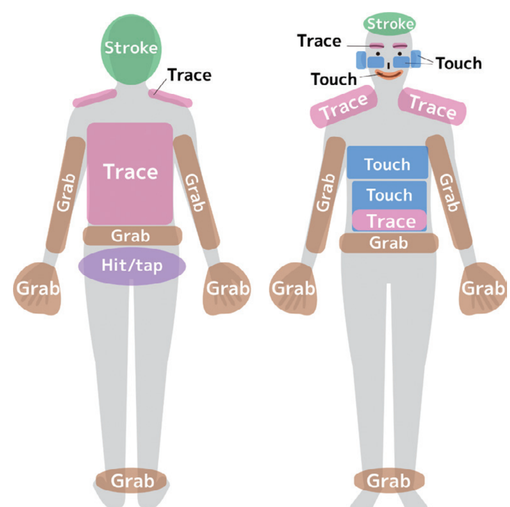

Fig. 1. The relationship between desired body parts and touch gesture.

3. The impact of the COVID-19 pandemic on desire to touch

Similar to the analysis in the previous section, we analyzed the data from before the outbreak of the COVID-19 pandemic to quantitatively investigate the change in the desire to touch before and after the pandemic began. The difference-in-differences method was used to analyze how the desire to touch people/animals changed after the outbreak of the pandemic. **Figure 2** shows the amount of text data that contains the phrase “want to touch people/animals.” Concerning the desire to touch people/animals, we can see that it was at a normal level immediately after the outbreak of the pandemic but became stronger when the first state of emergency was declared in Japan and has continued to become stronger. This indicates that skin-hunger may have become chronic. This change in desire to touch may have occurred due to the effect of requests to social distance and stay at home after the outbreak of the pandemic.

The same analysis was conducted on the avoidance to touch objects such as doorknobs. **Figure 3** shows the amount of text data that contains the phrase “don’t want to touch objects (e.g., doorknobs).” The avoidance

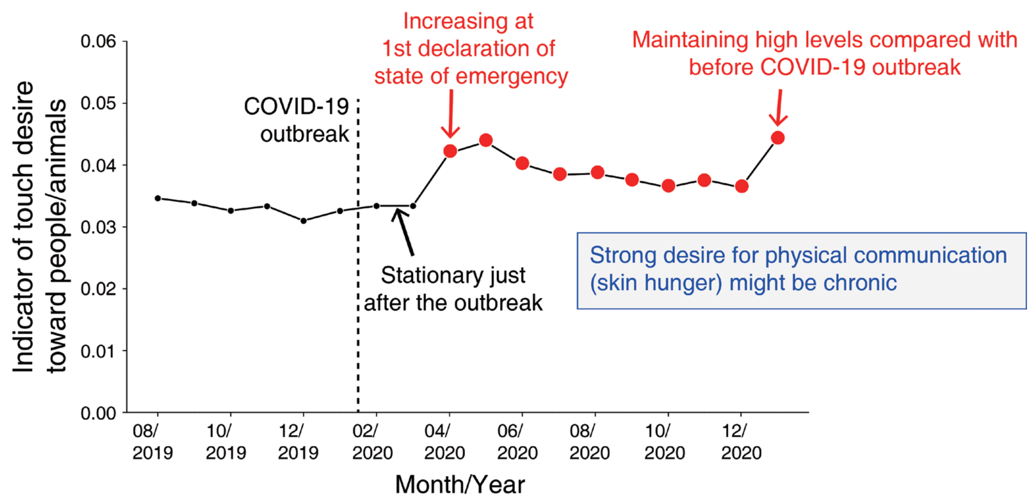

Fig. 2. Change in desire to touch people and animals.

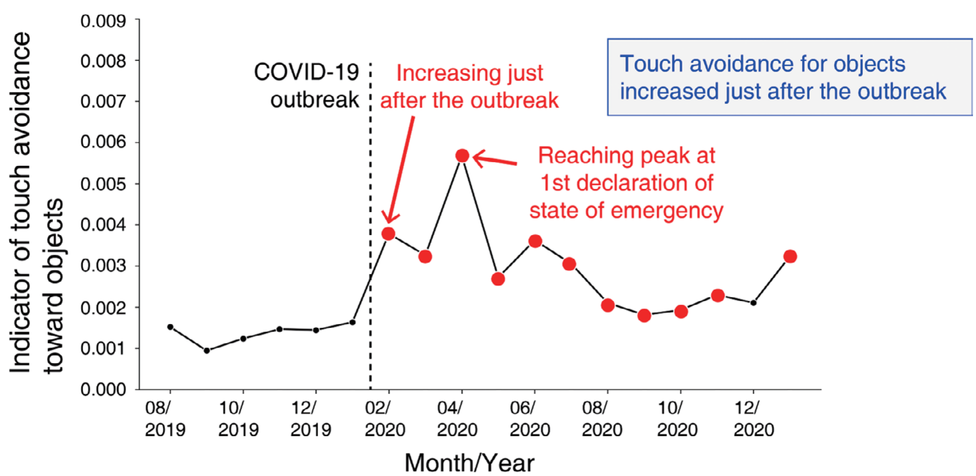

Fig. 3. Change in touch avoidance toward objects (e.g., doorknobs).

to touch objects has become stronger since the outbreak of the pandemic.

When the graphs in Figs. 2 and 3 are compared, we can see that the change over time in the desire to touch people/animals and avoidance to touch objects. The desire to touch people/animals did not change immediately after the outbreak but began to change around the time a state of emergency was first declared in Japan. The avoidance to touch objects changed immediately after the outbreak and temporarily increased when a state of emergency was first declared. This difference in the characteristics of temporal change might be related to the human tendency to prioritize risk avoidance.

4. Conclusion

This study clarified people's desire to touch and how it changed due to the COVID-19 pandemic. The findings can be applied to a wide range of problems and contribute to elucidating the psychological mechanism of when humans want to touch something and the development of haptic technology for providing the experience of touching something consumers would naturally want to touch.

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Standardization Trends in Real-time Communications at 3GPP

Yoshihiro Inoue and Rihito Suzuki

Abstract

Studies and specification work are proceeding at the 3rd Generation Partnership Project (3GPP) on functional enhancements to the IP (Internet protocol) Multimedia Subsystem (IMS), which is an international standard specifying IP telephone networks provided by telecommunication operators, and on support for real-time communications not limited to IMS functional enhancements. This article provides an overview of IMS functional enhancements in Release 17, the specification work of which was completed in June 2022, and introduces studies and specification work for real-time communications in Release 18 now in progress.

Keywords: 3GPP, real-time communications, IMS

1. PSTN to IP network migration/IP interconnection among telecommunication operators in Japan, and 3GPP IMS

In Japan, the migration of the public switched telephone network (PSTN) to Internet protocol (IP) networks and IP interconnection among telecommunication operators are moving forward with completion scheduled for January 2025. Interface specifications (such as TTC JJ-90.30) for inter-operator IP interconnection of telephone services in Japan are based on the inter-IP Multimedia Subsystem (IMS) network-to-network interface specification (TS 29.165) specified at the 3rd Generation Partnership Project (3GPP) [1]. 3GPP IMS is being widely applied in overseas IP telephone networks, the same as in Japan, and studies and specification work are currently underway on using the 5th-generation mobile communication system (5G) and making functional enhancements to services on the basis of the requirements and proposals of international standardization organizations such as the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), regional standardization organizations such as the Alliance for Telecommunications Industry Solutions (ATIS) in the United States and European Telecommunications Standards Institute (ETSI) in Europe, industry organizations such as the GSM Association (GSMA), and participating companies.

2. IMS standardization trends in 3GPP

3GPP uses a mechanism called "Release" for studies and specification work to enable equipment vendors and telecommunication operators to implement and use a stable platform at some point in time. The most recent set of 3GPP specifications ready for implementation in September 2022 are Release 17 specifications completed in June 2022. Studies and specification work are currently underway on Release 18 with completion scheduled for March 2024.

Looking at studies and specification work on 3GPP IMS specifications since Release 15 when the specification work for 5G began, two types of work have been conducted that can be broadly divided into functional enhancements related to linking IMS with 5G and functional enhancements of multimedia services provided by IMS.

Functional enhancements related to linking IMS with 5G were conducted in stages so that the existing IMS network can use 5G. Specifically, Release 15 supported the Diameter protocol, which is used at the interface between a 4G core network (EPC: evolved packet core) and IMS network, at the interface

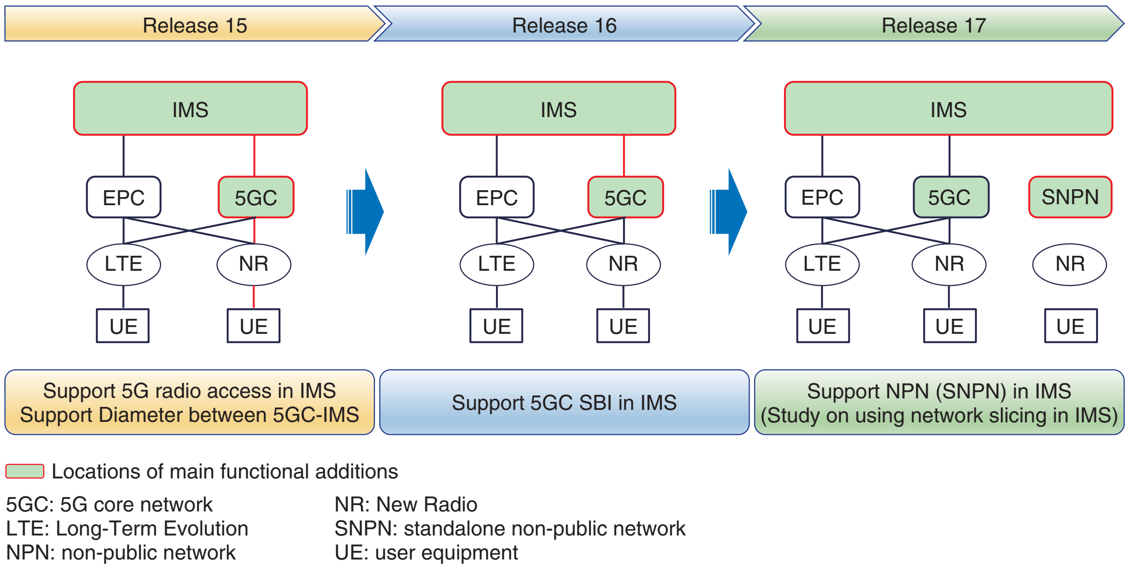

Fig. 1. Progress of studies and specification work linking 5G and IMS.

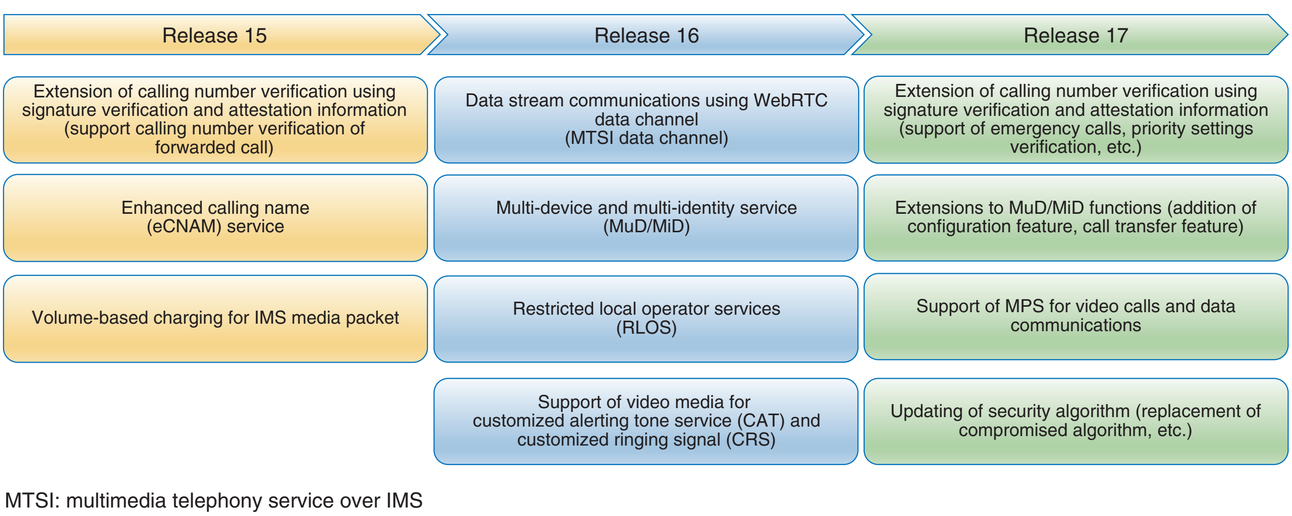

Fig. 2. Functional enhancements and service extensions in IMS.

between a 5G core network and IMS network to support connections between this 5G core network and the existing IMS network; Release 16 supported the HTTP (Hypertext Transfer Protocol)-based service based interface (SBI) protocol, which is applied in a 5G core network, for connections between that network and an IMS network to enable IMS to use 5G core network functions; and Release 17 studied functional enhancements to enable IMS to use specific functions newly introduced in 5G (**Fig. 1**).

Regarding the functional enhancements of IMS and service extension, studies and specification work were conducted on specification extensions to the calling number verification using signature verification and attestation information and on support for additional IMS supplementary services, multimedia priority service (MPS), data channels, etc. (**Fig. 2**). In Release 18, the IMS data channel supported in Release 16 is now being studied for the use of transmitting/receiving immersive video data to support

Key issues under study	Proposals for solving issue under study
#1 Enhancement to support data-channel usage in IMS network	• IMS architecture extension (definition of connection interface to data-channel function and interaction method) • Specification of method for discovering IMS data channel support/no-support by terminal/network
#2 IMS-based AR telephony communication	• Application of IMS data channel architecture to AR communications (transmitting/receiving of audio/video by RTP and AR media by data channel) • Support of terminal-rendering and network-rendering methods (coordinating with SA4 WG)
#3 Third-party-specific user IDs	• Extension of user authentication/permission function (use of OAuth2.0, extension of IMS HSS registration function, etc.) • Functional extension of originating ID verification function using signature information (support third-party ID use case)
#4 Study of applicability of service-based principles to IMS media control interfaces	• Support SBI by IMS U-plane entity • Application of 5G SBA network repository function (NRF) in IMS MRF discovery/selection

HSS: home subscriber server
MRF: media resource function
SBA: service-based architecture
U-plane: user plane

Fig. 3. Study of IMS functional enhancements in SA2.

new communication services providing augmented reality (AR), virtual reality (VR), and mixed reality (MR) in IMS.

3. Functional enhancements related to IMS in Release 17

Release 17 was completed in June 2022. Focusing on functional enhancements related to IMS and 5G, specification work for functional enhancements of non-public network (NPN) in 5G included NPN support in IMS and a preliminary study on the use of 5G functions through IMS. As the name indicates, NPN enables deployment of 5G for private network use. NPN specification defines two key NPN deployment options: a public network integrated non-public network (PNI-NPN) that uses a 5G network provided by a telecommunication operator as an NPN and a standalone non-public network (SNPN) that uses a 5G network created by a user (e.g., company) on its own independent of any 5G network provided by a telecommunication operator. Specification work on NPN support in IMS supported IMS emergency calls and voice calls. In addition, the preliminary study on the use of 5G functions through IMS limited the target of study to the use of network slicing, and a policy of extending data network name (IMS DNN) information registered in unified data management (UDM: subscriber data management/processing function) was adopted to support a scenario that selects a different network slice for each IMS network. The specification work to support the conclusion of this study is expected in Release 18.

4. Study of specifications for real-time communications in Release 18

Studies and specification work toward functional enhancements of communication services are also being conducted in Release 18, and among these services, lively discussions are being held on specifications to support user communication in virtual space such as the *metaverse* and immersive (based on AR, VR, etc.) real-time communications (RTC) with the aim of achieving more immersive communications with a high sense of presence.

3GPP Service and System Aspects Working Group 2 (SA2)[*1] is studying specification extensions to a 5G core network and additional functional enhancements to IMS to support high-performance media communications including AR/VR/MR. Further functional enhancements to IMS includes studies on supporting AR telephone communications (**Fig. 3**). This IMS functional enhancement is targeting extensions to data-channel use cases to be supported by IMS, support of AR telephone communications, support of third-party user identities (IDs), and application of

*1 3GPP SA2: Group studying specifications for architecture and services.

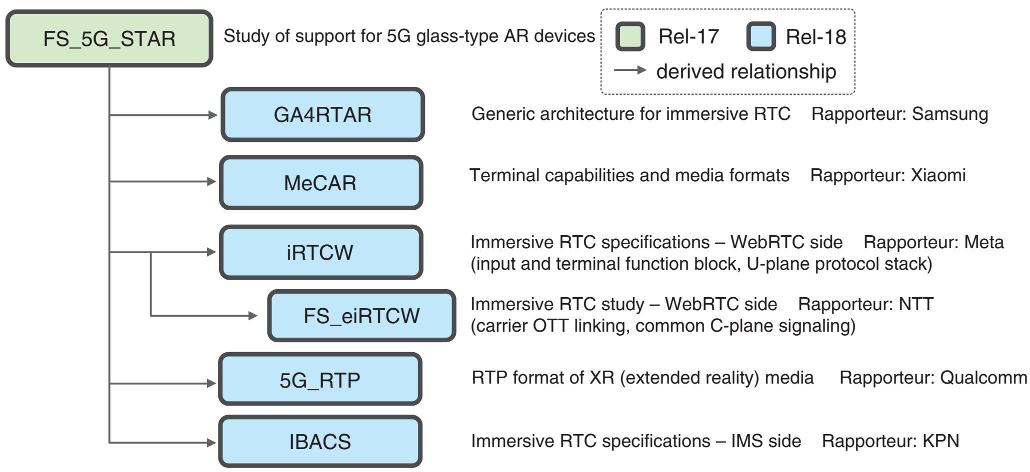

Fig. 4. RTC-related studies and specification work in SA4.

SBI to IMS media control interfaces. The support of AR telephone communications includes parallel studies on a method for transmitting/receiving audio/video media via the Real-time Transport Protocol (RTP) as before and transmitting/receiving AR media/data via the data channel by using architecture extensions to the data channel in IMS.

3GPP SA4[*2], meanwhile, is studying a method for IMS functional enhancements and a method for using WebRTC in conjunction with studies on achieving immersive RTC.

IMS has prescribed a signaling system with high interconnectivity as specifications for IP telephone services provided by telecommunication operators and has continued to make functional enhancements. However, while guaranteeing high interconnectivity, these built-in specifications have heightened the barrier to third parties participating in services; as a result, the market launch of new services has been lagging. Under these conditions, Release 18 includes a proposal for a method using WebRTC in addition to a method for IMS functional enhancements with respect to establishing immersive RTC media sessions. IMS functional enhancements are progressing in Work Item IBACS (IMS-based AR Conversational Services), and a new method using WebRTC is mainly being studied in Work Item iRTCW (Immersive Real-time Communication for WebRTC) (**Fig. 4**).

In iRTCW, the terminal architecture for achieving immersive RTC and specifications for essential input/output parameters, a mechanism for establishing media sessions and one for requesting the 5G system to execute quality of service (QoS) control are being studied on the basis of a policy of using functions specified in existing 5GMS (TS 26.501) media-streaming/architecture specifications. Given that external service providers such as over-the-top (OTT) service providers are the agents of service provision, this is an attempt to adopt a simple means of establishing a media path by removing interconnectivity between services provided by individual service providers from the scope of their operations.

While immersive RTC as a carrier service will lower the barrier to participation and enable rapid rollout of services on the market, studies will be needed from the viewpoint of interconnectivity between telecommunication operators and between service providers, the same as telephone communication service in PSTN and IMS. WebRTC specified by the Internet Engineering Task Force (IETF) and the World Wide Web Consortium (W3C) assumes the use of a client application provided by a specific service provider under a model in which the installation of the same client application secures closed connectivity within the service. To secure interconnectivity between services without limiting it to specific service providers, there will be a need for common specifications in signaling with regard to establishing sessions that have so far been service dependent.

NTT considers the study of common signaling specifications necessary for bolstering interconnectivity in immersive RTC using WebRTC to be introduced in the future. NTT has therefore been proposing contributions since 2021 at the time of preliminary

*2 3GPP SA4: Group studying specifications for codecs and media.

studies on AR communications for Release 17 and has been holding discussions on that need. Thus, it was approved to study a common signaling method as Preliminary Study Item FS_eiRTCW for implementing functional enhancements to the iRTCW method mentioned above in Release 18. In FS_eiRTCW, an extensible signaling method is being studied that can be achieved by applying as many current 3GPP specifications and those of other standardization organizations such as IETF and W3C as possible while guaranteeing interconnectivity. It is also expected that this common signaling method will enable new use cases to be flexibly supported and enhance cloud affinity by using web-based technology all while satisfying the main requirements for establishing a session (signaling server's discovery procedure and registration process, client authentication, QoS negotiation, etc.).

5. Future prospects

IMS has been at the core of IP telephone services provided by telecommunication operators, and it is expected that IMS will continue to provide robust communication services and functional enhancements as a lifeline provided by telecommunication operators. Studies have also begun on a new method for achieving immersive RTC services including the metaverse using WebRTC. As a telecommunication operator, NTT plans to keep a close watch on these standardization trends in real-time communications while making proposals on improving user experience and interconnectivity and contributing to studies and specification work toward the provision of attractive services.

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External Awards

Paper Award

Winners: Tatsuya Iizuka, NTT Space Environment and Energy Laboratories; Takuya Sasatani, University of Tokyo; Naoko Kosaka, NTT Space Environment and Energy Laboratories; Masaki Hisada, NTT Space Environment and Energy Laboratories; Koya Narumi, University of Tokyo; Yoshihiro Kawahara, University of Tokyo
Date: July 15, 2022
Organization: Information Processing Society of Japan

For "Corner-reflector-based Chipless RFID for Wide Range Readout with Low Power Millimeter Wave Radar."
Published as: T. Iizuka, T. Sasatani, N. Kosaka, M. Hisada, K. Narumi, and Y. Kawahara, "Corner-reflector-based Chipless RFID for Wide Range Readout with Low Power Millimeter Wave Radar," Proc. of Multimedia, Distributed, Cooperative, and Mobile (DICOMO) 2022 Symposium, 5H-3, pp. 1085–1091, July 2022.

20th JSAP Photo & Illustration Contest (Science As Art), Excellent Award

Winners: Masato Takiguchi, NTT Basic Research Laboratories; Sylvain Sergent, NTT Basic Research Laboratories; Masaya Notomi, NTT Basic Research Laboratories; Stéphane Vézian, Centre national de la recherche scientifique; Benjamin Damilano, Centre national de la recherche scientifique
Date: October 12, 2022
Organization: The Japan Society of Applied Physics (JSAP)

For "Nano-size Pencil?"
An image of hollow-core nanowire lasers.
Published as: M. Takiguchi, S. Sergent, M. Notomi, S. Vézian, and B. Damilano, "Nano-size Pencil?", 20th JSAP Photo & Illustration Contest (Science As Art), Oct. 2022.

MIKA Poster Award for Senior Researchers

Winner: Takashi Satake, NTT Network Service Systems Laboratories
Date: October 15, 2022
Organization: Multiple Innovative Kenkyu-kai Association for wireless communications (MIKA), Institute of Electronics, Information and Communication Engineers (IEICE) Communications Society

For "An Effective Location Registration Method in Environments with Large Amount of IoT User Equipment - Use Cases under Large-scale Failures -".
Published as: T. Satake, Y. Narusue, and H. Morikawa, "An Effective Location Registration Method in Environments with Large Amount of IoT User Equipment - Use Cases under Large-scale Failures -", MIKA 2022, Oct. 2022 (in Japanese).

Papers Published in Technical Journals and Conference Proceedings

Composing General Audio Representation by Fusing Multi-layer Features of Pre-trained Model

D. Niizumi, D. Takeuchi, Y. Ohishi, N. Harada, and K. Kashino
Proc. of the 30th European Signal Processing Conference (EUSIPCO 2022), pp. 200–204, Belgrade, Serbia, August/September 2022.

Many application studies rely on audio DNN (deep neural network) models pre-trained on a large-scale dataset as essential feature extractors, and they extract features from the last layers. In this study, we focus on our finding that the middle layer features of existing supervised pre-trained models are more effective than the late layer features for some tasks. We propose a simple approach to compose features effective for general-purpose applications, consisting of two steps: (1) calculating feature vectors along the time frame from middle/late layer outputs, and (2) fusing them. This approach improves the utility of frequency and channel information in downstream processes, and combines the effectiveness of middle and late layer features for different tasks. As a result, the feature vectors become effective for general purposes. In the experiments using VGGish, PANNs'CNN14, and AST on nine downstream tasks, we first show that each layer output of these models serves different tasks. Then, we demonstrate that the proposed approach significantly improves their performance and brings it to a level comparable to that of the state-of-the-art. In particular, the performance of the non-semantic speech tasks greatly improves, especially on Speech commands V2 with VGGish of +77.1 (14.3% to 91.4%).

Multiple Beat-noise Suppression in Polarization-multiplexed Pump Light for Forward-pumped Raman Amplifier

H. Kawakami, T. Kobayashi, and Y. Kisaka
Proc. of the 48th European Conference on Optical Communication (ECOC 2022), We4D.6, Basel, Switzerland, September 2022.

We show that orthogonally polarized pump light emitted from two different laser sources in a forward-pumped Raman amplifier system induces beat noise on amplified signal light. Utilizing our proposed noise suppression technique, we improved the signal-to-noise ratio of a 36-QAM (quadrature amplitude modulation) signal after a 1920-km transmission.

Quantifying Fermionic Nonlinearity of Quantum Circuits

S. Hakkaku, Y. Tashima, K. Mitarai, W. Mizukami, and K. Fujii

Physical Review Research, Vol. 4, 043100, November 2022.

Variational quantum algorithms (VQAs) have been proposed as one of the most promising approaches to demonstrate quantum advantage on noisy intermediate-scale quantum (NISQ) devices. However, it has been unclear whether VQAs can maintain quantum advantage under the intrinsic noise of the NISQ devices, which deteriorates the quantumness. Here we propose a measure, called *fermionic nonlinearity*, to quantify the classical simulatability of quantum circuits designed for simulating fermionic Hamiltonians. Specifically, we construct a Monte Carlo type classical algorithm based on the classical simulatability of fermionic linear optics, whose sampling overhead is characterized by the fermionic nonlinearity. As a demonstration of these techniques, we calculate the upper bound of the fermionic nonlinearity of a rotation gate generated by four fermionic modes under the dephasing noise. Moreover, we estimate the sampling costs of the unitary coupled cluster singles and doubles quantum circuits for hydrogen chains subject to the dephasing noise. We find that, depending on the error probability and atomic spacing, there are regions where the fermionic nonlinearity becomes very small or unity, and hence the circuits are classically simulatable. We believe that our method and results help to design quantum circuits for fermionic systems with potential quantum advantages.
