NTT Technical Review

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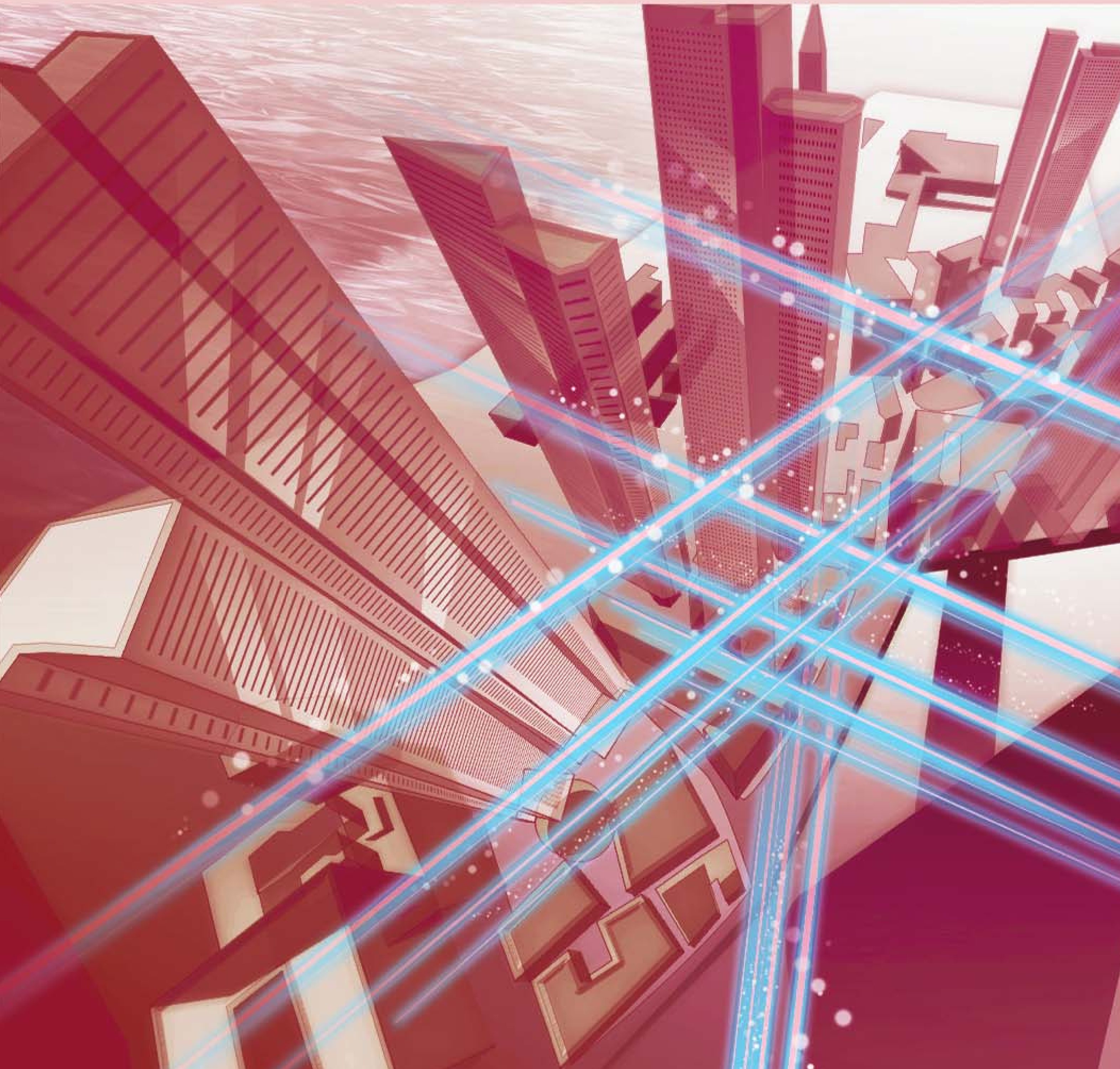
2024



January 2024 Vol. 22 No. 1

NTT Technical Review

January 2024 Vol. 22 No. 1

Elucidating the Relationship between Implicit Quick Manual Reactions and Mechanisms of Sensory-motor Information Processing in the Brain

Hiroaki Gomi
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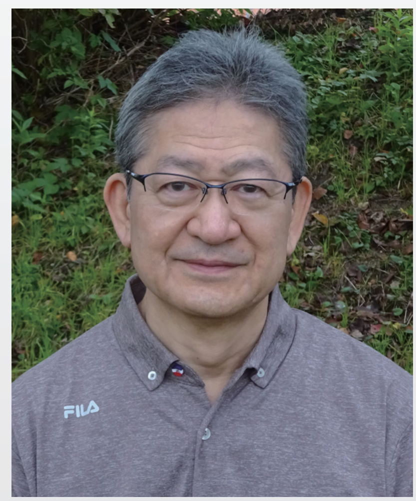


Abstract

Many of our daily movements are skillfully controlled by the involvement of the unconscious information-processing mechanisms in the central nervous system, such as stretch reflex. Although we may think that such an unconscious sensory-motor system is governed by a relatively primitive nervous system, some reflexive responses are generated by signals that undergo high-level visual information processing. Hiroaki Gomi, a senior distinguished researcher at NTT Communication Science Laboratories, was the first in the world to reveal the hidden mechanism of quick manual responses generated by a background visual motion, called manual following response. We asked him about the implicit reflexive manual reaction and the sensory-motor information processing in the brain, as well as his mindset and ideas about enjoying research.

Keywords: sensory-motor information processing, reflexive motor response, visual motion

Elucidating sensory-motor information processing in the brain for a new idea of novel user interfaces

—Could you tell us about your current research?

One of my research aims is to build a foundation for creating human-friendly user interfaces through the discovery of new latent sensory-motor systems and the elucidation and modeling of information processing of such systems. In a previous interview (February 2021 issue), I discussed that my research colleagues and I have revealed that one of the unconscious body and limb movements, the stretch reflex, in which motor commands are generated by the passive stretching of muscles, is regulated not only by proprioceptive information but also body-state representations in the brain (i.e., the "body image" in the brain) obtained by integrating multiple sensory information, including vision. As an example application of somatosensory perception, I introduced a small device called "Buru-Navi," which can be used to navigate the user by stimulating the tactile sense of the finger, one of the somatosensory senses, with a particular vibration that gives the user the sense of being pulled.

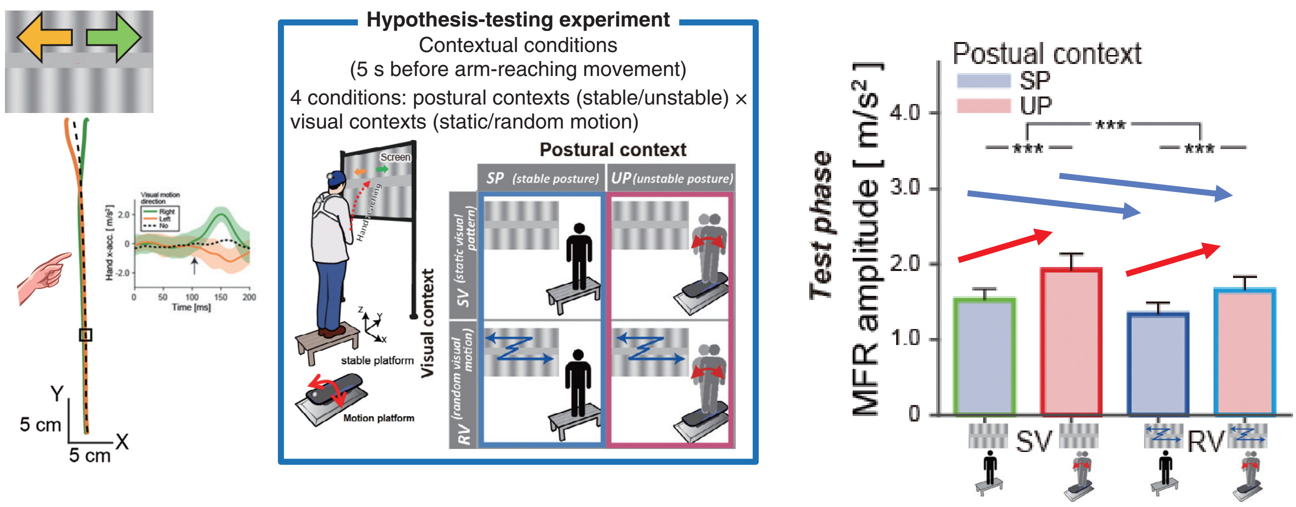


Fig. 1. Arm responses (MFR) induced by background-motion stimuli that vary with postural and visual contexts.

I'm currently working on clarifying the mechanism of information processing in the brain when a person reaches their hand for an object. I have been investigating this topic for quite some time. How does the brain use information from vision, touch, and sensors embedded in muscles to represent the external world and move the musculoskeletal system? When sensory information is slightly manipulated, mysterious phenomena on perception and movement occur, which is sometimes called "illusion." These phenomena can occur both consciously and unconsciously.

An example of such phenomena is while moving your hand, if a black-and-white pattern placed in front of your eyes is moved to the left, your hand will move to the left involuntarily, and if the pattern is moved to the right, your hand will move to the right involuntarily. This phenomenon is considered to be a reflexive response triggered by visual motion, called the manual following response (MFR), by which your hand involuntarily moves according to visual information instead of your own intention. About 20 years ago, we discovered this phenomenon and have been investigating how this information processing is executed in the brain. MFR has been generally explained by two alternative hypotheses. One proposed by another research group is that the representation in the brain of the reach target is shifted by visual motion, and that shift results in the correction of hand movements. Our hypothesis is that the large field visual motion creates the illusion that the body is moved, and the hand moves as a compensatory action. We have recently succeeded in providing experimental evidence of our hypothesis [1].

In this hypothesis-testing experiment, we compared the effects of the following four conditions on the magnitude of the hand response generated by visual motion (MFR): participants stand on a stable platform (first postural context) while a grating pattern projected on the screen in front of them is either stationary or moved randomly (visual context), and participants stand on an unstable platform (second postural context) while the grating pattern is either stationary or moved randomly (visual context). By calculating the amplitude modulation of MFR on the basis of our hypothesis by using a Bayesian model that estimates postural changes from visual motion, we predicted that MFR will be larger when the participant's posture is unstable and smaller when the visual field is unstable. The actual measurements of this experiment were consistent with the predictions using the Bayesian model and confirmed our hypothesis that MFR is a compensating action for posture change (**Fig. 1**).

By linking the finding that MFR is a compensatory action for postural change demonstrated in the above-described experiment and the finding that visual-motion analysis in the brain is involved in MFR generation revealed in previous studies, we formulated the hypothesis that visual-motion analysis for MFR is formed to estimate self-motion (postural movement) and synthetically tested this hypothesis. In this hypothesis testing, we first used a head-mounted camera with a built-in motion sensor to capture 30- to 70-s, first-person-viewpoint video

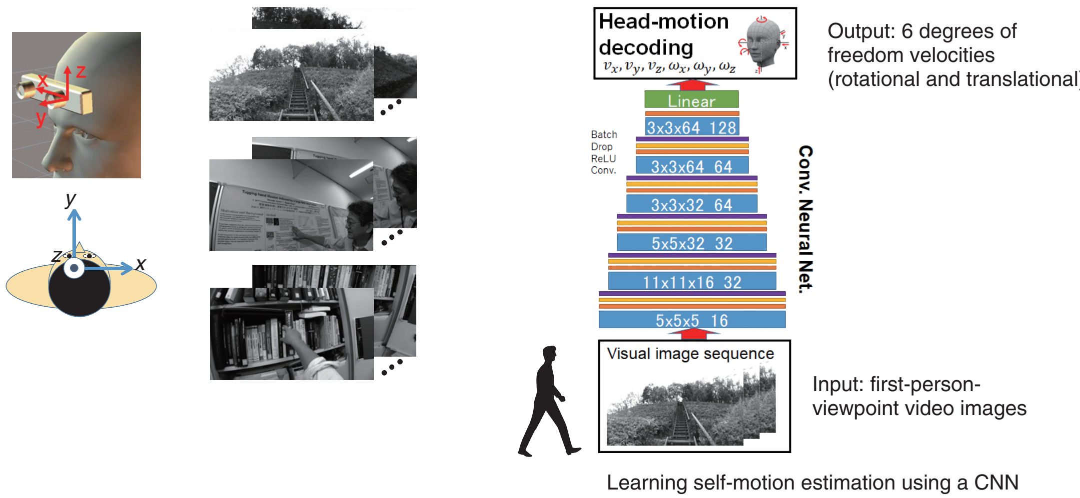


Fig. 2. Design of a CNN for estimating self-motion from first-person-viewpoint video images.

images of 30 scenes, such as indoor and outdoor walking, looking at a poster on the wall, and reaching for a book in a bookshelf. We then used a convolutional neural network (CNN) to estimate the camera motion (i.e., self-motion) with the images as input (**Fig. 2**).

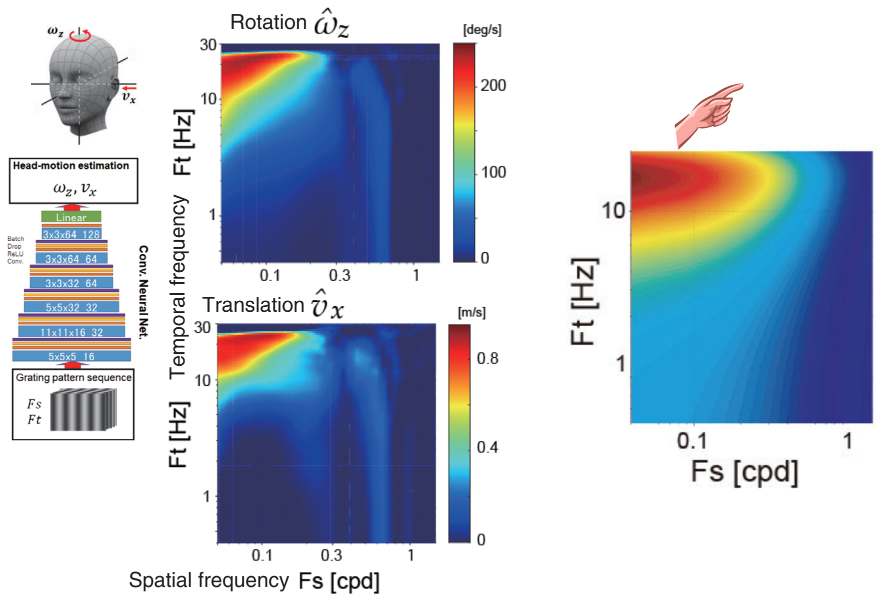
When the untrained first-person-viewpoint video was input into the trained CNN, we found that the output was almost identical to the measured values of self-motion, which indicates that self-motion consisting of rotational and translational velocities in six degrees of freedom can be inversely estimated from the first-person-viewpoint video taken during self-motion. Interestingly, when we investigated the properties of the middle layer of the CNN, we found that the CNN has information-processing characteristics similar to those of the cells responsible for visual-analysis processing in the brain, which have been previously identified. We also investigated the spatio-temporal frequency tuning of the trained CNN and found that the tuning was similar to that of the MFR. Together with further analyses, this result supports our hypothesis that visual-motion analysis for MFR is formed to estimate self-motion (**Fig. 3**). I believe that the progress of these studies has deepened our understanding of the mechanisms that generate latent motor control using visual information. These results were published in a paper in "Neural Network" in 2023 [2].

—You have come up with an interesting approach using Buru-Navi, right?

Regarding Buru-Navi, we have been investigating how the brain perceives vibrotactile information and creates the sensation of being pulled. The results of measuring the electroencephalograms during the sensation of being pulled by changing the vibration direction of Buru-Navi revealed that the information that creates the sensation of being pulled is coded around the parietal lobe. On the application side, we had a chance to try Buru-Navi for guiding a visually impaired person to a seat in a stadium. This trial allowed us to identify technical problems of a pedestrian-navigation system with Buru-Navi. I'd like to further advance our research and development to make Buru-Navi useful in the future.

—The understanding of the information-processing mechanism in the brain opens up a variety of possibilities. What are some of the challenges that lie ahead?

For the time being, I think it is important to further clarify the information processing between vision and motor commands in relation to MFR. The metaverse (virtual space) has been attracting much attention, and virtual interaction and communication within the metaverse is becoming more and more realistic. I believe that understanding the brain's information processing is one of the most-important aspects to consider in regard to interactions in the



Spatiotemporal-frequency tuning learned by the CNN is similar to that of MFR.

Fig. 3. Spatiotemporal-frequency tuning of the trained CNN (left panels) and of MFR (right panel).

metaverse. In the current metaverse, most people interact with avatars by moving them by cursor or mouse and communicate with them using video and voice. As devices such as head-mounted displays become more advanced, it will be possible to give the sensation of one being and moving in the metaverse. As that sense of immersion and presence increases, it will be necessary to understand the mechanism of information processing in the brain and consider interface devices and safety measures on the basis of that understanding.

Understanding the information processing and sensory-motor system in the brain will also become significant in using digital twins, but we are not talking about achieving that level immediately. I think it would be difficult to create a digital twin if we started working on it after the human brain is fully understood, and it would not become a reality no matter how many years we spent on it. In that sense, I think it is important to incorporate the elements of the information-processing mechanism in the brain partially as it is understood. In the meantime, I also believe that we, basic researchers, need to accelerate our efforts to clarify brain information processing related to problem settings in the real world.

Let's enjoy doing research

—What do you keep in mind as a researcher?

I always try to enjoy doing research. When I develop a hypothesis, I talk with my fellow researchers about what will happen if we conduct an experiment to test the hypothesis, and sometimes there are disagreements. I'm relieved if my hypothesis is correct, but when it is not, it is important to think about the reasons and logic behind the failure, and I find this thought process interesting. To enjoy my research, I try to formulate hypotheses that can be verified in a relatively short time and try to enjoy the process of verifying those hypotheses by thinking of it as a kind of game. In basic research, few research results can lead to business in the short term. Therefore, when considering a "large" hypothesis, I try to break down it into a set of "small" hypotheses that can be verified step by step. Even if the small hypothesis is experimentally shown to be wrong, I rethink my strategy for the next game—I review the logic of my hypothesis and devise a new hypothesis—and repeating this cycle of hypothesis and thinking leads to results.

As I pursue my research with this approach, it is crucial to monitor my position by always keeping an eye on the world's research. It is important to make hypotheses and models and design experiments while assessing the research of opposing and supportive groups and advancing our own research. It is necessary to think carefully without pandering to all of opinions, and new ideas, approaches, and experimental methods will emerge in the process of deliberation. If you look at your ideas and experimental results in the context of those from other research groups, you will not lose sight of where you stand. In that sense, a conference is a good place to present your research results and the thinking behind them and gain a great deal from the reactions of the participants.

Although face-to-face conferences were suspended during the COVID-19 pandemic, they have recently resumed, and it is again possible to communicate with people face-to-face just by being in the conference venue. Even if you are just chatting, you may get unexpected hints. Collaboration and communication with people in different fields will also broaden your knowledge and lead you to discover new directions. I've been focusing on information processing from somatic sensations to motions for a long time, but I have recently become interested in the study of visual information processing from the viewpoint of the motor processing since I have been able to think about it in a new way by attending presentations by researchers in vision science at conferences and exchanging opinions with them. In that sense, I think attending conferences is very useful.

—What is your message to younger researchers?

Let's just enjoy doing research. Enjoying something does not mean taking it easy. To enjoy research, you need hard work, effort, and ingenuity to make it enjoyable. During the course of your research, sometimes you have to deal with seemingly useless matters, and other times you will be troubled by a lack of results. The hardships and efforts required to overcome them can be turned into enjoyment with just one way of thinking. If too many things in a different field are unknown to you, you may not be interested in that field and just do what you are instructed from senior researchers or supervisors. It is necessary to pause and look around if you are not getting results instead of focusing only on the difficulties in front of you. I think it is fun to actively seek to know what you don't know, understand what you don't know, and be able to do things you didn't think you could do before. I hope that with that mindset, you will change your perspective and enjoy working on problems. Such efforts and ingenuity may lead to discoveries and new creations. You will be the first person in the world to arrive at the results of your research, and I think that realization is the real thrill of research and the most enjoyable part of it. The more effort and hard work you put in, the stronger this feeling will become. To enjoy doing research, however, it is also important to be able to distinguish between on- and off-duty work. You need to take a good rest when you get tired of your research. Perhaps a good idea will suddenly come to you while you are relaxing on holiday, even when you have thought it through and cannot find a solution at work. I have had such experiences myself.

Collaborating with others is also crucial. It is impossible for a single researcher to complete all of their own research, which is why it is necessary to communicate and collaborate with other researchers. Researchers who have a slightly different viewpoint from your own or have a different specialty may be suitable as collaborative researchers. Conflicting arguments are needed to improve the quality of research. It is not effective to form a clique only with people who agree with you. If you talk with them with the mindset that learning something you don't know is interesting and enjoyable, you can expand the scope of your research and enjoy doing research and having discussions.

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■ **Interviewee profile**

Hiroaki Gomi received a B.E., M.E., and Ph.D. in mechanical engineering from Waseda University, Tokyo, in 1986, 1988, and 1994. He was involved in biological motor control research at ATR (Advanced Telecommunication Research Labs., Kyoto) from 1989 to 1994, where he developed computational models of human motor control, robot learning mechanisms (demonstration learning), and a manipulandum system for investigating human arm movement. He was an adjunct lecturer at Waseda University (1995–2001) and adjunct associate professor (2000–2003) and adjunct professor (2003–2004) at Tokyo Institute of Technology. He was also involved in the CREST (1996–2003, 2010–2015) and ERATO (2005–2010) projects of Japan Science and Technology Agency, and the Correspondence and Fusion of Artificial Intelligence and Brain Science Project (2016–2020). He served as a committee member of the neuro-computing technical group of the Institute of Electronics, Information and Communication Engineers (IEICE) (1997–2000), its vice chair (2006), and chair (2007), committee member of the Japanese Neural Network Society (JNNS) (2012–2018, 2020–2024), president of JNNS (2021–2023), and chair of the Brain and Mind Mechanism workshop (2015–2020). His current research interests include the computational and neural mechanisms of implicit human sensorimotor control and interaction among sensory, motor, and perception, and the development of tactile interfaces. He is an IEICE fellow and member of the Society for Neuroscience, the Society for the Neural Control of Movement, the Japan Neuroscience Society, Japanese Neural Network Society, and the Society of Instrument and Control Engineers.

Applied Neuroscience Technology toward Mind-to-mind Communication by Visualizing the State of the Brain to Deepen Mutual Understanding between People

Shinya Shimizu
Distinguished Researcher, NTT Human Informatics Laboratories

Abstract

In traditional communication based on linguistic expression, it has been difficult to convey information to the other party with 100% accuracy due to small misunderstandings (miscommunications) or failure to establish a conversation (discommunication). There have been efforts in recent years to convey information accurately and deepen mutual understanding by transmitting brain information directly to the other party without the use of language. We can expect progress in this research field to create a world in which facial expressions can be generated for people with amyotrophic lateral sclerosis (ALS) by measuring their brain waves or where anyone can enjoy the amazing features of generative artificial intelligence (AI) by accurately conveying one's intent to a generative AI system. In this interview, we talked with NTT Distinguished Researcher Shinya Shimizu to learn about his research in the area of applied neuroscience technology toward mind-to-mind communication.

Keywords: mind-to-mind communication, neuroscience, brain-representation visualization technology

Achieving mind-to-mind communication by visualizing brain waves and conveying accurate information

—Dr. Shimizu, what exactly is "applied neuroscience technology toward mind-to-mind communication?"

"Applied neuroscience technology toward mind-to-mind communication" that I am now researching is a technology that aims to establish communication in which information that one person wants to convey to another person is conveyed with 100% accuracy by using knowledge and technologies in neuroscience. In traditional communication using language, information cannot be conveyed to another person with 100% accuracy due to small misunderstandings (miscommunications) or failure to establish a conversation (discommunication). For example, if a person was to say "Please, something a bit more classy," the image arising in the other person's head by the word "classy" depends on the person, which makes it easy for a communication mix-up to occur. To solve this traditional problem, I began research on achieving mind-to-mind communication that can convey information with greater accuracy by visualizing the state of the brain using knowledge from neuroscience. I believe that conveying information to another person with greater accuracy through mind-to-mind communication can lead to new solutions, facilitate consensus building, and maximize the degree of satisfaction with the communication results among the parties concerned.

To give some background to this research, modern society places importance on respecting the various ways of thinking that people have and understanding diversity. Here, the first step in recognizing such diversity is to ask oneself "how do other people think." I believe that doing so will enable more accurate understanding of another person's way of thinking, which, in turn, should lead to the creation of new things and new value. By the way, the period in which I began this research coincided with the COVID-19 pandemic when the opportunities for remote communication were plentiful. In everyday communication, it is possible to communicate in a way that includes the atmosphere of the place where you and your conversation partner are present. This is not possible with remote communication, so solving this problem was one short-term goal that I set.

As my ultimate goal, I am carrying out my daily research with the aim of making mind-to-mind communication part of a new communication tool that transcends the telephone, mail, chat, and other traditional means of communication. In short, my goal is to achieve technology that will enable people to understand each other's sensibilities and the way that others feel and perceive things in a more accurate manner to promote mutual understanding.

—What specific approach do you take in conducting your research?

As a specific research approach to achieving mind-to-mind communication, I constructed "brain-representation visualization technology" for perceiving brain expressions in real time through multidimensional representation. With this technology, we can display geometrical figures based on the state of brain waves during communication making it possible for a person to not only understand the inner state of another person with greater accuracy but to also grasp one's own emotional state. In my current research, I have succeeded in transmitting a portion of a person's inner state that up to now could not have been done by extracting only distinctive features from "brain expressions" inferred from brain waves in several hundred dimensions and representing them as low-dimensional information.

Since brain waves arise due to neuron activity in the brain, I hold the hypothesis that "a neuron group should behave with a characteristic pattern according to what that person is currently thinking or feeling." In my present stage of research, I am undertaking brain-wave measurements under a variety of conditions based on this hypothesis. As a measurement method, I am studying brain-wave measurement using a consumer-oriented electroencephalograph (EEG) based on my personal idea of "wanting to disseminate technology throughout society." Here, however, I am struggling with the problem that collecting reliable data is difficult due to the noise carried by sources other than brain waves. On the other hand, while EEGs for research applications can be used to collect basic data, this requires the application of gel and electrolytic solution between electrodes and the scalp when measuring brain waves to suppress electrical resistance, so considerable labor and time is needed to collect data in this way.

In addition, human emotions are complex. They can be subdivided into an endless number of emotions with fine gradations making it impossible to express them in only easy-to-understand categories like "happy" or "sad." I have therefore concentrated on human "discomfort." This is because I thought that understanding "discomfort" in a variety of scenarios—such as "Did the other person understand me completely?" "Am I stuck on something in my mind?" or "Is this a new discovery?"—could be useful in communication.

As one research result, I discovered that brain waves that indicate N400 and N600 negative potential fluctuations (event-related potentials) occur as a brain response when one's own way of thinking disagrees with a proposal given by another person. Moreover, in the case of accepting a proposal despite the fact that it is not consistent with one's own way of thinking, I found that this event-related potential is smaller than that when not accepting the proposal. Research on brain response to such "discomfort" has existed in the past, but that research targeted responses to text such as "the earth is square" or "the color of sunflowers is blue" that would make anyone feel uncomfortable. With this in mind, my present goal in research is to deepen my knowledge while discovering new responses by investigating "whether an uncomfortable response the same as found in prior research would occur when ways of thinking differ between people" and "what kind of response would actually occur if different from that of prior research."

The initial plan when first launching this research was to extend communication without targeting any specific person. However, as studies progressed, I wondered whether reading the brain waves of amyotrophic lateral sclerosis (ALS) patients could generate facial expressions for conveying their emotions to other people. The jumping-off point for my research here occurred amid much research and development of a brain-machine interface (BMI) that transmits thoughts for inputting text or selecting a command. It was at that time that I wondered whether emotions could be expressed as an aid to transmitting thoughts. Then, as times changed, the remarkable progress in generative artificial intelligence (AI) functions that could generate images of facial expressions provided a strong tailwind to my research. Against this background, the catalyst for initiating my research was the idea that "if information on the kind of facial expression that is being attempted could be read from brain waves, couldn't generative AI interpret that information and generate human facial expressions?"

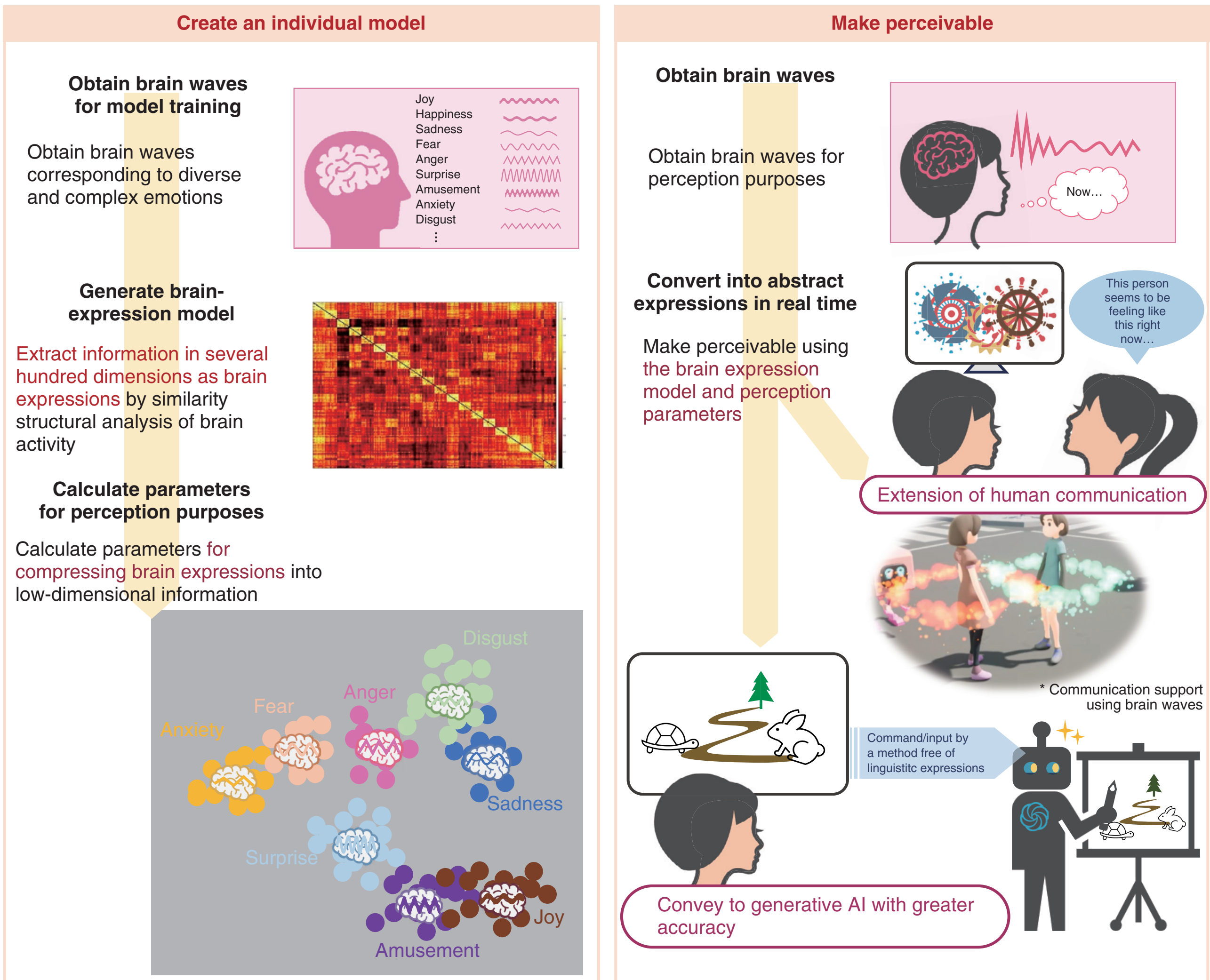
In the end, this research also became a study of technology that could be useful in communicating with generative AI. Although generative AI is a powerful tool, it is essential that the user correctly convey his or her intention. Generative AI requires that a command or instruction be conveyed to AI in linguistic form, but what is actually conveyed may differ from one's original intent. This is a problem that occurs frequently. I therefore would like to use "brain-representation visualization technology" to achieve a world in which conveying brain waves directly to AI will enable everyone to enjoy the benefits of AI regardless of language ability (**Fig. 1**).

Becoming a researcher who can proudly tell people about one's own technology

—Please tell us about your research vision going forward.

My research theme is "digitalizing humans by modeling brain information and its processing process," which is fundamental research for creating digital twins as part of the Innovative Optical and Wireless Network (IOWN) vision put forward by NTT. It is predicted that research on determining the inner state of a person will span a long period of time due to many unknown areas and an abundance of issues. Going forward, I would like to make progress in achieving our major goal of digitalizing humans to enable human information processing by clarifying and modeling brain mechanisms based on neuroscience while investigating engineering methods based on the knowledge gained in that process. If the human brain can be expressed as digital information, it should be possible to not only increase our understanding of the brain but to also use digital models to simulate things about humans that could not be understood in the past since there was never any attempt to do so. For example, it would be possible to determine beforehand "whether work could be made more efficient by forming a team with a certain combination of people and assigning certain roles to each of them." The field of neuroscience is still developing, and I myself do not yet see a specific path toward the above objective, so I would like to make more progress from here on.

In addition to the above, I would like to research technology that could guide the state of the brain from the outside. The way that things are perceived not only differs from person to person but also changes greatly according to one's current state. For example, the world may look bright when one is in good health. So my approach here is to search out a method for guiding the state of the brain not by directly stimulating and controlling the brain but by clarifying the mechanism of human sensibility using neuroscience and to use that mechanism to transform the way



* https://group.ntt/en/newsrelease/2023/02/01/230201a.html

Fig. 1. Overview of brain-expression modeling and perception.

in which a person perceives things.

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

Yes, of course. The reason why I chose NTT originated in thoughts like "I wanted to develop services that could actually be used in the world" and "I wanted to disseminate in the world services that I could proudly say were technologies that I myself created." Actually, the origin of these feelings was that I wanted to tell my parents, who were not very familiar with research, about technologies that I created. Now, however, I would like to tell my children when they get older and any future children about my research. This all comes out of a feeling of wanting to proudly tell people about my work and to create technology that can touch all sorts of people in the real world. This view of mine is largely unchanged today.

In the beginning, my research was closer to "applied" in terms of "basic" and "applied" research. So today, it's extremely interesting as a researcher to wonder whether I can achieve something new by combining the various forms of knowledge that I possess. In the field of neuroscience, I think that there are areas in which I cannot keep up with scientists who have been conducting basic research in this field for many years, even with much study. On the other hand, there are few researchers that have a varied background like mine, so there are pleasurable moments in which I can use my experiences in finding ways of using knowledge gained from fields that I've been involved in such as media and signal/image processing.

At the same time, basic research in the field of neuroscience that I am currently engaged in is still far from mature, so while there are things that I certainly want to achieve, there are many things that I cannot due to a lack of knowledge. At present, I am fortunate to be in an environment at NTT in which basic research can be pursued over the long term, so I feel that I can pursue my research steadily and approach my goals over time. Moreover, in basic research, discovering something new that shakes up my intellectual curiosity can be a very interesting moment, and in applied research, receiving feedback from the real world can be very enjoyable, so an environment in which you can experience the blessings of being a researcher is precious.

Since neuroscience is not my original specialty, I make an effort to acquire basic knowledge about neuroscience by listening to lectures given by a variety of people and reading papers and publications. From here on, to be able to say proudly that this is my research, I would like to build up my research achievements from the "basics" that are all so important in research. If any of you reading this article are involved in technology, I would like to encourage you to undertake the research of technology that "you can tell people about without any sense of shame." In addition, I hope that you continue to have much faith in your research so that you can proudly say "This is correct!" or "This is a new discovery!"

■ Interviewee profile

Shinya Shimizu received his B.S. from the Undergraduate School of Informatics, Kyoto University in 2002. He received his M.S. from the Graduate School of Informatics, Kyoto University in 2004 and joined NTT Cyber Space Laboratories the same year. He has been engaged in the research and development of 3D video processing including free viewpoint video and light field displays. He has been participating in ISO/IEC JTC1/SC 29/WG 11 (MPEG) international standardization activities since 2007. He is a member of the ISO/IEC JTC1/SC 29 subcommittee in Japan and the SC 29/WG 11/Video subcommittee. He has received the IDW '19 Best Paper Award (coauthor), Contribution Award for Standardization from the Information Technology Standards Commission of Japan, Information Processing Society of Japan (IPSJ), and the Award for International Standardization Contributor (Industrial Science and Technology Policy and Environment Bureau Director-General's Award), Ministry of Economy, Trade and Industry (METI) among other awards. He holds a Ph.D. in Engineering and has been an NTT Distinguished Researcher since 2020.

On Publishing Feature Articles on International Standardization Trends

Hiroshi Yamamoto, Jiro Nagao, and Kota Kodai

Abstract

As a means of introducing Feature Articles on International Standardization Trends in this issue, this article describes the historical background and economic benefits of international standardization. Since January 2023, Mr. Seizo Onoe has been Director of the Telecommunication Standardization Bureau of the International Telecommunication Union (ITU). The Ministerial Declaration of the G7 Digital and Tech Ministers' Meeting calls for cooperation in international standardization. This resulted in interest in international standardization in Japan reaching an unprecedented level. Accordingly, this article also introduces recent trends surrounding international standardization and provides an overview of the NTT Group's efforts in this area.

Keywords: international standardization, ITU, standardization office

1. Need for and significance of international standardization

1.1 Need for international standardization

Vital prerequisites for the success of services in the information and communication field are that the devices needed for these services must be interconnected and operate as designed. This means that the interfaces between terminals, networks, and network operators must be specified. Since information and communication involves a wide range of technologies, it is practically impossible for a single company to provide all the technologies and devices. Thus, it is essential, for example, to standardize physical interfaces and signal conversion protocols. Long time ago, international standardization in the information and communication field was promoted to provide telegraph and telephone services across national borders. Therefore, standardization topics were centered around interface specifications, numbering, and settlement of accounts for international telecommunication services. However, today, the scope of the study for standardization is broadening to include environmental and climate change countermeasures, multimedia, and security. As a reference, the issues studied in the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), the United Nations specialized agency in charge of international standardization in the telecommunications field, are listed in **Table 1**.

As information and communication services become more advanced and complex, the need for international standardization has become ever more pressing. To spread and deploy the Innovative Optical and Wireless Network (IOWN), a concept the NTT Group seeks to implement, international standardization activities will also play a pivotal role.

1.2 Economic benefits of international standardization

One of the benefits of international standardization that first comes to mind may be better interconnectivity, but there are many other benefits: (1) the specification of device interfaces is expected to boost competition among device suppliers, resulting in improved quality and lower prices; (2) the incorporation of standardized technology in many products will boost the expected profits from and efficiency of research and development (R&D); and (3) standardization will establish criteria for quality and safety and contribute to the establishment of a fair competitive environment.

Table 1. ITU-T Study Groups (study period 2022–2024).

Study Group	Study Group title
SG2	Operational aspects of service provision and telecommunication management
SG3	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
SG5	EMF, environment, climate action, sustainable digitalization, and circular economy
SG9	Broadband cable and TV
SG11	Signalling requirements, protocols, test specifications and combating counterfeit telecommunication/ICT devices
SG12	Performance, quality of service (QoS) and quality of experience (QoE)
SG13	Future networks and emerging network technologies
SG15	Networks, technologies and infrastructures for transport, access and home
SG16	Multimedia and related digital technologies
SG17	Security
SG20	Internet of things (IoT) and smart cities and communities (SC&C)

EMF: electromagnetic field
ICT: information and communication technology
TV: television

Table 2. Analyses of economic impact of international standardization.

Countries	Publication year	Data gathering period	Economic impact	Sources
Germany	2000	1960–1996	Increased GDP by 27%	K. Blind, A. Jungmittag, and A. Mangelsdorf, "The Economic Benefits of Standardization: An update on the study carried out by DIN in 2000," DIN German Institute for Standardization, 2011.
Australia	2006	1962–2003	Increased GDP by 22%	Centre for International Economics Canberra & Sydney, "Standards, Innovation and the Australian Economy," 2006.
France	2008	1950–2007	Improved GDP by 24%	H. Miotti, "The Economic Impact of Standardization: Technological Change, Standards Growth in France," AFNOR Group, 2009.
United Kingdom	2015	1921–2013	Increased GDP by 28%	O. Hogan, C. Sheehy, and R. Joyasuriya, "The Economic Contribution of Standards to the UK Economy," Centre for Economics and Business Research (CEBR) and British Standards Institution, 2015.
Norway	2018	1976–2014	Increased GDP by 28%	Menon Economics, "The Influence of Standards on the Nordic Economies," Menon-Publication, No. 31, 2018.
Belgium	2020	1994–2018	Increased GDP by 19%	C. Buts, M. Dooms, F. Soyeur, E. V. Droogenbroeck, and K. Willems, "The Impact of Standards on the Belgian Economy," Bureau de Normalisation (NBN), 2020.
Canada	2020	1981–2019	Increased GDP by 17.4% Increased labor productivity by 17.4%	D. Liao, "Every Standard Counts – How Standardization Boosts the Canadian Economy," Ottawa: Standards Council of Canada, 2021.

While it is difficult to quantify the economic benefits of international standardization, by way of example, some estimates from other countries are listed in **Table 2**. These should give the reader some idea of just how huge the economic benefits generated through international standardization are.

1.3 WTO agreements

With a view to maintaining free and fair trade, the World Trade Organization (WTO) put into effect in 1995 the Agreement on Technical Barriers to Trade (TBT Agreement). The agreement obliges member countries to harmonize their mandatory or voluntary standards and conformity assessment procedures with international standards [1]. With the de jure standard defined by ITU and other bodies in mind, WTO also stipulates the Agreement on Government Procurement (GPA), which requires that technical specifications for the performance of goods procured by governments and their related organizations must be based on international standards, if such standards already exist.

GPA applies not only to central and local government agencies, but also to their affiliated organizations.

NTT (the holding company), NTT EAST, and NTT WEST are listed as applicable organizations in the Annex of the agreement. Therefore, should these three companies procure telecommunications devices that do not conform to international standards, they would risk being accused of violating the WTO agreement. A case in point, although not one involving the NTT Group, is a complaint filed with the WTO's relevant committee against East Japan Railway Company for violating the above agreement when the company announced the adoption of the Felica e-money system, which was not a de jure standard at the time [2].

While international standardization brings economic benefits, it is also attended by the risk of violating WTO agreements. It is therefore more important than ever to involve ourselves in standardization.

2. Trends surrounding international standardization

2.1 Standardization organizations

Standardization organizations can be classified into the following three categories in accordance with their formation, standard development process, and their effective regions.

(1) De jure standard organizations: These organizations produce standards in accordance with a formal and clearly stated process. In principle, these standards have their effect across the whole world. According to a WTO agreement, only three organizations fall into this category: ITU, the International Electrotechnical Commission (IEC), and the International Organization for Standardization (ISO).

(2) Fora: These organizations are formed by companies interested in a specific field. Although compliance with their standards is limited to the members of each forum, the limited number of participants expedites the development of standards with an appropriate granularity. Typical examples include the 3rd Generation Partnership Project (3GPP) and the Institute of Electrical and Electronics Engineers (IEEE).

(3) Regional and national standardization organizations: These organizations produce standards that are applicable only within a specific region or country. They are also used to coordinate policy proposals from each region to de jure standard organizations such as ITU. Representative examples include the European Telecommunications Standards Institute (ETSI), the Asia-Pacific Telecommunity (APT), and national standards organizations in Japan, such as the Telecommunication Technology Committee (TTC) and the Association of Radio Industries and Businesses (ARIB).

Each of the three types of standardization organizations has its strengths and weaknesses. Therefore, it is important to maintain a balance among the activities of the three types and coordinate these activities as necessary. A well-known example of working with each of them is to use a forum, which works relatively fast, to establish forum standards then submit them to a de jure standard organization to establish de jure standards. To use this process, it is vitally important to have an accurate understanding of each organization's situation and establish and maintain channels for collaboration with each of them.

2.2 Ministerial Declaration of the G7 Digital and Tech Ministers' Meeting

At the G7 Digital and Tech Ministers' Meeting held in Takasaki, Gunma Prefecture in April 2023, discussions were held on safe and resilient digital infrastructure, and recommendations for international standardization were presented in the outcome document [3]. Some of the recommendations are introduced below.

- Annex 2: In addition to these efforts to improve security and resilience of current digital infrastructure, we note the importance of sharing a vision of the next-generation network in the Beyond fifth-generation mobile communication system (5G)/6G era, and endorse the G7 Vision for future networks in the Beyond 5G/6G era. We are committed to enhancing cooperation on research, development, and international standards setting, toward building digital infrastructure for the 2030s and beyond.
- Annex 3: We endorse the G7 Action Plan for Building a Secure and Resilient Digital Infrastructure that outlines the above efforts to build a secure and resilient digital infrastructure. In supporting such infrastructure in developing countries, we seek to cooperate with international organizations and development agencies such as the World Bank and ITU.

The G7 ministers' meeting recognized the importance of international standardization and presented a policy on future cooperation.

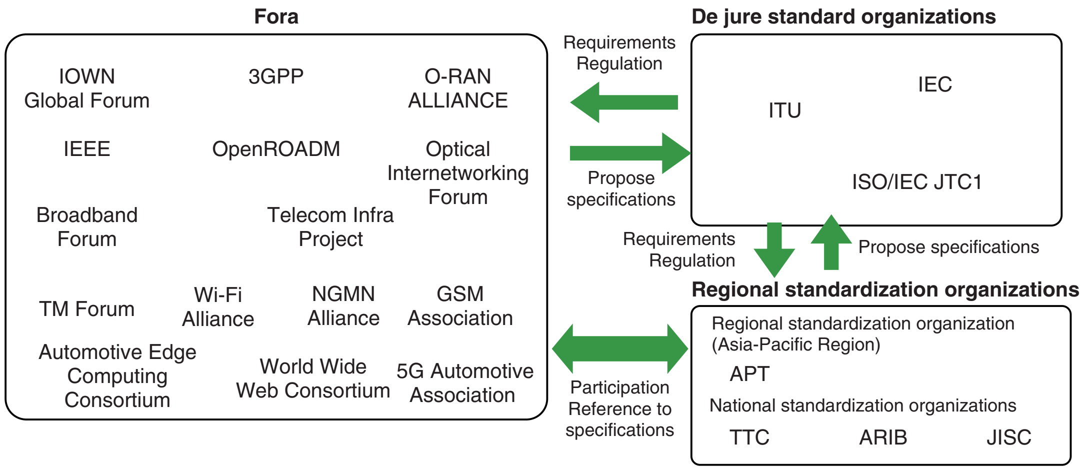


Fig. 1. Major international standardization organizations in which the NTT Group participates.

2.3 NTT Group's efforts

As shown in **Fig. 1**, the main standardization organizations which the NTT Group participates in or is associated with are classified into one of the above organization categories of de jure, forum, and regional/national.

In de jure standard organizations, especially in ITU, we pursue a wide range of activities in fixed-line and wireless networks, environment and operations, and applications and services.

Regarding regional standardization organizations, we use APT, the world's largest body of this kind, to compile proposals from the Asia-Pacific region and submit them to ITU. Within Japan, we are working on national standardization (downstream) of ITU standards at national standardization organizations such as the TTC (see TTC President's message at the end of this article) and ARIB.

For the fora, we have been particularly active in the IOWN Global Forum, of which NTT is one of the founding members, and 3GPP, which formulates and oversees mobile technology standards.

Going forward, with a view to making IOWN and a 6G world a reality, we will enhance our activities within each organization and strengthen standardization efforts across the NTT Group to facilitate collaboration among standardization organizations.

3. On publishing the Feature Articles

Major events surrounding Japan's international standardization activities have occurred recently. Mr. Seizo Onoe, who has served as chief technology officer at NTT DOCOMO and chief standardization strategy officer at NTT (the holding company), was appointed as the head of ITU-T (Director of the Telecommunication Standardization Bureau (TSB)) in January 2023 (see TSB Director's message at the end of this article). The Ministerial Declaration of the G7 Digital and Tech Ministers' Meeting calls for a cooperative framework for international standardization. These events are generating greater momentum to advance international standardization activities in Japan and raise it to an unprecedented level. To further strengthen the NTT Group's international competitiveness, NTT is reinforcing the Standardization Office and the collaborative system across the NTT Group.

To provide a broad overview of the NTT Group's international standardization activities and their current status, we included in this issue the following articles on international standardization trends concerning technologies related to fixed-line networks "Standardization Trends in Technologies Related to Fixed-line Networks" [4], those related to wireless networks "Standardization Trends Related to Wireless Communications" [5], those related to environment and operations "Standardization Trends Related to Environmental and Operations Technologies" [6], and those related to applications and services "Standardization Trends Related to Application- and Service-related Technologies" [7]. These articles are authored by those who work at the forefront of international standardization. We hope they will help deepen readers' understanding and interest in international standardization.

Bringing True Value to the World by International Standardization

Seizo Onoe
Director, Telecommunication Standardization Bureau, International Telecommunication Union (ITU)

It has already been eight months since I assumed the post of Director of the Telecommunication Standardization Bureau of ITU in January 2023. I would like to express my deep appreciation for the support of everyone, including the Japanese government and the NTT Group, during the election campaign.

There are many standardization bodies that work on information and communication technologies (ICTs), and it is becoming increasingly important for them to work together in a way that leverages their respective strengths. ITU's greatest strength is its global reach, including into developing countries, and we intend to play our role with the awareness of this strength kept uppermost in our mind.

Through its standardization work, ITU-T will contribute to ITU's strategic goals: (1) universal meaningful connectivity and (2) sustainable digital transformation.

Standardization brings real value only when the technical standards are widely adopted. The dissemination of technical standards around the world expands the market, which in turn activates the principle of competition and works to lower costs and prices. This leads to a virtuous cycle of further dissemination of standards and brings us closer to the provision of affordable services. The role of the industry in implementing and deploying technical standards is significant. It is my sincere hope that NTT and other organizations in the private sector will continue to develop implementable standards through ITU and promote the dissemination of technical standards, thus support ITU's activities in bringing value to the lives of people and society worldwide as well as enabling companies to prosper.

TTC's Activities and Contributions to Standardization Activities

Hideyuki Iwata
President, Director-General,
The Telecommunication Technology Committee (TTC)

The international rule-making sector for the information and telecommunication field is becoming increasingly diverse as issues and subjects to be handled grow in scope. The sector now encompasses standardization organizations, such as ITU, as well as industrial associations, such as forums and consortiums, and open source communities.

To fulfill its role under these circumstances as a standardization organization for domestic discussions, the TTC has strengthened its efforts in the Inter-Industry Innovation Working Party to support cross-technical field and cross-industry activities, in addition to the activities of its existing technical committees that correspond to the organization of ITU-T. This working party provides an environment in which companies and organizations can collaborate to discuss, examine, research, develop, and demonstrate new initiatives.

In addition to collaborating with domestic and international standardization organizations, we also cooperate in various ways with organizations in related industries, such as the automotive, medical, and agricultural industries. As an initiative to address social issues, we have been promoting and disseminating ICT utilization and standardization in Southeast Asia for more than 10 years. Our activities in this area have been facilitated by the relationships of trust we have built up with government agencies and other organizations in each country.

Finally, while the TTC has continued to work on human resource development, considering social changes and the urgent need to respond to them, we have established a new time-limited advisory group focusing on human resource development to study what specific measures need to be taken.

The TTC will also contribute to serving as a standardization organization for domestic discussion, collaboration, and human resource development during the process in which ICTs originating in Japan, including IOWN, are used and discussed to formulate international rules in various industries.

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Hiroshi Yamamoto

Director, Standardization Office, Research and Development Planning Department, Research and Development Market Strategy Division, NTT Corporation.

He received a B.S. and M.S. in information and computer science from Waseda University, Tokyo, in 1999 and 2001. In 2001, he joined NTT Service Integration Laboratories, where he was engaged in the performance evaluation of Internet protocol (IP) networks, web applications, and video delivery. In 2006, he joined NTT Communications, where he engaged in the development of voice-over-IP systems. In 2010, he joined NTT Network Technology Laboratories, where he engaged in research and development of a quality-of-experience control video-delivery mechanism. In 2015, he was assigned as the primary USA liaison based in Washington, D.C. and was engaged in enhancing collaborations with US academia and industry. In 2020, he was assigned as a senior research engineer, supervisor at NTT Network Technology Labs and engaged in the research and development of future network architecture. He is currently the head of Standardization Office and oversees the NTT Group's standardization activities. He is currently the chair of the Asia-Pacific Telecommunity (APT) Preparatory Group for WTSA-24 Working Group 1 (Working Methods).

Jiro Nagao

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

He received a Ph.D. in information science from Nagoya University, Aichi, in 2007 and joined NTT the same year. From 2007 to 2011, he was engaged in research and development of image-processing and content-distribution technology. From 2012 to 2017, he worked for NTT Communications, serving as the technical leader of commercial video-streaming services. From 2017 to 2021, he was engaged in research and development of immersive media and presentation technology at NTT Service Evolution Laboratories. Since 2022, his mission has been promoting standardization activities for global deployment of NTT R&D technologies and services at Standardization Office, R&D Planning Department, NTT Corp. He is currently an associate rapporteur of ITU-T Study Group 16 Question 8 (Immersive Live Experience since 2022).

Kota Kodai

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He received a Bachelor of engineering in civil engineering in 2005, and Master of Informatics in social informatics in 2007 from Kyoto University. He joined NTT DOCOMO in 2007 and engaged in mobile network deployment. In August 2023, he transferred to NTT. He is currently engaged in supporting the NTT Group's standardization activities.

Standardization Trends in Technologies Related to Fixed-line Networks

Kota Asaka, Hiroshi Ou, Chihiro Kito, Ryo Koma, Ryo Koyama, Yoshihiro Kondo, Taiji Sakamoto, and Yoshiaki Sone

Abstract

Confronted by the development of various services, such as cloud computing, fifth-generation mobile communications, telemedicine, and high-definition video transmission, as well as the increase in fixed-line network traffic, international standardization organizations and forums have been expanding the specifications of fixed-line transmission networks and optical components and ensuring interoperability. This article provides examples of NTT's activities in the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), International Electrotechnical Commission (IEC), Broadband Forum (BBF), and OpenROADM Multi-Source Agreement.

Keywords: fixed-line network, optical fiber, optical connector

1. Overview of international standardization of technologies related to fixed-line networks

The International Telecommunication Union (ITU) is a United Nations (UN) agency and an international standardization organization consisting of UN member states and regions. The ITU Telecommunication Standardization Sector (ITU-T) is a division of ITU. Its work is divided into 11 Study Groups (SGs), each of which focuses on a particular issue or topic. Among them, SG15 (Transport, access & home) is responsible for several technical areas (Questions) related to transmission networks, which are the foundation of telecommunications [1]. This article introduces the international standardization trends in transmission networks and optical component technologies in SG15, including NTT's involvement in SG15, as well as the activities of a related international standardization organization, the International Electrotechnical Commission (IEC), and related forums, Broadband Forum (BBF) and OpenROADM Multi-Source Agreement (MSA).

2. Trends in transmission network technology

This section outlines the standardization trends in access, home, metro, and core networks.

International standardization of access networks, which are used to provide fiber to the home (FTTH) services, are carried out by ITU-T SG15 Question 2 and the Institute of Electrical and Electronics Engineers (IEEE). FTTH uses a passive optical network (PON) system, which connects an optical line terminal (OLT) located in a telecommunication central office to optical network units (ONUs) located in each user's home via an optical splitter. Time division multiple access (TDMA)-based PON systems, in which ONUs communicate with an OLT using different time slots, are widely used in Japan, and telecommunication operators have begun to provide 10-Gbit/s-class FTTH services. In 2020, the IEEE 802.3ca Task Force standardized the 25-Gb/s Ethernet Passive

Optical Networks (25G-EPON) and 50-Gb/s Ethernet Passive Optical Networks (50G-EPON), which can provide communication services at a maximum transmission rate of respectively 25 and 50 Gbit/s for both uplink and downlink. The 50G-EPON is based on wavelength division multiplexing (WDM) in addition to TDMA and combines two wavelengths, each carrying 25-Gbit/s signals, to achieve a transmission rate of 50 Gbit/s.

As part of its work on Question 2, ITU-T SG15 standardized the 50-Gigabit-capable Passive Optical Networks (50G-PON) in 2021. The 50G-PON is based on a conventional configuration, i.e., using a single wavelength to provide a transmission rate of 50 Gbit/s. SG15 is also developing specifications for a configuration based on time and WDM (TWDM), which allows time slots and wavelengths to be flexibly assigned to each user. NTT's contributions to these efforts include the proposal of a frame structure that assumes an expansion of preamble due to the application of digital signal processing (DSP) and a cost analysis of TWDM-based structure. Furthermore, SG15 is studying a supplemental document that summarizes service requirements and elemental technologies needed for the development of G.VHSP (very high speed PON), which will provide bandwidths in excess of 50 Gbit/s per wavelength, to reach agreement in July 2024. NTT, as a telecommunications carrier, will continue to propose service and technical requirements and lead the discussions.

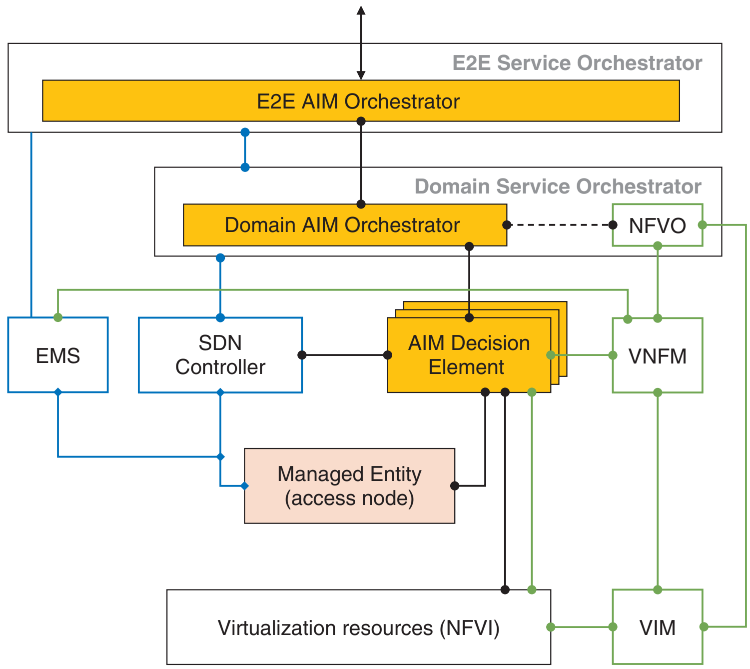
In relation to home networks, SG15 is standardizing, as part of Question 3, optical wireless transceivers that use visible light in addition to wire-line based transceivers that use telephone lines, power lines, coaxial lines, and optical fibers. It is developing standards for transmission technology and overall home network architecture to provide broadband services in the home and other premises, including smart grid applications such as smart meters. SG15 has revised G.9964 to include a new orthogonal frequency-division multiplexing (OFDM) parameter, which reduces subcarrier spacing to improve transmission efficiency in environments where only narrow bandwidths are available for power-line communications. These specifications were proposed by European electric power companies for smart grid applications. At the same time, SG15 standardized the narrowband OFDM power-line communication specifications proposed by another European power company, as G.9901 and G.9903. Systems based on these specifications are already in practical use in Europe. With a view to enabling next-generation optical communications capable of a transmission rate of over 10 Gbit/s by developing a recommendation, G.vlc (visual light communications), SG15 is working on a method of expanding bandwidth by increasing the number of subcarriers as well as use cases and requirements for the standardization of new technologies such as narrow beam optical wireless communication (OWC) transceivers. It has completed the standardization of the system architecture for high-speed indoor transceivers for fiber to the room (FTTR) and continues to discuss the physical, data-link, and control/management layers. During these discussions, SG15 is considering comparisons and interoperability with PON technology in access networks, extensions to the ONU Management and Control Interface (OMCI) protocol based on the transmission quality from the access network to the terminal (Wi-Fi, etc.), and overall architecture for operations and management.

Management and control technologies for access networks are being standardized by BBF, which is a global forum intended to promote broadband services and develop system management and control protocol specifications, and interconnection specifications. In recent years, BBF has also been developing specifications for access systems that incorporate virtualization technologies, such as software-defined networks (SDN) and network function virtualization (NFV), as well as specifications for automated management and control. The following describes BBF-specified Automated Intelligent Management (AIM) for automated management and control of access networks.

AIM was specified as TR (Technical Report)-436 "Access & Home Network O&M Automation/Intelligence" [2], where O&M is Operation and Maintenance. **Figure 1** shows the framework of AIM, which collects the status and information of the target nodes (managed entities) to be managed and controlled, analyzes the appropriate settings, on the basis of its changes, in accordance with a predefined policy, and automatically controls the target nodes. The main functional elements needed to achieve AIM are as follows:

(1) AIM Decision Element (DE): Collects status and information of managed entities and analyzes it on the basis of a predefined policy.
(2) End-to-End (E2E) AIM Orchestrator and Domain AIM Orchestrator: Sets the analysis policy specified by the carrier in the AIM DE.

The AIM DE is implemented on a virtual resource. The analysis results (new settings) are applied to the target managed entities via the SDN controller. This



EMS: Equipment Management System
NFVI: Network Function Virtualization Infrastructure
NFVO: Network Function Virtualization Orchestrator
VIM: Virtualized Infrastructure Manager
VNFM: Virtualized Network Function Manager

Fig. 1. AIM framework [2].

technology is expected to enable automatic execution of the management and control of access networks such as detection of a fault in an access node and establishment of an alternative path. TR-436 defines the architecture and functional requirements for AIM. BBF is currently studying interface requirements for AIM and extensions to AIM. To support the extensions to AIM, NTT is proposing real-time automatic management control across multiple domains such as optical access networks and wireless access networks.

In the area of optical WDM in metro and core networks, the OpenROADM MSA is defining interconnection specifications for open and flexible reconfigurable optical add/drop multiplexer (ROADM) networks. The OpenROADM MSA was launched in 2016. As of August 2023, it has 31 member companies: 16 carriers and 15 optical equipment manufacturers. The aim of the OpenROADM MSA is to achieve open and flexible networks by specifying open standard interfaces, enabling carriers to avoid a lock-in to a specific vendor due to a vertically integrated system, which has been an issue in conventional carrier networks.

Figure 2 shows the network structure and interface definitions for a ROADM as envisioned in the OpenROADM MSA. The interconnection specifications being defined by the OpenROADM MSA consist of the specifications of optical transmission interfaces (physical layer) and the application programming interface (API) for controllers. The controller API is specified in a model-driven manner using the Yet Another Next Generation (YANG) model*1. The optical interface specification is available as a spreadsheet document on the OpenROADM website [3]. Regarding the API interface, the latest version of the YANG model is available on the OpenROADM's Open Git Hub [4]. Whitepapers providing guidelines for the implementations of API models are also available from the OpenROADM website.

In the physical layer, the OpenROADM MSA assumes functional blocks, such as ROADM, X-ponders (transponder, muxponder, and switch-ponder),

*1 YANG model: A network configuration and state modeling language used in equipment control protocols, such as Netconf.

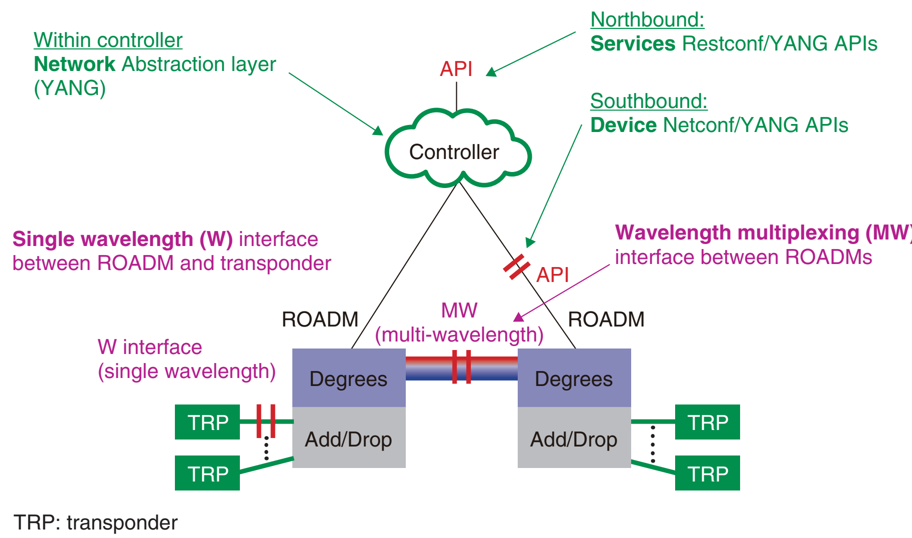


Fig. 2. Open interfaces being specified in the OpenROADM MSA.

Table 1. Optical interface specifications specified by the OpenROADM MSA (100 to 400 Gbit/s).

Specification	Modulation method	Baud rate [Gbaud]	FEC	rOSNR [dB]
100G	QPSK	28.0	SC-FEC	17
100G	QPSK	31.6	oFEC	12
200G	16QAM	31.6	oFEC	20.5
200G	QPSK	63.1	oFEC	17
300G	8QAM	63.1	oFEC	21
400G	16QAM	63.1	oFEC	24

QAM: quadrature amplitude modulation. A multi-level modulation scheme for optical transmission that enables multiple bit transmission with a single clock.
QPSK: quadrature phase shift keying. A multi-level modulation scheme for optical transmission that enables multiple-bit transmission with a single clock.
rOSNR: required optical signal-to-noise ratio. A measure of optical receiver performance in optical wavelength division multiplexing.
SC-FEC: Hard-decision error correction scheme specified in ITU-T G.709.

and in-line amplifier (ILA), and specifies interconnection interfaces between them. The connection of optical WDM transmission signals between a ROADM and ILA is specified as a multi-wavelength (MW) interface. The single-wavelength optical interface for the connection from an X-ponder to a ROADM Add/Drop is called a wavelength (W) interface. **Table 1** lists the W specifications (Optical specification ver. 5.1) that have been released. The OpenROADM MSA has established optical specifications that apply oFEC*2, a standardized soft-decision forward error correction (FEC). The supported interfaces use multiple modulation schemes to provide multiple rates in metro optical WDM transmission. According to an open panel discussion held by the OpenROADM MSA, the next-generation Beyond 400G specification is being actively examined.

The OpenROADM MSA has defined three models for the controller control API: service, network, and device. The service model responds to service requests from upper-layer operations systems. The network model converts physical-layer facility information into abstract information and manages the

*2 oFEC: A soft-decision error-correction scheme standardized by the OpenROADM MSA.

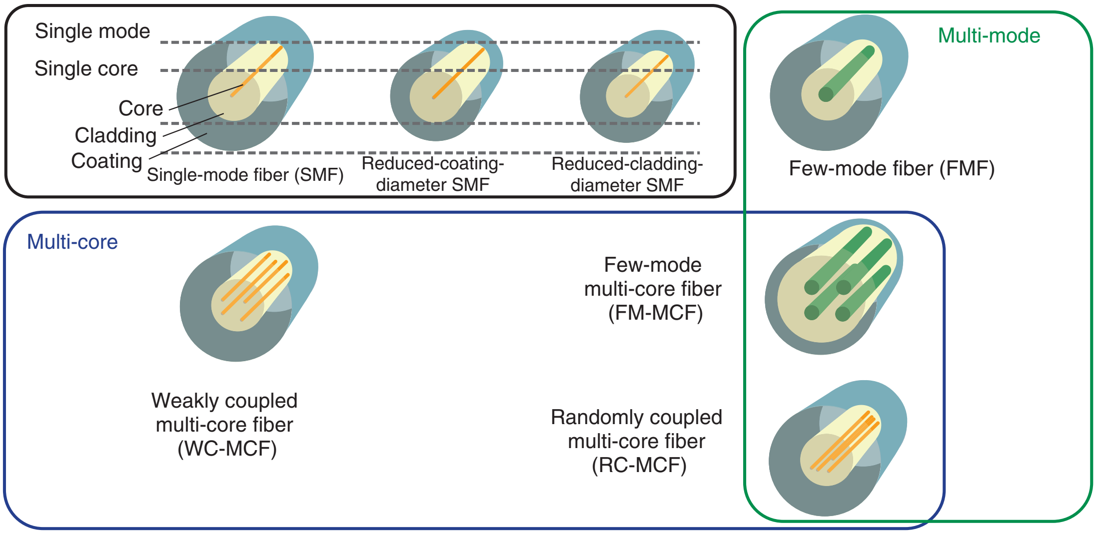


Fig. 3. Various SDM fibers.

latter as topology information. This allows devices to be replaced without affecting the upper layers. The device model is a template for managing device parameters. It helps enable plug-and-play functions of devices. The Ver. 7.1 of the YANG model can cover the operation of 400-Gbit/s systems in commercial networks. The model is being continuously improved. As of August 2023, the latest release is Ver. 13.1.

In its study of the All-Photonics Network (APN), the IOWN Global Forum (IOWN GF, where IOWN is the Innovative Optical and Wireless Network) has selected the specifications of the OpenROADM MSA as candidate specifications. At the same time, IOWN GF identified the functions that the OpenROADM should extend to satisfy the requirements of the APN. NTT is collaborating with other IOWN GF members to discuss extensions to the APN loopback function and remote transponder monitoring function. The device model for the loopback function was published as part of Ver. 13.0 in March 2023. NTT will continue standardization efforts to ensure harmonization between IOWN GF and OpenROADM MSA specifications.

In addition to the OpenROADM MSA, ITU-T SG15 is studying, in relation to several Questions, international standards for related technologies, such as optical WDM transmission, time division multiplexing transmission, packet transmission, and synchronous signal transmission for metro and core networks [1].

3. Trends in optical component technology

This section outlines the standardization trends for the operation and maintenance of optical fiber cables, optical submarine cable systems, and outdoor optical facilities.

The main standards for optical fiber cables consist of ITU-T recommendations produced by SG15 and IEC standards produced by IEC Subcommittee 86A (SC 86A: Fibres and cables). ITU-T recommendations help ensure interoperability and quality of service for telecommunications carriers, while IEC standards are widely recognized as de jure standards for the products that make up networks. One of the recent topics worthy of attention is that in its Question 5. SG15, which is in charge of ITU-T recommendations related to optical fibers, agreed on a technical report on space division multiplexing (SDM) optical fiber cables in September 2022 [5]. This technical report comprehensively describes the technical maturity of and issues with the SDM optical fibers shown in **Fig. 3**. It is expected to serve as a roadmap for the future international standardization and practical deployment of SDM optical fibers and is widely disseminated through ITU-News and technical flyers.

Optical cable technology has seen a shift from conventional optical fiber ribbons, in which multiple optical fibers are aligned and fixed as shown in **Fig. 4(a)**, to sparsely bonded optical fiber ribbons, in which fibers are partially bonded with an adhesive as shown in **Fig. 4(b)**. The latter has enhanced flexibility

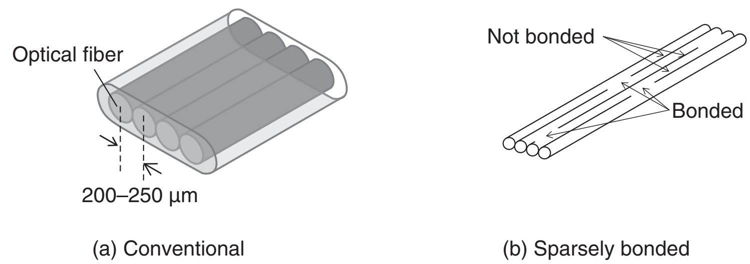


Fig. 4. Appearance of optical fiber ribbons.

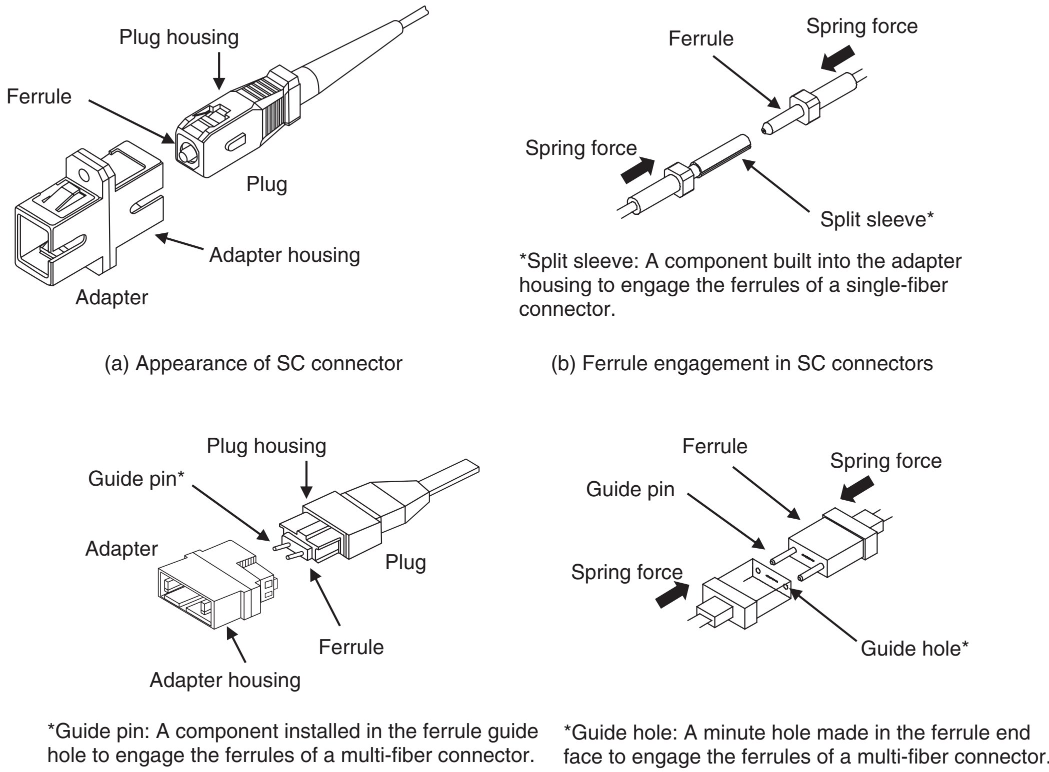
in the bending direction. It was proposed and put into practical use by NTT [6] and approved by an IEC standard (IEC 60794-1-31 Optical fibre cables - Part 1-31: Generic specification -), which was released in 2017. Having a simple cable structure, sparsely bonded fiber ribbons enable high-density cable installation similar to the installation of metallic cables [7].

A trend in submarine cables is a growing need to increase the number of fiber cores in cables to meet the demand for boosting the capacity of transcontinental communication systems. There have been intense studies on applying reduced-coating-diameter single-mode fiber (SMF) cables, the coating diameter of which is 200 µm (with 125 µm cladding) compared with 245 µm of the SMF cables that have been conventionally used for submarine long-distance transmission. To support the practical deployment of reduced-coating-diameter SMF cables, IEC is revising the related IEC standard (IEC 60793-2-50: Optical fibres - Part 2-50: Product specifications - Sectional specification for class B single-mode fibers). The revised document is scheduled to be published in fiscal year 2024. It is expected that optical fiber cable technology will see progress in the studies of high-density and high-capacity cables using SDM based on technologies for sparsely bonded fiber ribbons, multi-core fiber (MCF), and reduced coating diameter.

A joint task force involving the World Meteorological Organization (WMO) and United Nations Educational, Scientific and Cultural Organization (UNESCO) is studying the use of optical submarine cable systems for optical sensing, such as ocean monitoring and earthquake detection [8]. To achieve this, ITU-T SG15 Question 8 is working on two new ITU recommendations, one for submarine cable systems dedicated to sensing and the other for submarine cable systems used for both communications and sensing. The recommendations are expected to be approved in 2024. These sensing systems measure temperature, pressure, and acceleration and are expected to be used to detect earthquakes and tsunamis and collect information on climate change.

The maintenance and inspection of outside optical facilities had been left to each carrier's own operational scheme. However, with the widespread adoption of optical communications, it is growing in importance as a social infrastructure, resulting in a heightened interest in sustainable and efficient operation of outside optical facilities. ITU-T SG15 Question 7 agreed to systematically develop an international standard for the inspection of outside optical facilities based on an NTT's proposal. In 2020, Recommendation L.330 (Telecommunication infrastructure facility management) was approved, which defines 17 outside optical facilities to be inspected as well as the requirements for and flow of basic inspection tasks. This recommendation exhaustively presents guidelines on inspection frequency, inspection items, and the level of accuracy of measuring degrading events required at the time of precision inspection. In 2023, the revision of Recommendation L.340, which describes specific methods of inspection, related technologies, and safety issues for inspection work in underground telecommunication facilities, was completed. It is expected that the development of new recommendations and revision of existing recommendations will continue on issues related to the maintenance of aerial facilities and conduits attached to bridges.

In addition, ITU-T SG15 Question 7 is revising Recommendation L.250 (Optical access network topologies for broadband services) to define requirements for wiring topologies used to provide network services, including those other than FTTH, such as centralized radio access networks. Considering that a reliable access topology is indispensable to meet various network service requirements, SG15 is



(a) Appearance of SC connector

(b) Ferrule engagement in SC connectors

(c) Appearance of MPO connector

(d) Ferrule engagement in MPO connector

Fig. 5. SC and MPO connectors.

expected to incorporate a concatenated loop topology for optical access networks [9] in L.250 as an effective means of ensuring reliable redundant paths throughout the service area.

Optical connectors are used in a wide variety of applications, such as interfaces for optical communication devices, optical measuring instruments, and optical communication services in addition to connecting optical cables in optical transmission networks. Since it is necessary to make it easy for anyone to connect and disconnect optical connectors no matter who the manufacturers are, international standardization is essential to guarantee the compatibility of optical connectors. International standardization of optical connectors is mainly carried out by IEC SC 86B (Fibre optic interconnecting devices and passive components). As of August 2023, among the 187 committees in IEC, SC 86B boasted the largest number of published documents and was the fifth in terms of the number of working documents, indicating how intensively optical connectors are being standardized in response to the recent expansion of optical communications. NTT has been leading the world in commercial deployment of optical networks and developed and standardized many optical connectors required for this deployment. Among these connectors, the single-fiber coupling (SC) and multi-fiber push-on (MPO) connectors developed in 1986 and 1991, respectively, are particularly easy to handle and highly compatible, with the result that they are now the most widely used single-fiber and multi-fiber connectors in the world. In 2021, they received the IEEE Milestone Award, which is conferred on historical achievements that have made significant contributions to the development of society.

The main points of the standardization of optical connectors are described below based on the structures of SC and MPO connectors shown in **Fig. 5**. In optical communication systems, the optical loss and return loss[*3] that are allowed in optical connectors are specified. It is generally required that the optical loss be 0.5 dB or less and the return loss be 40 dB or more.

*3 Return loss: A measure of the weakness of the reflected light.

Table 2. Standards document system for optical connectors in IEC.

Document number	Document name	Number of documents	Main specification items
IEC 61755 series	SMF optical compatibility standard	15	Ferrule dimensions, fiber-core position, and Ferrule end-face shape
IEC 62367 series	MMF optical compatibility standard	3	
IEC 61754 series	Engagement standard	37	Housing dimensions, spring force
IEC 61753 series	Performance standard	5	Optical performance (loss, return loss, etc.), mechanical performance (bonding strength, etc.), and resistance to environment, etc.
IEC 61300 series	Testing procedures	84	Test procedures to verify compliance with each specification

The loss in optical connectors mainly depends on the core misalignment, so the core misalignment must be 0.75 µm or less if we are to achieve an optical loss of 0.5 dB or less. This is so stringent that no elastic deformation of the component due to external forces is tolerated. To satisfy this requirement, optical connectors have a double engagement structure, as shown in Figs. 5(b) and 5(d): the engagement of extremely high-precision parts called ferrules and the engagement of the housings, which are needed for stable connection. While connectors are engaged, the ferrules are pressed against each other by the spring built into the plug housing to maintain the engaged state. The engaged plug housings and adapter housings protect the ferrule-engagement parts from external forces and prevent the optical loss from changing due to elastic deformation of the ferrules. The return loss of an optical connector is highly dependent on the Fresnel reflection*4 at the connection point of the connector. Since a large Fresnel reflection arises at the boundary plane between glass and air, the cores must be in tight contact with each other so that no air is present between the cores (physical contact (PC) connection) if we are to achieve a return loss of 40 dB or more. To establish a PC connection, the ferrule end faces are polished to a spherical shape so that the cores contact each other easily. To guarantee connection compatibility in the above connector structure, the following four items must be specified, as shown in **Table 2**: (1) ferrule dimensions, (2) housing dimensions and spring force, (3) performance of optical connector products, and (4) test procedures to confirm that the above three specifications are met. As mentioned above, a ferrule is a component used for axial alignment of an optical fiber core. Therefore, (1) ferrule dimensions must be specified for each optical fiber type, even if the ferrules are of the same type. However, (2) housing is specified for each connector type. (3) Connector performance is specified for each application. On the basis of this technical background, IEC has adopted a documentation system in which an optical connector product is specified by combining three documents, respectively related to (1) type of optical fiber to be connected, (2) connector type, and (3) application. They correspond to the following documents: (1) optical compatibility standard (IEC 61755 and 63267 series), (2) engagement standard (IEC 61754 series), (3) performance standard (IEC 61753 series), and (4) testing procedures (IEC 61300 series).

Lastly, let us present the latest trends in standardization. There has been intense research and development on SDM optical fibers capable of high-capacity transmission exceeding that of SMF. Anticipating forthcoming practical application of MCF, NTT has started standardization work on MCF connectors. On the occasion of revising the document on optical-connector testing procedures (IEC 61300 series), we are adding MCF connector tests. As the first step, a measurement procedure for MCF connectors was added to the loss measurement procedures (IEC 61300-3-4:2023), which were revised this year (2023). Standardization of single-core connectors has also started for 4-core MCFs with a clad outer diameter of 125 µm, which are products closest to practical application. **Figure 6** shows an overview of a 4-core MCF. As mentioned above, only the ferrule dimensions need to be specified for each optical fiber type. However, since the optical fiber for 4-core MCFs has not yet been standardized, the amount of

*4 Fresnel reflection: A phenomenon in which a portion of propagating light is reflected due to a change in the refractive index of the medium.

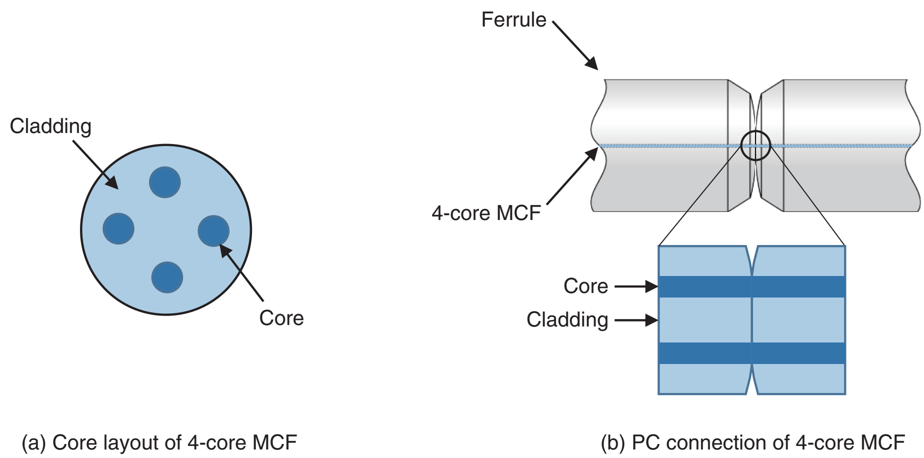


Fig. 6. Appearance of 4-core MCF.

core-axis misalignment as part of the ferrule dimensions cannot be specified at this time. Since the conditions for the spherical shape to achieve PC connection have been reported [10], a public specification that specifies only the end-face shape will be released within this year based on this report. As shown in Fig. 6, a 4-core MCF requires tight contact of wider end faces, making the end-face shape requirements more stringent than ever. Consequently, it may become necessary to change the ferrule end-face polishing process. SC 86B is seeking to accelerate the early practical use of 4-core MCF connectors by making the ferrule end-face shape specifications public.

4. Future outlook

In the coming years, fixed-line transmission networks, along with optical components, will play an increasingly important role as a high-capacity infrastructure for providing various services, such as those envisioned with IOWN. Therefore, there are high expectations that extensions to specifications and promotion of common specifications by international standardization organizations and forums will shorten development time and ensure interoperability. NTT will continue to work actively on international standardization in the field of fixed-line transmission networks to meet diverse service requirements.

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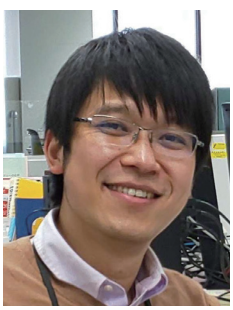

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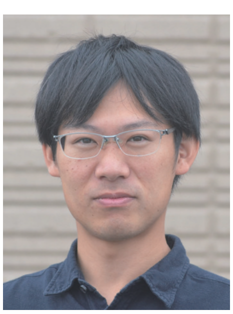

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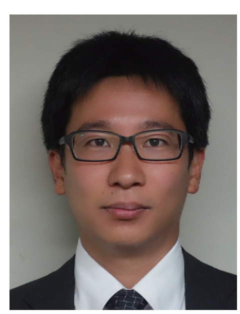

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Standardization Trends Related to Wireless Communications

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Abstract

Wireless communications, encompassing mobile communications, satellite communications, wireless local area networks (LANs), and fixed wireless systems, play a major role in communication networks. In preparation for the World Radiocommunication Conference 2023 (WRC-23) that was held in November 2023, the International Telecommunication Union - Radiocommunication Sector (ITU-R), a de jure standards organization, conducted studies and discussions broader than those limited to Beyond 5th-generation mobile communication system (5G) and 6G. The 3rd Generation Partnership Project (3GPP), a private standardization organization, has also started to study specifications after Release 18 under the name "5G-Advanced," as a further evolved version of 5G. The IEEE 802.11 Working Group (WG), a WG of the Standards Association under the Institute of Electrical and Electronics Engineers (IEEE), is studying next-generation wireless LANs. This article introduces these standardization efforts as well as the NTT Group's activities for standardization of satellite communications, fixed wireless communications, and radio-wave propagation.

Keywords: Beyond 5G, 6G, wireless LAN

1. Introduction

International standardization organizations focusing on wireless communications include the 3rd Generation Partnership Project (3GPP) and the Institute of Electrical and Electronics Engineers (IEEE), both of which are forums, and the International Telecommunication Union - Radiocommunication Sector (ITU-R), a de jure standard organization, that defines methods of using frequencies. The NTT Group has been actively involved in these standardization organizations to expand services, promote global adoption of the technologies it has developed, and contribute to the efficient use of frequencies. This article introduces the NTT Group's activities and recent trends in the following standardization organizations: 3GPP and ITU-R Study Group (SG) 5/Working Party (WP) 5D, both working on International Mobile Telecommunication (IMT); ITU-R SG 4/WP 4A, working on fixed satellite communications; IEEE and ITU-R SG 5/WP 5A, both working on wireless local area networks (LANs); ITU-R SG 5/WP 5C, working on fixed wireless communications; and ITU-R SG 3, working on radio-wave propagation, which supports the studies being undertaken by the above organizations.

2. Trends related to mobile communications

2.1 Trends in 3GPP

3GPP is a partnership project launched in December 1998 by national and regional standardization organizations to develop standard specifications for third-generation mobile communication systems

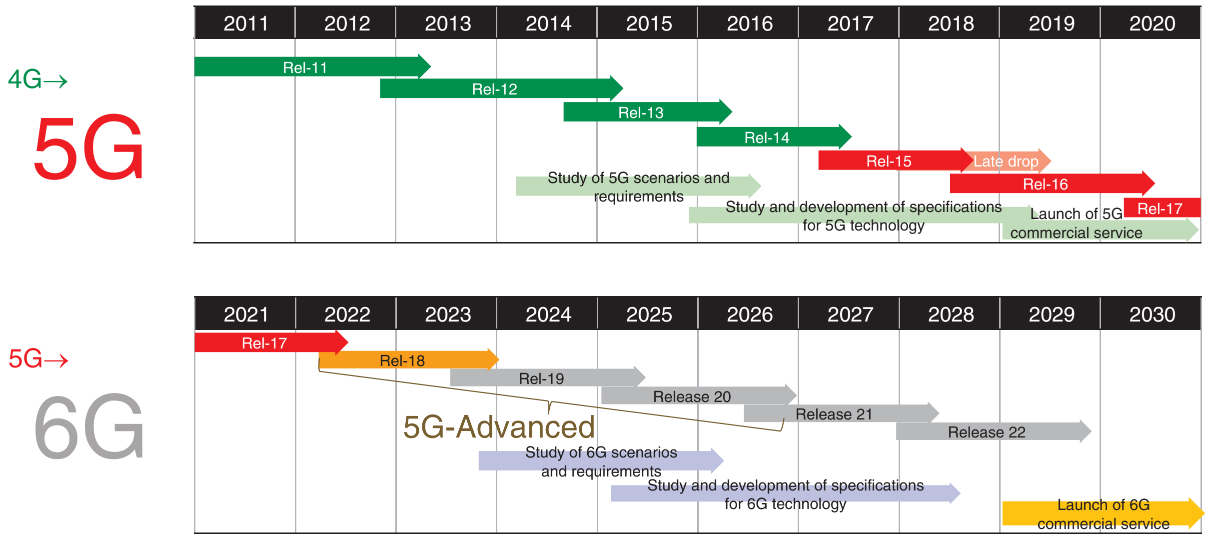


Fig. 1. 3GPP standardization timeline for the 2010s and 2020s.

(3G). The standard specifications created by 3GPP are published as national and regional standards by the six standardization organizations in different parts of the world that serve as organizational partners (OPs) in standardization. OPs collaborate to propose standard specifications to ITU. These become international standards when ITU approves them as recommendations. 3GPP consists of two major groups: the Technical Standardization Group (TSG), in which companies and other organizations directly participate to create technical specifications, and the Project Coordination Group (PCG) in which OPs participate to determine the overall timeline and manage progress. 3GPP publishes standard technical specifications, for which a release number is assigned to each functional set, called a "Release." Release 15 (Rel-15), which was completed in 2018, defined 5G, which is now commercially deployed worldwide. After formulating Rel-15, 3GPP issued Rel-16 and Rel-17 to expand the scope of functionality and improve the performance of 5G. 3GPP calls Rel-18 and follow-up releases "5G-Advanced" and started the development of the Rel-18 specifications in 2022. 5G-Advanced is targeted for commercial service in the late 2020s and will serve as a steppingstone toward 6G, which is targeted for commercial service by around 2030. **Figure 1** shows the 3GPP standardization timeline for the 2010s and 2020s. The 6G-related schedule in the figure is a projection backward from the target for commercial service launch by around 2030. At this point, the schedule for future 3GPP releases and their correspondence to 6G have not been determined, but it is expected that 5G-Advanced will be covered by Rel-18 to Rel-20, just before the 6G specifications are developed.

2.2 Trends related to IMT

NTT DOCOMO works on standardization related to wireless communications, such as mobile service operations, including IMT, which is a mobile communication system compliant with international standards, radio communication systems, and the frequencies used. Specifically, NTT DOCOMO actively participates in SG 5, which is in charge of terrestrial wireless communications in ITU-R, and WP 5D within SG 5. The following summarizes the activities of WP 5D, focusing on three topics that have been attracting attention.

(1) Identification of new IMT frequencies

The study on the use of new IMT frequencies started after the World Radiocommunication Conference 2019 (WRC-19). The Second Session of the Conference Preparatory Meeting for WRC-23 (CPM23-2) held in March through April 2023 summarized the studies to date on frequency sharing; thus, the preparations for WRC-23 were well underway. Specifically, with experts on IMT and other radio systems participating, WP 5D held meetings for detailed preliminary discussions on whether the use of a new frequency will cause interference to other radio systems and on what conditions are needed to avoid such interference. In WRC-23 Agenda Item 1.2

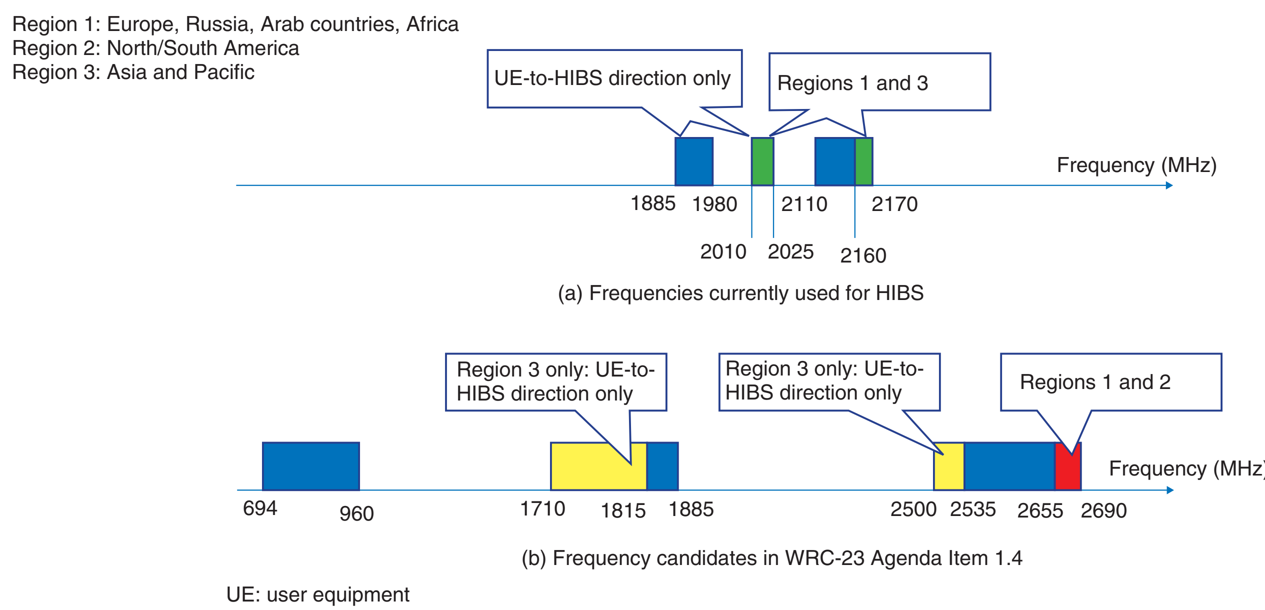


Fig. 2. Frequency for HIBS.

on the additional identifications of IMT frequencies, Region 3 (Asia-Pacific region), including Japan, is considering the 100-MHz bandwidth from 7025 to 7125 MHz. WRC-23, held in November 2023, decided whether this frequency would be identified as a candidate for IMT.

(2) Study on frequencies for high-altitude platform stations as IMT base stations

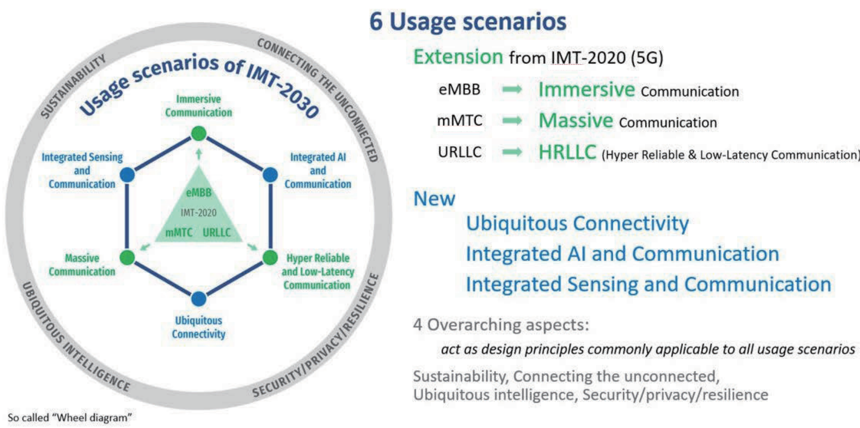
High-altitude platform stations (HAPS) have been attracting attention as a next-generation telecommunications infrastructure. The frequencies to be used for HAPS as IMT base stations (HIBS) has been discussed as WRC-23 Agenda Item 1.4. As with WRC-23 Agenda Item 1.2, CPM23-2 has summarized the studies to date on frequency sharing; thus, the preparations for WRC-23 were well underway. As of 2022, the frequency bands, 1885–1980, 2010–2025, and 2110–2170 MHz, were available for HIBS in Region 3, including Japan. In addition to these frequencies, further expanding the frequencies for HIBS by using candidate frequencies below 2.7 GHz, shown in **Fig. 2**, was studied in WRC-23 Agenda Item 1.4 and decided upon in WRC-23.

(3) Development of Recommendation ITU-R M.[IMT.FRAMEWORK FOR 2030 AND BEYOND]

In a somewhat different vein from previous frequency topics, WP 5D began discussions in 2021 with the aim of developing a new draft recommendation that defines the future role of IMT and the framework and objectives for that role. Specifically, WP 5D has had extensive discussions on the framework for IMT development beyond 2030, called IMT-2030, usage scenarios of IMT-2030, the definition of capabilities, and their target values. Through more than two years of integration and deliberation of proposals from different countries, the WP 5D meeting in June 2023 agreed on a new draft Recommendation ITU-R M.[IMT.FRAMEWORK FOR 2030 AND BEYOND], which includes an IMT-2030 usage-scenario diagram (**Fig. 3(a)**) and capability diagram (**Fig. 3(b)**). This issue was discussed at SG 5 held in September 2023. After approval of this recommendation, more detailed technical requirement specifications will be developed in cooperation with 3GPP and other organizations to achieve IMT-2030.

3. Trends related to fixed satellites

WP 4A belongs to ITU-R SG 4, which is in charge of satellite services, and deals with the effective use of orbits and frequencies for fixed satellite services and broadcasting satellite services. In connection with WRC-19 Agenda Item 1.5, a technical study was conducted on the use of Earth stations in motion (ESIM) for communications at 17.7–19.7 and 27.5–29.5 GHz with space stations in geostationary-satellite orbit (GSO), and Resolution 169 (WRC-19) was



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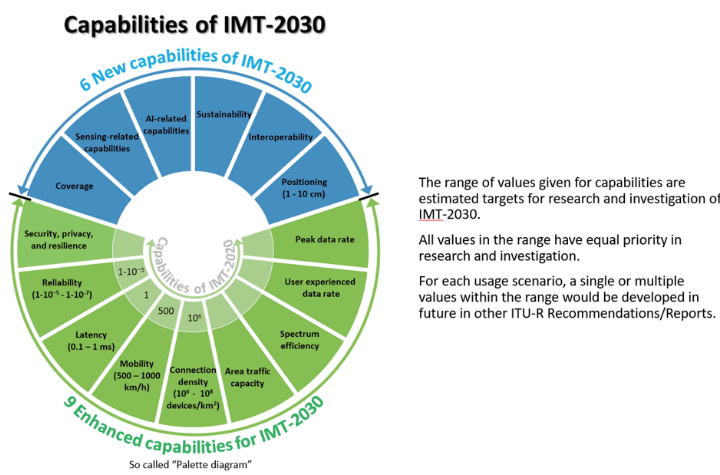
(a) Usage scenario diagram



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(b) Capability diagram

Fig. 3. IMT-2030.

developed. Resolution 169 (WRC-19) requested, in particular, regulation on aeronautical ESIM (A-ESIM), which is mounted on airplanes, to protect terrestrial wireless services (mainly 5G) operating at 27.5–29.5 GHz. In July 2023, WP 4A agreed on a draft new recommendation that defines a calculation method based on the A-ESIM's flight altitude and location for complying with the transmission power requirements, and SG 4 approved this recommendation. During the WRC-23 study cycle, WP 4A was in charge of mainly five WRC-23 agenda items. One is Agenda Item 1.16, in which the use of ESIMs for communications at 17.7–18.6, 18.8–19.3, 19.7–20.2, 27.5–29.1, and 29.5–30 GHz with space stations in non-GSO was studied. As with WRC-19 Agenda Item 1.5, Japan is contributing to appropriately protect terrestrial wireless services on the basis of Resolution 169 (WRC-19).

4. Trends related to wireless LANs

NTT laboratories are engaged in the development of standards for wireless LANs, particularly in the IEEE 802.11 Working Group (WG). The laboratories are also involved in the discussion on the international regulations governing the use of radio waves/frequencies. Specifically, the laboratories participate in the discussion in WP 5A responsible for land

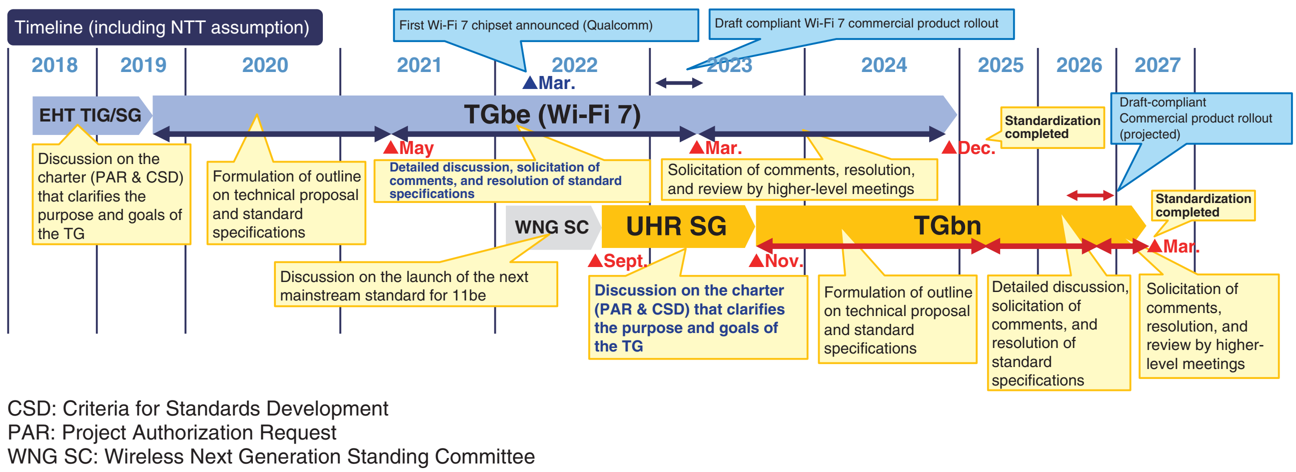


Fig. 4. IEEE 802.11be/UHR SG timeline.

mobile wireless systems other than IMT within ITU-R SG 5, which is in charge of terrestrial services, and in the discussion in the WRC, which is responsible for the revision of the Radio Regulations (RR), an international treaty on radio waves.

4.1 Trends in IEEE 802.11 WG

IEEE 802.11 WG is discussing various functions and topics to develop new standards. There are several discussion groups in IEEE 802.11 WG, among them, Task Group be (TGbe) and the Ultra High Reliability (UHR) SG are discussing the latest and forthcoming wireless LAN standards. TGbe focuses on IEEE 802.11be (11be), the next-generation high-speed standard succeeding the current (as of August 2023) standard IEEE 802.11ax (corresponding to Wi-Fi 6/6E). The UHR SG is discussing a standard that will succeed the above next-generation standard.

IEEE 802.11be (corresponding to Wi-Fi 7) is aimed at achieving a maximum throughput of 30 Gbit/s or higher and low latency and expected to include specifications on the modulation multi-level number for 4096 QAM (quadrature amplitude modulation); the bandwidth utilization of 320 MHz, which is twice the conventional bandwidth in the 6 GHz frequency band; multi-link operation, which coordinates multiple wireless transmission functions that are implemented in a single chassis; and restricted target wake time, which gives high priority to the transmission of periodic traffic requiring low latency. TGbe is revising the draft standard and scheduled to complete its standardization in December 2024, as shown in **Fig. 4**.

While major standards focus on achieving high-speed transmission, the UHR SG mainly aims at standards that will achieve low latency and high reliability in wireless access. Candidate technologies being considered for achieving the above goals include: multi-AP coordination technology, in which multiple access points (APs) cooperate in transmission and reception; a function that gives priority to low-latency transmission of non-periodic traffic; uninterrupted handover when stations switch from one AP to another; and technology for improving the efficiency of frequency utilization. In November 2023, TGbn began discussions on the development of a new standard on the basis of the deliberations at the UHR SG, with the goal of completing its standardization as IEEE 802.11bn (11bn) in March 2027. The UHR SG was also discussing the functionality of the 60-GHz spectrum (millimeter wave band), which is assumed to be used as a supplement to 11bn, and the IMMW (Integrated Millimeter Wave) SG was established in November 2023 as a new SG separate from TGbn and will begin discussions on this functionality.

4.2 Trends in ITU-R and WRC

The following wireless LAN-related topics have been studied in ITU-R. WRC-19 agreed in 2019 to revise the RR to enables outdoor use and higher transmission power in the 5.2-GHz band [1]. The technical foundation for this revision was studied by WP 5A. NTT laboratories were actively involved in this study. Although WRC-23 had no agenda item addressing wireless LANs, WP 5A continues to discuss

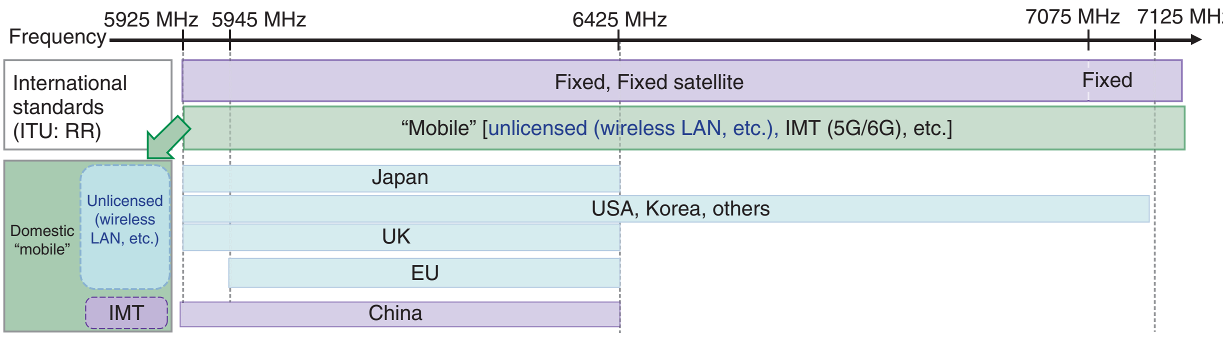


Fig. 5. Allocations in the 6-GHz band.

wireless LANs, focusing on the following two issues.

The first is modifications to Recommendations ITU-R M.1450 and M.1801, which specify the technical characteristics for wireless LANs. One focal point is a proposal to add IEEE 802.11ax, which operates in the 6-GHz band, in the light of updating IEEE 802.11. However, China, Russia, and other countries expressed concern that the increased use of the 6-GHz band for wireless LANs intensifies interference with other systems and proposed instead to restrict the use of the 6-GHz band for wireless LANs. This issue is still being discussed. Japan has submitted a proposal to reflect the revision of the RR in WRC-19 and recent amendments to the national regulations to allow the use of the 6-GHz band for wireless LANs as well as an objection to the proposed restriction on the use of the 6-GHz band. NTT's proposal and objection are tentatively reflected in working documents.

Second, WP 7C, which is in charge of Earth exploration satellites, has requested WP 5A to study the parameters of the wireless LAN that are appropriate for evaluating shared use of the 6-GHz band for both wireless LANs and Earth exploration satellites. As shown in **Fig. 5**, both issues center on the shared use of the 6-GHz band with other systems. NTT laboratories continue to be active in WP 5A as the body responsible for wireless LANs within the Japanese delegation.

5. Trends related to fixed wireless systems

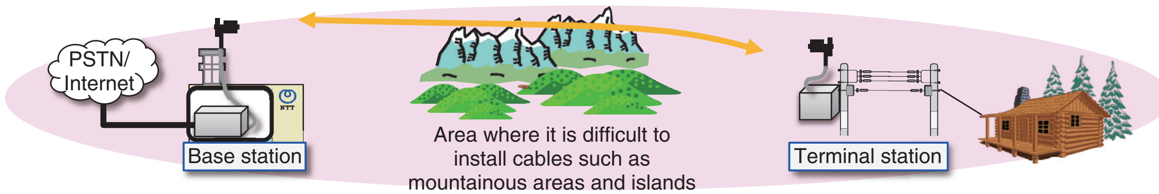
WP 5C, a working party under ITU-R SG 5, is responsible for the standardization of fixed wireless systems, and NTT laboratories are involved in its activities.

With the technical progress in the use of sub-terahertz waves (92 GHz and above), which make high-speed, broadband communications possible, major topics currently discussed in WP 5C include recommendations on the channel arrangement of the frequencies used for fixed wireless systems in the W-band (92–94, 94–100, 102–109.5, and 111.8–114.25 GHz) and D-band (130–134, 141–148.5, 151.5–164, and 167–174.8 GHz) to achieve global harmonization and protect passive sensors for Earth exploration satellites. The completion of these activities is expected to facilitate the worldwide deployment of high-capacity fixed wireless systems for mobile backhaul and fronthaul links.

WP 5C is also studying future trends and use of fixed wireless systems. Its study results are summarized in Report ITU-R F.2323 "Fixed service use and future trends." The use of fixed wireless systems includes the provision of telecommunication services to areas where it is difficult to install wired facilities, as shown in **Fig. 6**. To promote the deployment of the VHF (very high frequency)-band subscriber digital wireless system (TZ-68D) [2, 3] developed by NTT Access Network Service Systems Laboratories to the rest of the world, NTT laboratories have submitted to WP 5C a document reporting that TZ-68D has technical features that enable long-distance (several dozen kilometers) and out-of-sight transmission and that TZ-68D is now operational in Japan.

6. Trends in standardization related to radio-wave propagation

NTT laboratories are engaged in standardization activities in ITU-R SG 3, which deals with radio-wave propagation. Specifically, the laboratories participate in WP 3J, in charge of propagation fundamentals, WP 3K, in charge of point-to-area propagation,



PSTN: public switched telephone network

Fig. 6. Image of VHF band subscriber wireless system (TZ-68D) in use.

WP3K, in charge of ionospheric propagation, and WP 3M, in charge of point-to-point and Earth-space propagation. SG meetings are held approximately once every two years, and WP meetings are held in principle once a year. In 2023, SG and WP meetings were held from May 22 through June 2. The SG meeting was attended by 210 participants from 27 organizations and 32 countries (15 participants from Japan), and 156 contributions were submitted to the 4 WP meetings and 39 to the SG meeting. As a result of the discussions, SG 3 revised 18 Recommendations, revised 2 Reports, revised 3 Questions, and added one Question.

This article presents an overview of the activities in SG 3, focusing on topics related to the high-frequency band, which have attracted much attention.

6.1 Recommendation ITU-R P.1238 (Propagation data and prediction methods for the planning of indoor radiocommunications)

Japan, the UK, and Korea contributed example measurements of propagation above 100 GHz in various environments. SG 3 will discuss the prediction methods in offline meetings with the aim of completing a recommendation at the next meeting. A new recommendation for a new propagation-attenuation prediction model below 100 GHz applicable to conference room environments was made by adding new measurement data. A new off-line group was also established to discuss the issue of human body shielding, which becomes problematic in the high-frequency band, with the goal of developing a new recommendation. The group will continue the discussion on this issue up to the next meeting.

6.2 Recommendation ITU-R P.1411 (Propagation data and prediction methods for the planning of short-range outdoor radiocommunications)

It was agreed that, based on the measurement data provided up to the 2022 meeting, parameters mainly for broadband characteristics, such as delay spread and angular spread, would be added to the table in this recommendation. The contributions from Japan and the United States triggered a heated discussion on a line-of-sight probability-prediction model. It was decided that further study was needed, and a new off-line group was established.

7. Future outlook

The demand for wireless communication systems and radio spectrum is increasing yearly. It is expected that a wide variety of discussions will take place in 3GPP, the ITU-R (including WRC-23), and IEEE to study technical standards and broader frequency bands, with an eye to Beyond 5G, 6G, and next-generation wireless LANs. We will continue to drive our international standardization activities, taking not only domestic use but also international coexistence into consideration.

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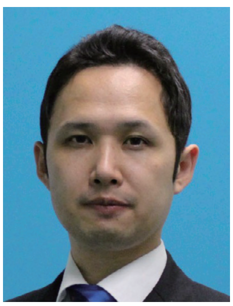

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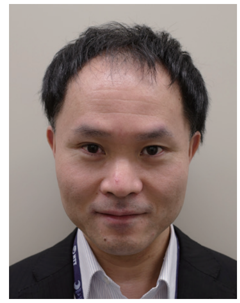

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Standardization Trends Related to Environmental and Operations Technologies

Yuichiro Okugawa, Minako Hara, Shingo Horiuchi, and Kazuhisa Yamagishi

Abstract

To provide sustainable and stable information and communication technology (ICT) services, the NTT Group is addressing various issues, such as standardizing indicators for application service quality, promoting network services, protecting telecommunication equipment from electromagnetic interference and lightning surges, assessing the impact of ICT on climate change, and promoting a circular economy conductive to sustainable development. This article introduces the activities and standardization trends in each of the above fields.

Keywords: quality, operations and management, environment

1. Operation of application services

To efficiently operate (design, monitor, and manage) application services, it is important to develop indicators for quality of experience (QoE) and network quality of service (QoS). This section outlines the standardization trends of indicators used for application services.

1.1 Speech-quality estimation technology (ITU-T Recommendation G.107.2)

The International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) Recommendations G.107, G.107.1, and G.107.2 were standardized as quality-planning tools for Internet Protocol (IP) telephony services respectively for narrowband (300–3400 Hz), wideband (50–7000 Hz), and super-wideband (50–14000 Hz)/fullband (20–20000 Hz) and are widely used in the quality planning of domestic and international IP telephony services. Super-wideband speech services using Enhanced Voice Services (EVS) codecs have become the mainstream, and attention is being paid to G.107.2, which defines a mathematical algorithm that uses a number of parameters related to speech quality as input. However, G.107.2 uses default values for some parameters. To cover background noise, burst packet loss, and delay, G.107.2 has been revised by modifying the algorithm for calculating the equipment impairment factor (Ie,eff), delay impairment factor (Id), basic signal-to-noise ratio (Ro), and simultaneous impairment factor (Is) by adding new parameters. This revision has made super-wideband and full-band E-models suitable under a variety of conditions.

1.2 Quality-estimation and degradation-factor-analysis technologies for adaptive bitrate streaming (ITU-T Recommendations P.1203, P.1204, and P.DiAQoSE)

Adaptive bitrate streaming is a video-streaming technology. It varies the quality of video that the user receives depending on the network quality. The user's QoE varies greatly depending on the quality of the video received. In response to the use of adaptive bitrate streaming, P.1203 has been formulated to define a technology for monitoring the quality of high-definition video coded using H.264/AVC

(Advanced Video Coding), and P.1204.3, P.1204.4, and P.1204.5 have been formulated as technologies for monitoring the quality of 4K video coded using H.265/HEVC (High Efficiency Video Coding) or VP9. These recommendations are being revised in response to an increase in the use of a new coding scheme, AV1 (AOMedia Video 1). As mentioned above, ITU-T Study Group 12 (SG12) is extending quality-estimation technology in response to the development of various video-coding schemes.

Recommendations P.1203 and P.1204 have been formulated to define technologies for monitoring video quality. They express QoE on a scale of 1–5. Although quality degradation can be detected from the degree of drop in the quality value, it is not possible to identify the degradation factors (e.g., quality degraded due to encoding or a stalling event). To solve this problem, SG12 is studying P.DiAQoSE to define a method for analyzing quality-degradation factors. P.DiAQoSE calculates the degree to which quality parameters (bitrate, resolution, framerate, and stalling event information) that are input to one of the models in P.1203, P.1204.3, P.1204.4, or P.1204.5 reduce quality value (impairment value). Specifically, P.DiAQoSE calculates the degree of impairment of each quality parameter by distributing the difference between the current quality value (total degradation value) and maximum quality value that can be selected for a given viewing to quality parameters on the basis of Shapley theory. In addition to using conventional quality-monitoring technologies, knowing the degradation value for each quality parameter makes it easier to study how to improve quality.

1.3 Method for estimating the object-recognition rate in autonomous driving (ITU-T Recommendation P.obj-recog)

Europe and Japan have started providing autonomous driving services assuming that vehicles are monitored at remote monitoring centers. Video captured by a vehicle-mounted camera is encoded and sent to a monitoring center. At the monitoring center, a monitoring operator checks for obstacles on the road. The quality of the video transmitted from the onboard camera must be clear enough to enable the operator to recognize objects. To develop a technology for constantly monitoring whether the transmitted video is clear enough for object recognition, ITU-T SG12 launched a new work item (P.obj-recog). This technology will be developed on the basis of the results of subjective assessment experiments on object recognition using videos from onboard cameras.

1.4 Summary

Certain indicators are needed to operate application services efficiently. This section outlined the technologies that contribute to the operation of speech communication, video streaming, and autonomous driving services. For future services, it is important to develop indicators and use them in actual operations. Therefore, we need to keep abreast of the standardization trends in this field.

2. Standardization trends in TM Forum

2.1 What is TM Forum?

The original aim of TM Forum was to standardize the operations and management of telephone networks, ensuring stable provision of telephone services in each country. However, TM Forum has been working in cooperation with other industries on projects aimed at promoting network services. It has over 850 member companies mainly in the telecommunications and information technology (IT) industries.

TM Forum has set five key themes: Cloud Native IT & Networks, Data & AI, Autonomous Operations, Ecosystems, and People & Planet and is currently working on the following 18 projects:

- End-to-end ODA Project
- Information Systems Architecture Project
- Components and Canvas Project
- Open APIs Project
- AI Governance Project
- Data Governance Project
- Autonomous Network Project
- AI Closed Loop Automation Project
- AI Operations (AIOps) Project
- Measuring and Managing Autonomy Project
- Digital Twin for Decision Intelligence Project
- Business Architecture Project
- Business Assurance Project
- Digital Ecosystem Management Project
- Standardizing Wholesale Broadband - Fibre Access (BFA) Project
- Digital Maturity Model Project
- Customer Experience Management Project
- TechCo Organizational Design Project

NTT is pursuing digital transformation (DX) and IOWN (Innovative Optical and Wireless Network)/ Cognitive Foundation. We believe that the key drivers in these efforts are speeding up service provision by using business support systems (BSS) and operation support systems (OSS) that comply with standards, providing network services on the basis of abstract customer requirements, and creating organizations, including staffing, that are suitable for the DX era. From these perspectives, this section describes trends in the following four projects.

2.2 Components and Canvas Project

Conventional BSS/OSS architectures assume a telephony service. To develop architectures and frameworks capable of supporting various forms of business, TM Forum is discussing Open Digital Architecture (ODA) and Open Digital Framework (ODF). Specifically, TM Forum is defining an ODA that can support collaborations with other business partners, diversification of customer experience (CX), and dramatic enhancement of operations using artificial intelligence (AI), etc. This ODA has the following functions:

- Engagement Management: management designed to support the functional part that serves as points of contact with customers and operators and to enhance CX.
- Party Management: management of relationships with stakeholders, such as personnel involved and procurement partners in the B2B2X (business-to-business-to-x) business model.
- Core Commerce Management: management of customers and products (corresponding to the BSS domain).
- Production: management of end-to-end services and resources, including networks (corresponding to the OSS domain).
- Intelligence Management: management domain for AI technology, etc. to achieve a closed loop in each management domain.

TM Forum is currently studying the ODF, which uses tools and maturity models, as a framework to achieve the ODA. Specifically, TM Forum is studying the utilization and mapping of business processes (enhanced Telecom Operations Map (eTOM)), applications (Telecom Application Map (TAM)), and an information model (Shared Information/Data Model (SID)), which it has specified earlier. eTOM is used as business requirements for constructing ODF systems, SID as information systems, and TAM as transformation tools.

2.3 Autonomous Network Project

The Autonomous Network Project aims to achieve autonomous/automated operations of networks. In collaboration with organizations, such as the 3rd Generation Partnership Project (3GPP), the European Telecommunications Standards Institute (ETSI), Zero Touch Network and Service Management (ZSM), and Experiential Networked Intelligence (ENI), TM Forum is discussing the implementation architecture and model and application programming interfaces (APIs) for autonomous/automated operations of networks. TM Forum aims to enable an autonomous network by dividing the overall architecture into a business-operation layer, service-operation layer, and resource-operation layer and link the management layers of these three layers. It seeks to achieve an autonomous network step by step by defining levels of automation achieved from L0 to L5. The level of automation can be raised from manual to automatic from different aspects, such as execution, cognition, analysis, and decision making. In addition, the definition of the level of automation is conceived in such a way that autonomous/automated operations are achieved by stepping up each of the intent and application aspects from manual to automatic. One of the project's latest discussion topics is the study of a tool for quantitatively evaluating the level achieved of each company's autonomous network. The architecture of the autonomous network is designed in such a way that a closed loop is created in each of the business, service, and resource operations layers. The aim with this architecture is to automate each management layer in an optimal manner and achieve globally optimized autonomous operations by linking the closed loops of the three layers. The goal with the closed loop of each layer is defined as "intent," and the intent is used as the key to link the layers of the autonomous network. Using the intent in this manner is now attracting attention. There are intense discussions on the required APIs and information models and many documents are being compiled in preparation for standardization.

2.4 Digital Ecosystem Management Project

Connectivity as a Service (CaaS) is defined as a form of service in which users of a network service specify only the starting and ending points and the network characteristics they require, and the service is provided using network slicing, etc. Users of CaaS may not have specific requirements regarding the routes in the network or may have no knowledge about routes in the network. CaaS is implemented by defining such user requirements, some of which may be ambiguous, as the intent, deriving a specific network configuration by combining the available services, then providing the service. The API for CaaS is being studied with the aim of compiling a document that summarizes the API requirements by the end of

FY2023. To provide CaaS, it is necessary to derive a specific service from the user's order that includes ambiguous requirements. Therefore, this project is studying a method for incorporating elements of the intent being studied for the Intent Management API and a method for using the intent as a means of providing network slicing.

2.5 TechCo Organizational Design Project

The TechCo Organizational Design (TCOD) Project is studying ways to ensure that the culture and skills of an organization and its operators continuously evolve along with the progress of DX. This project is compiling documents that describe the Digital Talent Maturity Model and TechCo Organizational Design. Therefore, it is important not only to discuss systems, such as BSS and OSS, as has been done conventionally, but to also ensure that communication service providers continuously and appropriately evolve their organizational culture. The TCOD Project aims to standardize best practices and guidelines that are based on the above perception.

2.6 Summary

In parallel with the above projects, TM Forum focuses on assessing the effectiveness of standard specifications and creating new requirements and businesses through a proof of concept and a technical demonstration called "Catalyst Project." TM Forum accelerates the use of standardization in actual business through both discussions on standard documents and technical demonstration.

3. Standardization trends related to environment, climate change, and circular economy

ITU-T SG5 aims to develop standards that contribute to enhancing the reliability of telecommunication services and reducing the environmental impact of business activities by protecting telecommunication facilities from electromagnetic interference and lightning surges, evaluating the impact of ICT on climate change, and addressing issues surrounding a sustainable circular economy. For these purposes, SG5 created three Working Parties. Working Party 1 focuses on electromagnetic compatibility (EMC) and electromagnetic exposure. Working Party 2 considers eco-efficiency, e-waste, circular economy, and sustainable ICT networks. Working Party 3 is focused on adaptation to and mitigation of climate change, e-waste, and net zero emissions.

3.1 EMC, lightning protection, and human-body exposure to electromagnetic fields

SG5 Question 1 investigates requirements for protecting telecommunication systems against lightning strikes and overvoltage to ensure electrical protection, reliability, safety, and security of ICT systems. Question 1 also considers revisions to the existing recommendations and supplementary documents related to soft errors in telecommunication equipment caused by particle radiation. This Question aims to develop recommendations for ensuring electromagnetic security in telecommunication equipment, including methods for protecting equipment against high-altitude electromagnetic pulse and high-power electromagnetic attacks as well as methods for evaluating and reducing risk of information leakage via electromagnetic waves. Question 2 examines requirements for protecting telecommunication systems against overvoltage and overcurrent as well as protective devices to protect equipment and devices against lightning and other electrical events. Question 3 examines procedures, calculation methods, and measurement methods for estimating the electromagnetic field strength around antennas to protect the human body from electromagnetic radiation fields emitted by mobile phones and wireless systems. Question 4 studies EMC issues in ICT environments, including the development of EMC standards for new telecommunication equipment, telecommunication services, and wireless systems.

3.2 Eco-efficiency, e-waste, circular economy, and sustainable ICT networks

Question 6 identifies the environmental efficiency requirement of digital and frontier technologies. It focuses on studying technical solutions, enhancements, metrics, key performance indicators, and related accurate measurement methods and reference values for different type of technologies. Question 7 seeks to address the e-waste challenges by identifying the environmental requirements of digital technologies including Internet of Things, end-user equipment, and ICT infrastructures or installations on the basis of the circular economy principles and improving supply-chain management. Question 13 aims to develop recommendations, supplements, and/or technical reports identifying requirements and providing guidance, innovative frameworks, and tools for the use and operation of digital technologies (i.e., AI, 5th-generation mobile communication systems (5G), etc.) in cities and communities that support the transition to a circular city. It also aims to develop metrics and key performance indicators that establish a baseline scenario of circular cities and communities.

3.3 Adaptation to and mitigation of climate change, and net zero emissions

Question 9 aims to develop assessment methodologies and guidance that allow the objective, transparent, and practical assessments of the sustainability impact of digital technologies, including ICT, AI, and 5G, to align their developmental trajectories with the Paris Agreement and United Nations Sustainable Development Agenda. Question 11 seeks to develop standards, guidelines, and measurement frameworks that support the development of a smart energy system and applying smart energy solutions to achieve a low-carbon economy. This Question aims to develop recommendations, supplements and/or technical reports on real-time energy service and control solutions for more effective and efficient energy management trough ICT and digital technologies. Question 12 aims to develop recommendations, supplements, and/or technical reports that support the deployment of digital technologies in accelerating climate-adaptation actions. This Question would improve the efficiency of power and cooling systems in ICT networks, support the development of energy-efficient ICT architectures such as up to 400 VDC power feeding systems, add energy saving features to ICT equipment and applications, improve air-flow-controlling technology, cooling technology and renewable energy systems, and more.

3.4 Summary

The subjects that are attracting attention in the field of ICT in ITU include electromagnetic effects of solar flares, methods for improving and evaluating energy efficiency at datacenters and 5G base stations, and supply-chain management and digital passports for achieving a circular economy. More general environmental management systems and environmental impact assessment are being studied by the International Organization for Standardization (ISO), and energy management systems and environmentally conscious design are being studied by the International Electrotechnical Commission (IEC).

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Standardization Trends Related to Application- and Service-related Technologies

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Abstract

This article describes the standardization trends in the International Organization for Standardization/International Electrotechnical Commission Joint Technical Committee 1 (ISO/IEC JTC 1)/Subcommittee 29 (SC 29), and International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) Study Group 16 (SG16) as well as ISO/IEC JTC 1/SC 27 and ITU-T SG17. Both SC 29 and SG16 deal with multimedia coding and transmission and are shaping the future of entertainment and business communication. Both SC 27 and SG17 work on standardization related to information security and communication security and are helping to strengthen the reliability and privacy protection of the rapidly evolving digital society.

Keywords: security, multimedia, international standardization

1. Standardization trends related to multimedia coding

The International Organization for Standardization/International Electrotechnical Commission Joint Technical Committee 1 (ISO/IEC JTC*1 1)/Subcommittee 29 (SC*2 29) previously had two Working Groups (WGs)*3: WG 1, commonly known as JPEG (Joint Photographic Experts Group) and WG 11, commonly known as MPEG (Moving Picture Experts Group). JPEG developed coding schemes, formats, and transmission methods for still images, while MPEG developed coding schemes, formats, and transmission methods for video and audio. Both WGs periodically produced media codecs and transmission methods, such as JPEG and Advanced Video Coding (AVC)/H.264*4, thus contributed to the growth of digital media. However, the variety of media handled by MPEG has grown so diverse and the number of participants in MPEG has become so large (several hundred) that it became inefficient for MPEG to continue working as a single WG.

To solve this problem, in July 2020, SC 29 created seven WGs based on the subgroups that existed within WG 11, each handling respectively video, audio, systems, and others; three Advisory Groups (AGs)*5, which support these WGs in working together as a single MPEG team; and one AG, which supports cooperation between MPEG and JPEG. This reorganization was an important step to keep pace with evolution in technology and changes in industries

*1 JTC: Joint Technical Committee of ISO and IEC. The first joint technical committee, for example, is referred to as "ISO/IEC JTC 1." The name of any standard published by ISO/IEC JTC 1 starts with "ISO/IEC," followed by a number.

*2 SC: A subordinate organization of ISO/IEC JTC 1. It focuses its activities on a specific field.

*3 WG: A subordinate organization of an SC. It is in charge of specific standardization projects and formulates and revises specific standards.

*4 AVC/H.264: A compression coding method for video data. Since the same specification is standardized as AVC by MPEG and as H.264 by ITU-T, the two names are sometimes combined in this way.

*5 AG: A subordinate organization of an SC. It provides advice and guidelines for specific areas and standardization projects.

and to ensure rapid and efficient standardization in this era when the technical domains of the video, still image, audio, and other media industries overlap. This reorganization has enabled SC 29 to address a broader and more diverse range of applications and develop standards not only in the areas of video, audio, and still images but also in new areas such as artificial intelligence (AI), genomics, and medical imaging. Although WG 11 ceased to exist, the name MPEG continues to be used as the common name for an across-the-board organization consisting of WG 2 through WG 8 and AGs 2, 3, and 5 and as the generic name for the standards created by these WGs. The international meeting that these organizations hold four times a year is also termed the MPEG Meeting.

The current WG structure of SC 29 and the name and activities of each WG are described below.

1.1 JPEG

- WG 1: JPEG Coding of Digital Representations of Images

WG 1 works on compression coding and formats of still and other images. It is standardizing still-image codecs, such as JPEG XL, which offers excellent compatibility for web applications, and JPEG XS, which provides low-latency lossless encoding for industrial applications. WG 1 is also developing standards for the JPEG Pleno series, which includes codecs for high-dimensional media such as light fields, point clouds, and holography. It is actively incorporating AI technology and studying learning-based tools for JPEG AI and JPEG Pleno Point Cloud.

1.2 MPEG

As mentioned above, the seven WGs, from WG 2 through WG 8, cooperate to develop common standards under the name of MPEG. The latest series is ISO/IEC 23090 MPEG-I, which targets immersive applications, such as virtual reality (VR) and augmented reality (AR), and covers a wide range of media, including video, audio, and three-dimensional (3D) point clouds.

- WG 2: MPEG Technical Requirement

In preparation for starting new standardization activities, WG 2 is conducting preliminary discussions, such as those on collecting use cases and identifying requirements. After discussions have made a certain amount of progress, each activity will move to a more specialized WG, where technical proposals will be solicited through Call for Proposal (CfP) and the standardization work will proceed in earnest.

- WG 3: MPEG Systems

WG 3 standardizes the formats of media that are coded with a range of codecs, various metadata used by applications, and transmission methods. It is currently standardizing MPEG-I Part 14: Scene Description for MPEG Media, a system for describing scenes composed of multiple media using an integrated approach.

- WG 4: MPEG Video Coding

WG 4 standardizes video codecs. It is currently standardizing MPEG-I Part 12: Immersive Video, which involves depth information for 3-degrees of freedom (3-DoF)/6-DoF representation of video and NNC (MPEG-7 Part 17: Compression of Neural Networks for Multimedia Content Description and Analysis), which compresses neural networks. WG 4 will soon begin the standardization of Video Coding for Machines (VCM) for coding video and images that are used in machine-learning tasks.

- WG 5: MPEG Joint Video Coding Team(s) with ITU-T SG16

WG 5 collaborates with ITU-T Study Group 16 (SG*6 16) to standardize video codecs. Since high-compression video codecs are of great industrial importance, ITU-T SG16 and ISO/IEC JTC 1/SC 29 have formed a joint working team and developed new standards on an approximately 10-year cycle. The current working team, known as Joint Video Expert Team (JVET), completed the first version of VVC (MPEG-I Part 3: Versatile Video Coding) in 2020, a higher-compression, multifunctional standard that succeeded HEVC/H.265 (MPEG-H Part 2: High Efficiency Video Coding). As the name “versatile” implies, VVC was designed to support a wide range of applications. For example, its first version already supports high dynamic range, 360°, and screen content, which HEVC supported as extensions of its second version. In 2022, WG 5 completed the second version, which features bit-depth extensions for industrial applications. It will continue to further improve compression efficiency and introduce learning-based tools.

- WG 6: MPEG Audio Coding

WG 6 standardizes audio and acoustic codecs. In 2019, it completed the standardization of MPEG-H Part 6: 3D Audio, an object-based audio codec. It is currently working on the standardization of MPEG-I Part 4: Immersive Audio with the aim of completing it in 2025.

- WG 7: MPEG Coding of 3D Graphics and Haptics

*6 SG: A subordinate organization of ITU-T.

WG 7 standardizes codecs for point clouds, haptic data, and other media that use 3D representations. The codecs for point clouds include V-PCC (MPEG-I Part 5: Video-based Point Cloud Compression), which has been customized to represent dense, time-varying point clouds (such as humans and small objects), such as those used in VR, G-PCC (MPEG-I Part 9: Geometry-based Point Cloud Compression), which can represent large-scale and sparse objects and scenes, such as LiDAR (light detection and ranging) data, and a standard that was derived from G-PCC. V-PCC converts 3D positions and the attribute information, such as color information, of a point cloud into an image and encodes it with any type of video codec. The first version was completed in 2021. The standardization of V-DMC (MPEG-I Part 29: Video-based Dynamic Mesh Compression), which extends the coding target to a dynamic mesh, is underway. G-PCC represents the positions of a point cloud in a tree structure and applies predictive encoding to the attribute information of the point cloud. The first version was completed in 2022. The second version, which extends the coding target to dynamic scenes and larger scenes, is being standardized. NTT is actively submitting proposals for the second version of G-PCC. Since July 2023, WG 7 has been preparing to issue a CfP for AI-based 3D Graphics Coding, which uses AI for compression.

Other standards being studied by WG 7 include MPEG-IoMT (Internet of Multimedia Things), which is an application programming interface (API) for handling multimedia content with Internet of Things (IoT), and MPEG-I Part 31: Haptics Coding, a codec for haptic data.

- WG 8: MPEG Genomic Coding

WG 8 standardizes the MPEG-G series, which cover codecs for genome data and various metadata and APIs for genome data analysis. It completed a series of standards in 2020 and is studying further functional expansion.

1.3 AGs

- AG1: Chair Support Team and Management
- AG2: MPEG Technical Coordination: Coordinates the entire MPEG
- AG 3: MPEG Liaison and Communication: Ensures communication between MPEG and other organizations
- AG 4: JPEG and MPEG Collaboration: Establishes a cooperative relationship between JPEG and MPEG
- AG 5: MPEG Visual Quality Assessment: Conducts subjective and objective performance evaluation for each standard

As described above, SC 29 works on standardization of a wide range of multimedia, from codecs, formats, and systems for multimedia to representation of neural networks used for media processing. SC 29 plans to expand the range of media it handles and develop codecs that make full use of AI technology, and these aspects are attracting attention.

2. Standardization trends related to multimedia transmission

International standardization is also advancing in the field of applications that transmit multimedia content to remote locations. As described above, ITU-T SG16 promotes multimedia coding in collaboration with ISO/IEC JTC 1/SC 29. It also studies standardization of Internet-protocol television (IPTV), digital signage, and other systems that transmit to and play multimedia content at remote locations, as well as technologies for live transmission of multimedia elements besides video and audio to enable ultra-realistic experiences, enabling people at remote locations to feel as if they are actually present where the particular event is unfolding.

In its early days, digital signage was normally used to distribute images on fixed displays in commercial buildings and train stations. It has also recently been mounted on autonomous robots connected to a network, such as delivery robots, which function as moving digital signage. Digital signage is also used as telepresence[*7] terminals, terminals in virtual spaces, and terminals for communication that coveys ultra-realistic sensations. The latter is discussed below. SG16 standardizes the requirements for multimedia functions that are needed in the above applications.

Standardization is in progress for a technology that makes more advanced use of video-transmission technology to implement services in which users can experience an event as if they were actually present at the event site in real time, rather than services in which users are simply watching the screen, as with conventional television. This technology, called immersive live experience (ILE), transmits 3D images that appear life size from the event site to a remote location (presentation side) in real time, enabling the audience to experience a sense of ultra-high reality that exceeds the limits of what can be reproduced

*7 Telepresence: Technology that enables interaction with people and objects at a remote location via robots.

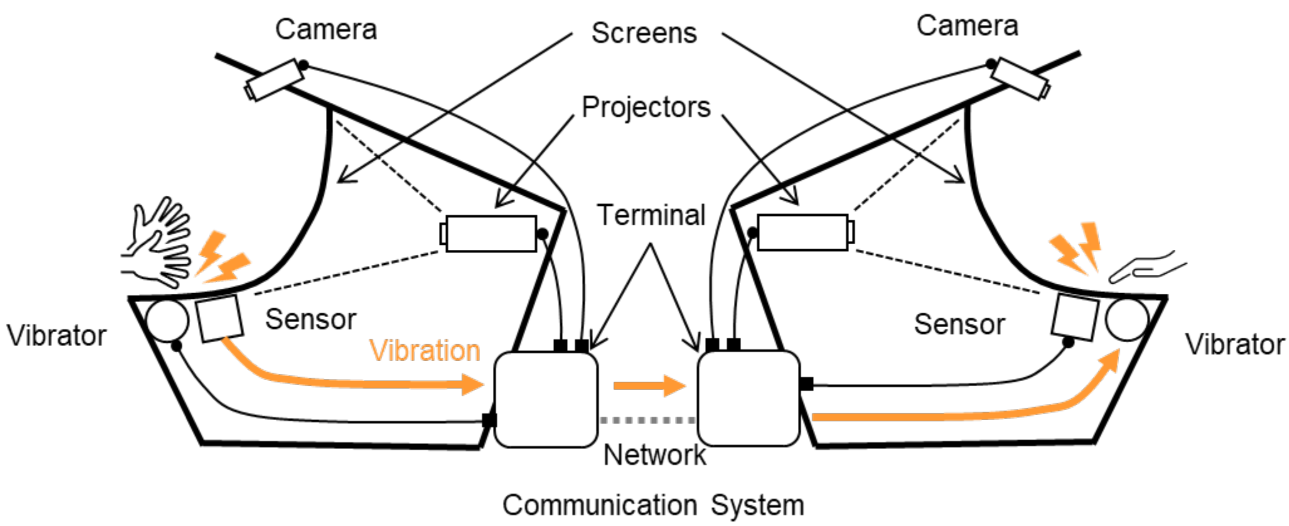


Fig. 1. Example configuration of a haptic information transmission system.

with flat images and sound, as is the case with a television set. Generating a sense of immersion on the presentation side involves technologies, such as VR and AR (recently often referred to as XR (extended reality)). It also involves a series of processes, from the sensing on the event side (corresponding to video capture with a camera) to real-time transmission and processing and reproduction on the presentation side (corresponding to video display). Therefore, it is necessary to consider this series of processes as a system and standardize the system architecture and protocols necessary for generating an ultra-realistic experience in real time. Another important role of standardization is to ensure international interoperability so that this ultra-realistic experience can be delivered across national borders. Furthermore, ITU-T SG16 has recently begun to study a technology for transmitting tactile information. The first recommendation for this technology was developed and agreed upon at the SG16 meeting in July 2023 under the leadership of NTT and is expected to be published by the end of FY2023 after passing through the approval process. An example of how this technology is used is shown in **Fig. 1**. SG16 is expected to further develop recommendations related to using tactile information to further enhance the ultra-realistic experience of ILE and will study further extension of ILE by transmitting other information besides tactile information. A Focus Group (FG)*8 related to the metaverse, which has been attracting attention, has been established in ITU. The FG might study the relationship between the metaverse and ILE.

3. Standardization activities in the security field

ISO/IEC JTC 1/SC 27 and ITU-T SG17 are de jure standardization organizations that deal with security. This section introduces and briefly compares these two organizations.

3.1 ISO/IEC JTC 1/SC 27

ISO/IEC JTC 1/SC 27 deals with methods, technologies, guidelines, etc. related to information security, cyber security, and privacy protection. It has five WGs, from WG1 through WG5:

- WG 1 deals with information security management systems (ISMS). The ISO/IEC 27000 series that it has standardized are well known.
- WG 2 deals with cryptography and security mechanisms. The ISO/IEC 18033 series it has standardized to define cryptographic algorithms is well known.
- WG 3 deals with security evaluation, testing, and specifications. The Common Criteria ISO/IEC 15408 series it has standardized is referenced by many information technology security certification systems as evaluation criteria.
- WG 4 deals with security control and services. For example, it has standardized the ISO/IEC

*8 FG: A time-limited group established to study new issues that are not covered by any of the existing SGs.

27400 series, which defines guidelines and requirements for IoT security.
- WG 5 deals with identity management and privacy technologies. A representative standard it has established is ISO/IEC 29100, which defines a privacy framework.

The WGs of SC 27 have been basically static, and the scope of each WG has not changed significantly, although there have been some additions and minor changes in names.

3.2 ITU-T SG17

ITU-T SG17 (Security) deals with the overall aspect of security. While security issues specialized in specific fields are handled by other SGs, SG17's role is to coordinate the security issues handled by various SGs in ITU-T. This role is quite similar to that of ISO/IEC JTC 1/SC 27. However, SG17 differs from SC 27 in that it has been covering directories, object identifiers, and technical languages in addition to security.

A representative recommendation made by SG17 is X.509, which defines a standard format for digital certificates. The syntax notation ASN.1 (Abstract Syntax Notation One), which was standardized by SG17, is also well-known.

As of July 2023, SG17 has five Working Parties (WPs), from WP 1 through WP 5, and handles 12 Questions. Each Question belongs to one of the WPs. Thus, the structure of WPs and Questions is more dynamic than that of WGs in SC 27. For example, Questions are added or merged as discussions or technologies advance (that is why some Question numbers are skipped). The scope of a particular Question may be expanded and WPs and Questions may be extensively reorganized or rearranged at regular intervals.

(1) WP 1 (Security strategy and coordination)
- Q1 Security standardization strategy and coordination
- Q15 Security for/by emerging technologies including quantum-based security

(2) WP 2 (5G, IoT and ITS security)
- Q2 Security architecture and network security
- Q6 Security for telecommunication services and Internet of Things
- Q13 Intelligent transport system security

(3) WP 3 (Cybersecurity and management)
- Q3 Telecommunication information security management and security services
- Q4 Cybersecurity and countering spam

(4) WP 4 (Service and application security)
- Q7 Secure application services
- Q8 Cloud computing and Big data infrastructure security
- Q14 Distributed Ledger Technology (DLT) security

(5) WP 5 (Fundamental security technologies)
- Q10 Identity management and telebiometrics architecture and mechanisms
- Q11 Generic technologies (such as Directory, PKI, Formal languages, Object Identifiers) to support secure applications

3.3 Comparison between ISO/IEC JTC 1/SC 27 and ITU-T SG17

The differences in the organizational structure between ISO/IEC JTC 1/SC 27 and ITU-T SG17 are reflected in the differences between the corresponding Japanese national committees. The Japanese national committee that corresponds to SC 27 does not conduct technical studies. Technical studies are primarily carried out by the national subcommittees. There are five national subcommittees from 1 to 5, corresponding to international WGs. In contrast, the Japanese national committee that corresponds to SG17 conducts technical discussions on all relevant matters. There are no subcommittees that correspond to the international WPs. (Of course, within the national committee, a person is selected to be in charge of each issue discussed.) Considering the aforementioned differences between the two international organizations, one having a static structure and the other a dynamic structure, it seems reasonable that the Japanese national committees are organized in this way.

It is not surprising that SC 27 and SG17 deal with many common technical issues, but their work on these issues complements each other in more than a few cases. Regarding public key cryptography, for example, SC 27 defines cryptographic algorithms and digital signature schemes, while SG17 defines the standard format and verification algorithms for public key infrastructure (PKI). The technologies defined by the two organizations are essential for the use of public key cryptography. Of course, many issues concerning guidelines and frameworks for security management and network security that are discussed in the two organizations are deeply related. Therefore, there are liaison teams (a group of people who participate in the meetings of the two organizations and stimulate the exchange of information between them) in both directions between SC 27 and SG17, enabling the two organizations to work closely in undertaking standardization.

3.4 Activities in ISO/IEC JTC 1/SC 27/WG 2

This section outlines the work trends in SC 27/WG 2, in which the authors are actively involved, focusing on the standardization of a technology, called secure computation, for analyzing (computing) data in encrypted form.

Let us consider a case in which a client collects data on a cloud server and analyzes the data. Ordinary cryptographic technology encrypts (1) the data that are exchanged between the client and cloud server and (2) the data that are stored on the cloud server for protection. However, during analysis, it is necessary to decrypt the data. In contrast, secure computation allows data analysis to be done without decryption. In other words, in addition to protecting (1) and (2), secure computation protects (3) the data being analyzed on the cloud server by keeping the data encrypted. Secure computation can analyze personal data of individuals or trade secrets of companies without decrypting them. To put it simply, secure computation enables us to utilize data without seeing its content.

Secure computation is now attracting much attention not only because it allows secure data processing but also because it makes it possible to bring together data that would otherwise be difficult to disclose to other organizations and use the data for applications that transcend the boundaries of companies and industries. It has been listed in Gartner's top trends in the strategic technology field as a technology group called privacy enhancing computation (PEC).

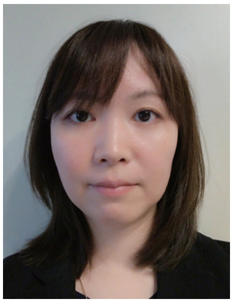
Considering the growing interest in secure computation, NTT pushed standardization of secure computation, and SC 27/WG 2 began the standardization work of the ISO/IEC 4922 series in 2020. The series consists of two parts: ISO/IEC 4922-1, which covers overall aspects of secure computation, and ISO/IEC 4922-2, which covers secret sharing-based secure computation. NTT is playing a leading role in the development of both ISO/IEC 4922-1 and 4922-2, with its employees serving as the editors for these standards. Secret sharing-based secure computation uses a method, called secret sharing, which converts data into special fragments. Secret sharing has been standardized as the ISO/IEC 19592 series.

ISO/IEC 4922-1 was published in July 2023, and ISO/IEC 4922-2 is in the final stage and is expected to be published soon. There have been moves to standardize other methods of secure computation, a sign that secure computation will continue to attract interest.

3.5 Other security-related standards discussed in ISO/IEC JTC 1/SC 27/WG 2

In addition to secure computation, SC 27/WG 2 is discussing various cryptographic schemes, from basic ones (block encryption and hash functions) to those with more advanced functions and properties, such as anonymous authentication and post-quantum cryptography.

In particular, post-quantum cryptography, which is said to be unsolvable even by quantum computers, has been actively discussed. Since it is known that quantum computers can theoretically decipher RSA (Rivest–Shamir–Adleman) signatures and other cryptographic schemes, advances in quantum computers have led to the standardization work of this form of cryptography. WG 2 is actively discussing post-quantum cryptography. The standardization of post-quantum cryptography is strongly affected by the results of the quantum cryptography competition held by the National Institute of Standards and Technology (NIST). This is why WG 2 is still at a stage of releasing a document, called standard document (SD), which describes the content of discussions in the WG, as a preliminary step toward standardization. Since the NIST competition ended in July 2022, the standardization work at WG 2 is expected to advance in the coming years.



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Efforts of NTT IOWN Integrated Innovation Center toward the Early Deployment of IOWN

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Abstract

NTT established NTT IOWN Integrated Innovation Center to incorporate the concept of the Innovative Optical and Wireless Network (IOWN) as early as possible through the practical application of various IOWN technologies developed by NTT laboratories and the provision of IOWN services/products to meet market needs and social demands. This article presents the activities of NTT IOWN Integrated Innovation Center, which aims to spread IOWN widely and contribute to a transformation of society.

Keywords: IOWN, photonics-electronics convergence device, All-Photonics Network

1. Introduction

As a unique entity among NTT research and development departments, NTT IOWN Integrated Innovation Center was established in July 2021 to accelerate the development of technologies and products related to the Innovative Optical and Wireless Network (IOWN) by bringing together several organizations with development missions within NTT laboratories. This Center was inaugurated by three centers: NTT Network Innovation Center for research and development of network and access systems, NTT Software Innovation Center for research and development of a computing platform and software, and NTT Device Innovation Center for research and development of optical and electronic devices. There is a clear reason for the name of “Center” rather than “Laboratory” because the aim of this organization is to incorporate the IOWN concept in a timely manner for market needs rather than to conduct conventional basic research looking to the distant future. In May 2022, NTT IOWN Product Design Center was established to accelerate the deployment of IOWN, so the total number of centers was increased to four (**Fig. 1**). While the three aforementioned centers are responsible for the practical application of IOWN-based technologies, the IOWN Product Design Center is responsible for spreading IOWN services and products backcast from market needs by combining those IOWN technologies with current technologies.

2. Target areas of IOWN deployment by NTT IOWN Integrated Innovation Center

NTT IOWN Integrated Innovation Center hopes that IOWN will not only be used within the NTT Group but also be deployed across society so that all people can enjoy the value of IOWN. As shown in **Fig. 2**, we have defined four layers as the deployment areas of IOWN—semiconductor devices, information technology (IT) equipment, communication networks, and information and communication technology (ICT) solutions—and NTT IOWN Product Design Center plays a central role in promoting initiatives in each area.

2.1 Semiconductor-devices area

For conventional information and communication systems, optical signals have been used only to transmit information processed by semiconductor devices to other locations. Semiconductor devices have evolved in line with Moore’s Law; however, as the

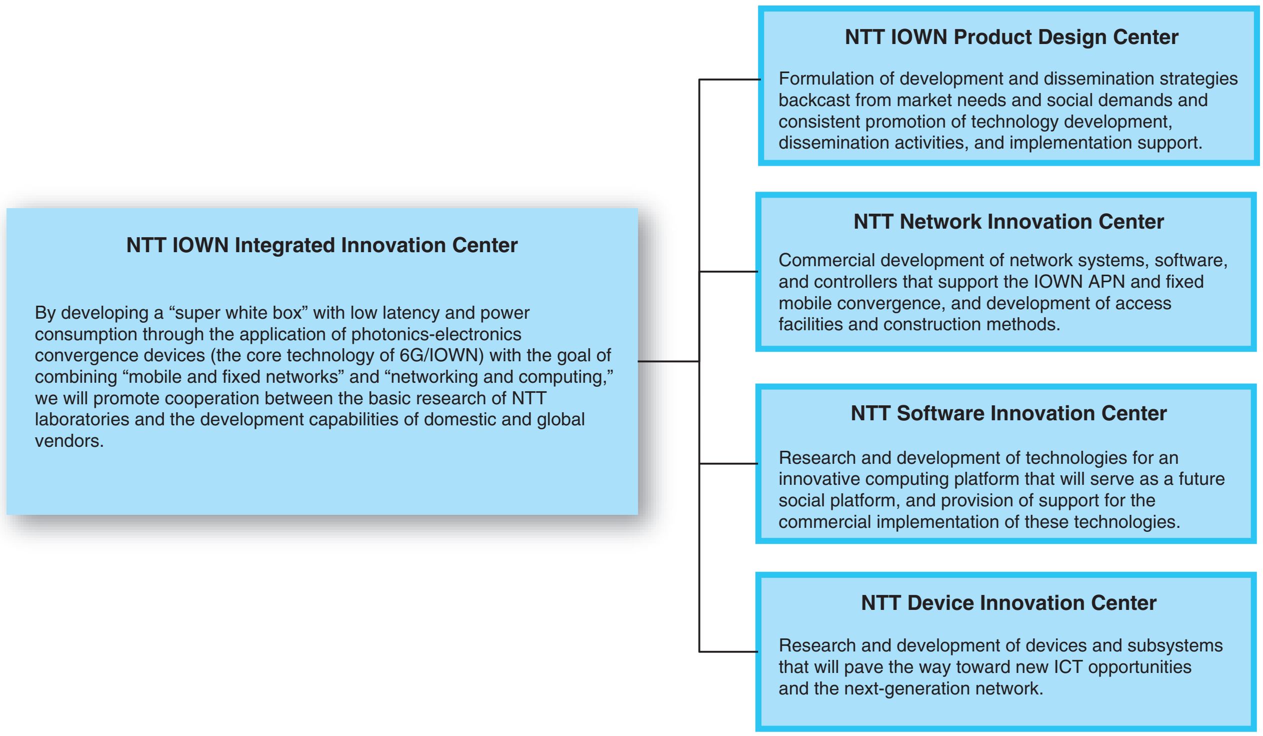


Fig. 1. Organization structure of NTT IOWN Integrated Innovation Center.

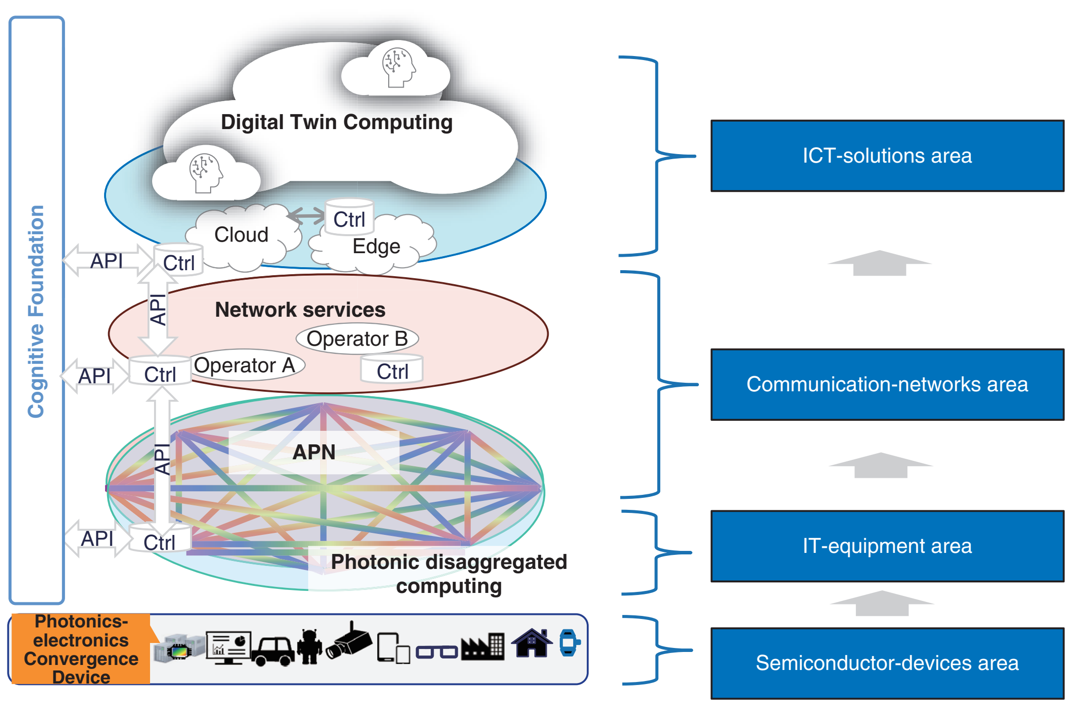


Fig. 2. Target areas for deploying IOWN.

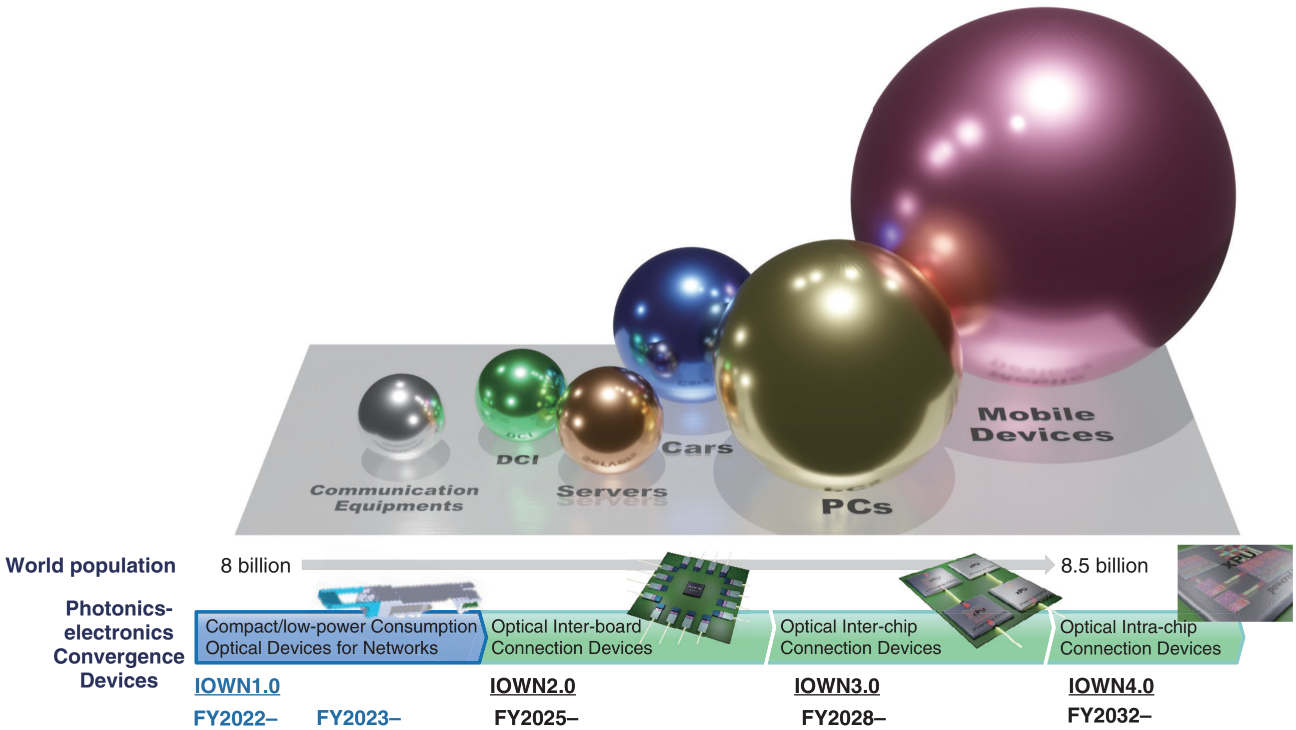


Fig. 3. Roadmap and applications for photonics-electronics convergence devices.

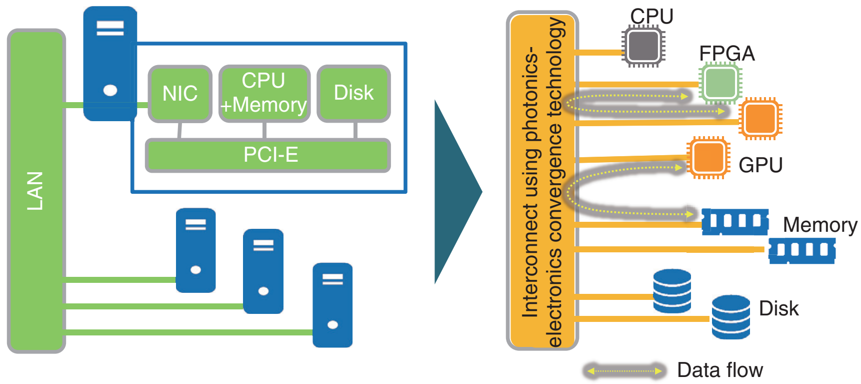
volume of information to be processed increases exponentially, the electrical signals traditionally used to transmit information within equipment or between semiconductors are reaching their limits in terms of speed and energy consumption; therefore, a new breakthrough is required. The photonics-electronics convergence technology that NTT has been researching and developing applies optical and electrical signals to the right place in conventional systems on the basis of conventional semiconductor devices. By using light not only for communications between sites but also at various other levels, it will be possible to achieve compact, economical, high-speed, and low-power consumption devices.

NTT has established a roadmap from IOWN1.0 to IOWN4.0 linked with the evolution of photonics-electronics convergence device technology (**Fig. 3**). IOWN1.0 will apply compact, low-power consumption devices for networks of All-Photonics Network (APN) services. IOWN2.0 will enable the use of light for board-to-board connections inside a server; thus, the application area of light will be extended to the field of computing. IOWN3.0 will enable optical transmission between chips on a board, and IOWN4.0 will enable the installation of optical wirings to the vicinity of a logic semiconductor that executes arithmetic processing. This stepwise evolution will expand the application area of photonics-electronics convergence devices from telecommunications to computing and solve the power-consumption problem with the growing use of artificial intelligence (AI) as a wide range of module vendors, equipment vendors, and hyperscalers adopt these devices. If the use of these devices spreads to consumer domains such as automobiles and mobile terminals, the number of products with the devices is expected to increase to hundreds of millions. As a result, the use of the device per product is also expected to increase, which will significantly contribute to achieving carbon neutrality around the world.

NTT Innovative Devices Corporation was established in June 2023 to commercialize and provide photonics-electronics convergence devices as early as possible. NTT IOWN Integrated Innovation Center will continue to work closely with NTT Innovative Devices.

2.2 IT-equipment area

NTT laboratories proposed an architecture for photonic disaggregated computing that takes advantage



LAN: local area network
NIC: network interface card
PCI-E: Peripheral Component Interconnect Express

Fig. 4. Photonic disaggregated computing.

of the characteristics of light. In this architecture, photonics-electronics convergence devices provide high-capacity, low-latency connections between accelerators via optical interconnects without central processing unit (CPU) intervention to avoid CPU bottlenecks and improve performance and power efficiency of computing. This architecture enables a computing system to add computing resources on a per-accelerator basis rather than on a per-server basis and allocate the optimal amount of accelerators, such as CPUs, graphics processing units (GPUs), and field-programmable gate arrays (FPGAs), in accordance with the processing executed by each application. Therefore, it is highly expected to improve energy-usage efficiency (**Fig. 4**).

We are currently researching and developing a super white box (SWB) that adopts photonic disaggregated computing. This SWB will not only be deployed in the NTT Group's internal systems to achieve our carbon-neutrality goal, but also be widely used by people outside NTT group companies in the form of a server system and an Infrastructure as a Service. We hope it will contribute to carbon neutrality for society as a whole.

2.3 Communication-network area

Using photonics-electronics convergence devices and the SWB, we will create innovative network services that have never been possible with conventional technologies. One of those services is the APN. It offers each customer a dedicated optical wavelength, and without converting light back to electricity, the light-only connection enables wideband data transmission with low power consumption. APN IOWN1.0 was launched as a commercial service by NTT EAST and NTT WEST in March 2023 (**Fig. 5**). Since it can provide a communication environment with large capacity, 1/200 delay, no jitter, and zero-latency fluctuation compared with conventional networks, it is possible to create a new user experience that has been difficult with conventional network services. For example, it enables telemedicine and smart factories to perform delicate tasks even from remote locations and guarantees a fair playing environment for e-sports across remote venues. In our demonstration to coincide with the commercial launch of the APN IOWN 1.0 service, the range of applications was expanded to include real-time remote concerts and comedy shows allowing viewers to experience new co-creation and appreciation of arts as well as remote dance lessons, enabling participants to experience a new type of social activity.

In mobile networks, it will also be possible to decrease power consumption of the fifth-generation mobile communication system (5G)/Beyond 5G services by deploying radio base stations with photonics-electronics convergence devices, building the mobile fronthaul based on the APN, and running vRAN (virtual radio access network) software on the SWB.

By further developing APN IOWN1.0 and implementing its benefits such as shorter lead times for line installation and expansion, increased capacity and guaranteed network quality compared with the conventional use of dark fiber, we plan to work with our customers to apply APN IOWN1.0 to datacenter

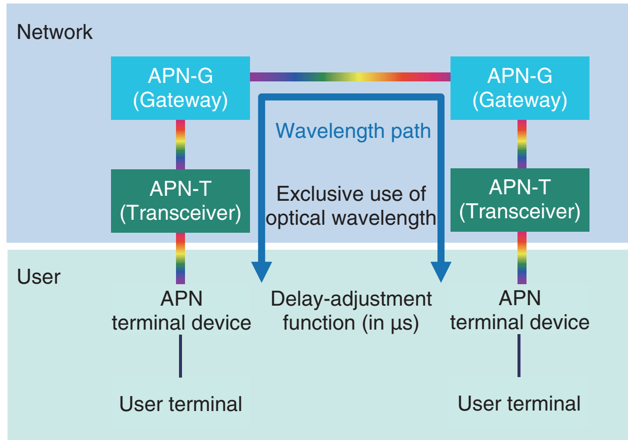


Fig. 5. APN IOWN1.0.

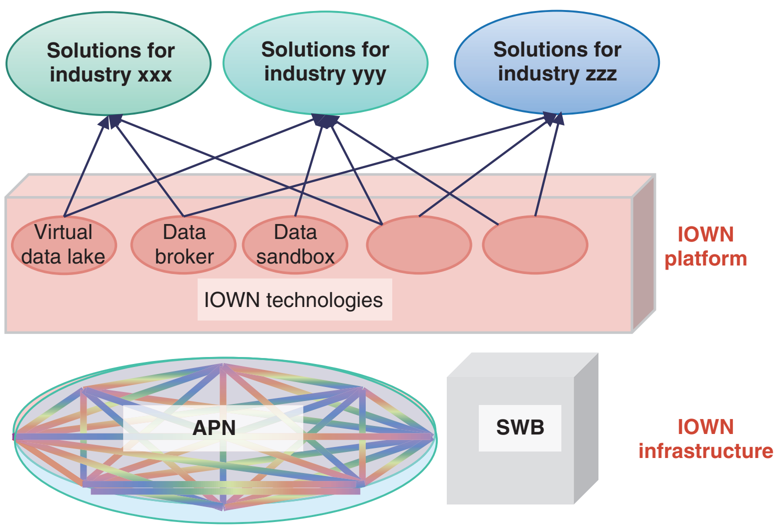


Fig. 6. Development as a solution service.

interconnects, smart factories, and 6G services.

2.4 ICT-solutions area

In addition to developing the IOWN infrastructure, such as the SWB and APN for high-speed, large-capacity, and low-power data transmission, NTT laboratories are also researching and developing security technology and data-processing technology that can take advantage of the characteristics of the IOWN infrastructure. For example, these IOWN technologies include (i) virtual data lake, which can obtain and use necessary data from data distributed in multiple locations quickly and efficiently; (ii) data broker, which enables efficient data transmission and reception among multiple locations; and (iii) data sandbox, which allows different organizations to execute data and algorithms while keeping them secret from each other [1].

We will construct the IOWN platform by combining the IOWN infrastructure and IOWN technologies to help many customers address business issues and develop new business solutions in a wide range of industries by using real-time processing of widely distributed data and safe and secure data distribution as the foundation for creating new value (**Fig. 6**). While expanding the IOWN technologies, we will also develop human resources as consultants with a deep understanding of the value provided by IOWN. We will thus promote various initiatives to create a world where people can widely benefit from IOWN—from the provision of best practices in specific industries to horizontal deployment in other industries.

3. Conclusion

The deployment areas of IOWN targeted by NTT IOWN Integrated Innovation Center were presented in this article. We will promote a wide range of practical applications of IOWN in collaboration with various parties so that various stakeholders can enjoy a new value as early as possible in a more effective manner.

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

APN-controller Technology for IOWN Service Provision and Expansion

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Abstract

The All-Photonics Network (APN), which is the basis of the Innovative Optical and Wireless Network (IOWN), has the characteristics of high speed, large capacity, low latency, and low power consumption compared with conventional networks. We aim to provide services that take full advantage of these characteristics as early as possible and expand their use. To operate high-quality services with these capabilities, the role of controllers has become more important than in conventional networks. In this article, we explain the APN-control function and APN-information-collection/analysis function, which are the main pillars of the APN-controller technology, as well as the value-added functions to implement the IOWN service.

Keywords: IOWN, APN controller, information collection and analysis technology

1. Introduction

To achieve high speed, large capacity, low latency, and low power consumption in the All-Photonics Network (APN), which is the basis of the Innovative Optical and Wireless Network (IOWN), and provide open interfaces to offer a wide variety of services and quickly and flexibly handle various network components, the role of the APN controller (APN-C), which manages and operates the APN, has become important. Therefore, we are developing functions of the APN-C to expand the use of services that use the APN.

We are also actively researching and developing value-added functions such as services that make maximum use of low latency, which is one of IOWN's characteristics, and security functions that will be essential in the future.

2. APN-C overview

The main functions of the APN-C are the APN-control (end-to-end (E2E) path setting) function, which is the basis for providing E2E services in multi-vendor, multi-carrier networks, and APN-operational-sophistication and intelligent functions that control the opening, maintenance, and information gathering functions necessary for business execution.

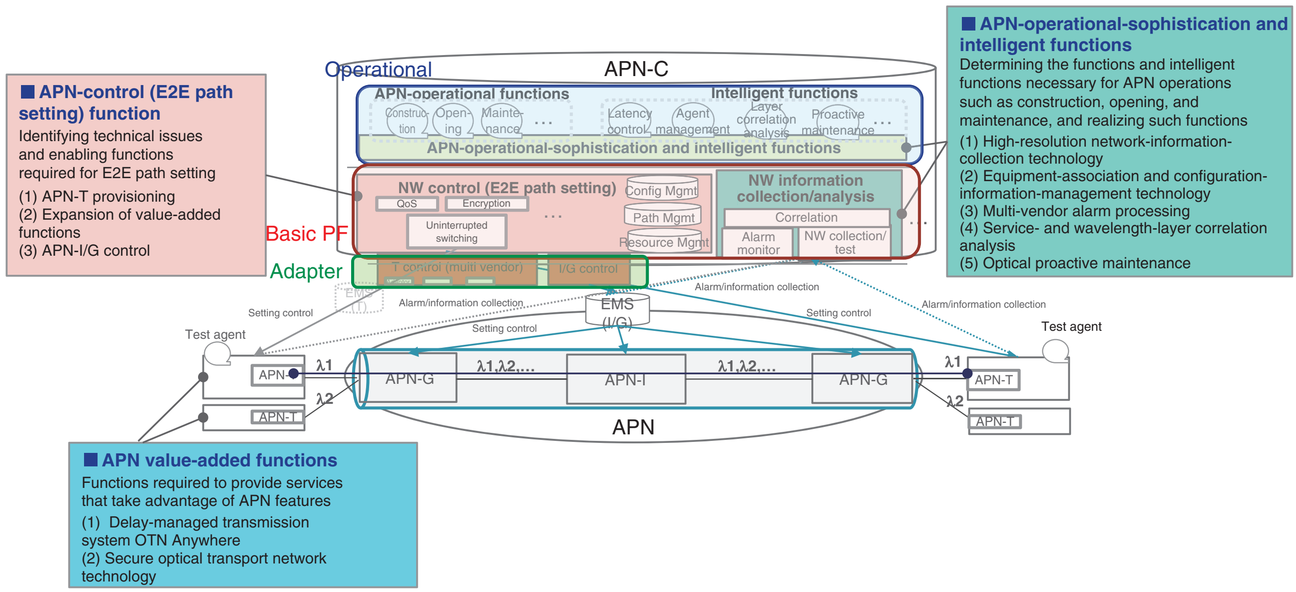
Regarding the APN-control function, we aim to achieve a complete E2E path setting, including final relay transmission equipment (APN-I[*1]/G[*2]) and terminal (APN-T)[*3] [1] control. It provides terminal-control functions that enable control of a variety of APN-Ts to become endpoints, as well as E2E path design and settings at APN-I/Gs.

To enable E2E operation in multi-vendor and multi-carrier networks, the APN-operational-sophistication

*1 APN-I: An interchange for wavelength switching at the midpoint of an Open APN optical path. To provide a direct optical path between any two endpoints, APN-I should have the following two functions; (1) wavelength cross-connect and (2) adaptation between interfaces.

*2 APN-G: A gateway for an optical path to permit optical transmission with the designated wavelength originating from APN-Ts.

*3 APN-T: An endpoint for an optical path. It transmits and receives optical signals on a path that utilizes a designated wavelength.



EMS: element management system
NW: network
PF: platform
QoS: quality of service

Fig. 1. APN-C implementation image.

and intelligent functions are necessary for APN maintenance operations such as information collection and alarm monitoring, and visualization analysis across optical and service layers. They also include operational and intelligent functions such as visualization analysis that spans optical and service layers and proactive maintenance that uses performance monitoring (PM) information (**Fig. 1**).

3. APN-C configuration

The basic policy for developing the APN-C's functions is to start small in line with the development of the APN and be able to provide functional parts as needed. The basic configuration is a three-layer structure consisting of the basic platform (PF) (i.e., a network management system (NMS)), adapter (equipment control), and operational intelligence. By developing the operational-intelligent and adapter component, it is possible to respond flexibly and quickly to new equipment and the addition of equipment functions. The APN, to which the initial APN-C is applied, has a single vendor's APN-I/Gs. Regarding an APN-T, we will enable wavelength connectivity for each vendor's equipment.

4. Details of APN-control function (E2E path setting)

For the E2E path setting with APN-Ts as both endpoints, including those compatible with open interfaces such as OpenROADM (reconfigurable optical add/drop multiplexer), the APN control function (E2E path setting) includes (1) APN-T provisioning for E2E path setting, (2) expansion of value-added functions, and (3) APN-I/G control.

(1) APN-T provisioning

APN-T provisioning provides an E2E-path automatic connection system to seamlessly connect an APN-T, including user-owned multi-vendor transceivers, and an APN-I/G. Specifically, there are technologies that execute parameter tuning for each pass and speed conversion that flexibly changes the speed of the line side to match the client side. As a network method, when the APN-C and various APN-Ts are connected, rechargeability is achieved in-channel using OSC (Optical Supervisory Channel) or maintenance wavelengths.

(2) Expansion of value-added functions

We are investigating controller-system-configuration technology that can easily accommodate the addition of variations in terminals that the APN-C

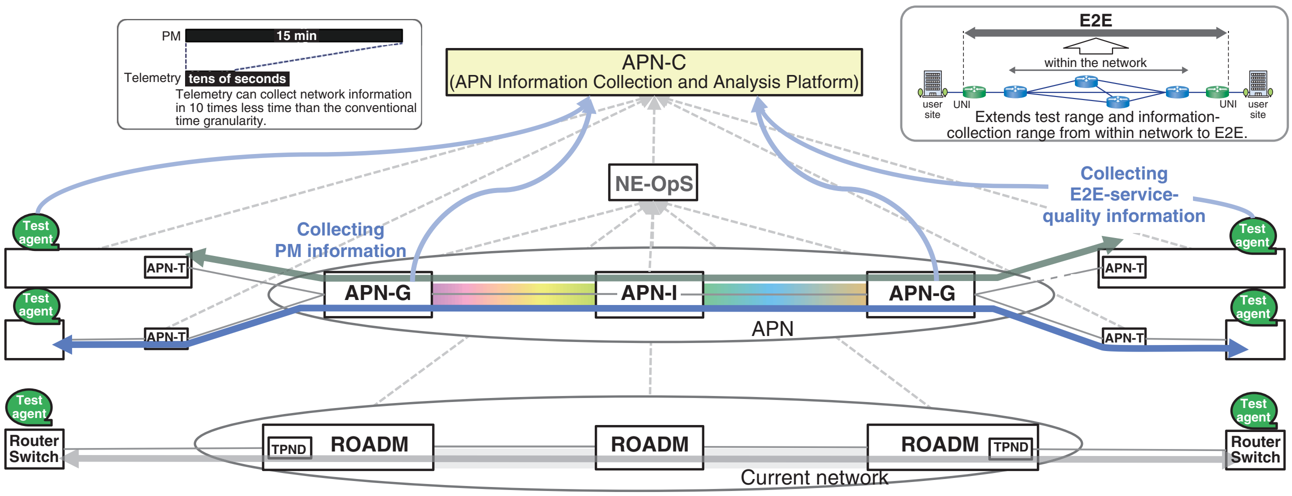


Fig. 2. High-resolution network-information-collection technology.

should control, including multi-vendor and various added value additions. Specifically, we are clarifying control scenarios for value-added functions, such as the delay-managed networking technology OTN Anywhere and secure transport network technology, and examining control-implementation methods using OpenROADM.

(3) APN-I/G control

To support various APN-Ts as APN-I/G control, we developed wavelength-allocation technology for each path in the relay-transmission section (APN-I/G), including NE-OpS (network element-operations system) coordination. It enables dynamic path setting of detour routes when a failure occurs in a relay section.

5. Details of APN-operational-sophistication and intelligent functions

The APN-operational-sophistication and intelligent functions enable E2E operation in multi-vendor, multi-carrier networks and include (1) high-resolution network-information-collection technology, (2) equipment-association and configuration-information-management technology, and (3) multi-vendor alarm processing (essential for management and operation with wavelength unit) and (4) service- and wavelength-layer correlation analysis and (5) optical proactive maintenance (essential for achieving operational efficiency and added value in the APN).

(1) High-resolution network-information-collection technology

This technology enables detailed and flexible information collection using telemetry and E2E test agents (**Fig. 2**) to provide detailed and proactive maintenance not available in conventional operations. This technology consists of two elements.

The first element, enhanced adaptive information collection, collects large amounts of data at high speed. By supporting telemetry-based information collection, it is possible to collect and use various types of information, such as performance monitoring at the wavelength layer (transmission layer), in several dozen seconds. This is more than 10 times shorter than the conventional time granularity. It also enables highly efficient information collection by actively switching data formats, frequencies, and destinations in accordance with the state of the network equipment or network conditions, for example, by collecting data at high frequencies and intensively only when degradation in communication quality is detected.

The second element, E2E test-information collection, enables testing and information collection using test agents that can be deployed at user sites. A test agent is a software application that can run on the basis of the Linux operating system. It can be used on white box switches (WBS), routers, and small terminals such as Raspberry Pi. Regarding WBS, the APN-C enables automatic deployment of agents (remote deployment) and detailed test control and collect test results such as service connectivity and network throughput. This element extends the test range from within a network to E2E.

(2) Equipment-association and configuration-information-management technology

This technology refines and systemizes network-configuration management across multiple vendors' network devices, which has been a challenge due to the lack of systemization and manual management, for the APN, which is complex to manage due to the mix of various user terminals. This technology consists of two elements.

The first element, vendor-oriented configuration association, uses optical input/output analysis of the opposite section to automatically and accurately determine the connection relationship. By comparing the timing of optical input/output fluctuations between opposite interfaces, this element always provides correct configuration information from an APN-T to an APN-G section and the section spanning multiple vendors' network devices such as between a router and ROADM in an existing network.

The second element, interlocking test at wavelength-path setting, automatically identifies the service associated with the wavelength path (equivalent to a user virtual private network) when the path is set in the APN and simultaneously executes a connectivity test, ensuring service connectivity.

These two elements are designed to work on the APN-C. By combining them during wavelength-path setting, it is possible to feed information, such as correct connection relationships and service connectivity, back to the configuration information managed by the APN-C.

(3) Multi-vendor alarm processing

Multi-vendor alarm processing provides the same level of maintainability in a network consisting of multiple vendors (mainly between APN-I/Gs and APN-Ts) as in a conventional network consisting of only a single vendor. In a single-vendor network, when a failure occurs, E2E information is available, and the main cause and sub-cause alarms that contribute to isolation can be determined by the vendor's OpS and NMS. In a network consisting of multiple vendors, however, it is possible to identify (isolate) the main cause alarms within the range closed to each vendor, but since there is no entity to unify and analyze information across E2E that spans multi-vendors, it becomes difficult to isolate the main cause of the failure in E2E. This technology instantly correlates the configuration information over E2E collected and managed by the APN-C with the alarm information when a failure occurs. In addition to estimating the cause of the failure in E2E by alarm type, it also analyzes the configuration information, including the connection relationship between devices and upstream and downstream communication, to identify the main cause alarms in E2E, even in networks consisting of multiple vendors.

(4) Service- and wavelength-layer correlation analysis

This technology analyzes various device and network information across service and wavelength layers to provide rapid maintenance in an environment that spans multi-network layers (**Fig. 3**). This technology is composed of two elements.

The first element, layer-spanning impact analysis, enables the understanding of failure impact across layers from network information collected at both service and wavelength layers (traffic flow, result of E2E test, PM information) and network-configuration information. For example, it is possible to clarify which user communications in the service layer above the wavelength layer are affected by a failure occurring in the wavelength layer.

The second element identifies service-affected sections across layers and calculates the correlation of data variations, such as traffic, PM information, and E2E test result, at both service and wavelength layers. It then enables accurate and rapid identification of affected sections, such as which section is the causal section of a failure, on the basis of the collapse of correlations.

(5) Optical proactive maintenance

Optical proactive maintenance is aimed at preventive maintenance through monitoring and optical measurement of optical devices. The technology consists of the following three elements.

The first element, estimating the degradation and predicting the failure timing of optical devices inside the APN-I/G, uses a combination of continuous monitoring along the optical path and time-series outlier analysis to estimate the degradation and predict the failure timing of the optical devices inside the APN-I/G.

The second element, in-service estimation of optical signal (wavelength) quality, enables optical signal branching (multicasting) at APN-I/Gs and uses unused functions of the digital signal processor (optical signal-to-noise ratio measurement, chromatic dispersion estimation, differential group delay measurement, etc.) to estimate optical-signal quality on arbitrary sections, independent of signal speed and modulation scheme.

For the third element, estimating the quality of transmission lines (tunnels through which optical signals (wavelengths) pass) using APN-I/Gs, we will

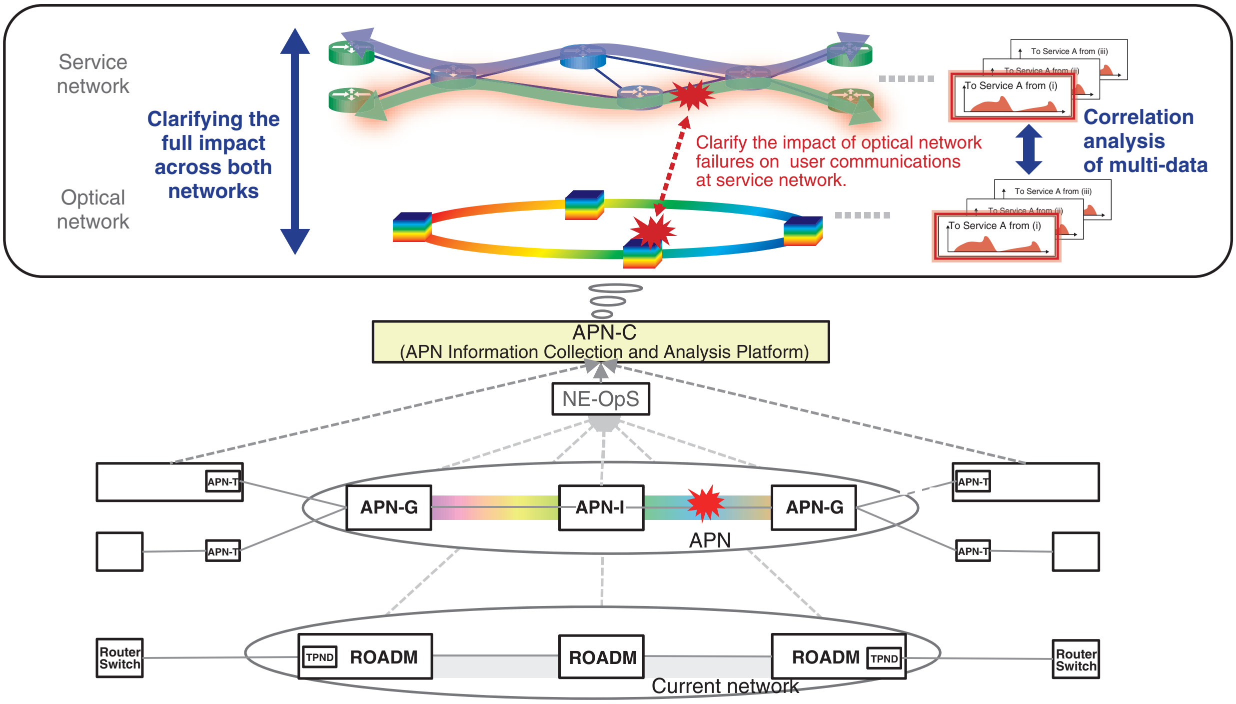


Fig. 3. Service- and wavelength-layer correlation analysis technology.

implement high-resolution and high-frequency input/output optical-level-monitoring functions and transmission-line fiber-monitoring functions using APN-I/Gs and develop analysis techniques to estimate that waveform distortion and optical noise in each section are within a desired range.

6. Details of APN value-added functions

We introduce two APN value-added functions.

6.1 Delay-managed networking technology OTN Anywhere

In 2022, we developed OTN Anywhere, which is connected to the edge of the APN, to offer extra value to end customers. It can be connected to various transmission systems worldwide via the standard interface of OTU4 (optical transport unit 4), which is specified in the Optical Transport Network (OTN) standards of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T). OTN Anywhere can be installed at customer premises and can directly transfer the user signal into the OTN, which enables 100% dedicated capacity, ultra-low latency approaching physical limit, and no latency fluctuation. In addition to the above features, OTN Anywhere has the newly developed functions of delay measurement and delay adjustment. These functions can provide unprecedented user experience (UX) to the customer in various use cases, especially latency-sensitive and interactive remote activities.

OTN Anywhere provides delay measurement and delay adjustment for E2E ODU (optical data unit) paths [2]. The delay-measurement function can measure round-trip delay with microsecond accuracy. OTN Anywhere can also offer delay adjustment if needed. These two functions enable the flexible control of communication latency and can enable, for example, fair remote e-sports competitions between multiple cities by controlling network latency. The two functions are implemented in layer 1 and independent from upper-layer protocols, so they support many use cases.

We have just taken the first step of APN IOWN1.0 by developing OTN Anywhere. We would like to evolve the APN by continuously creating new functionalities and technical innovations. In the near future, the APN-C will control not only various optical-transport equipment but also OTN Anywhere and provide E2E communication paths seamlessly to offer unprecedented UX to every customer.

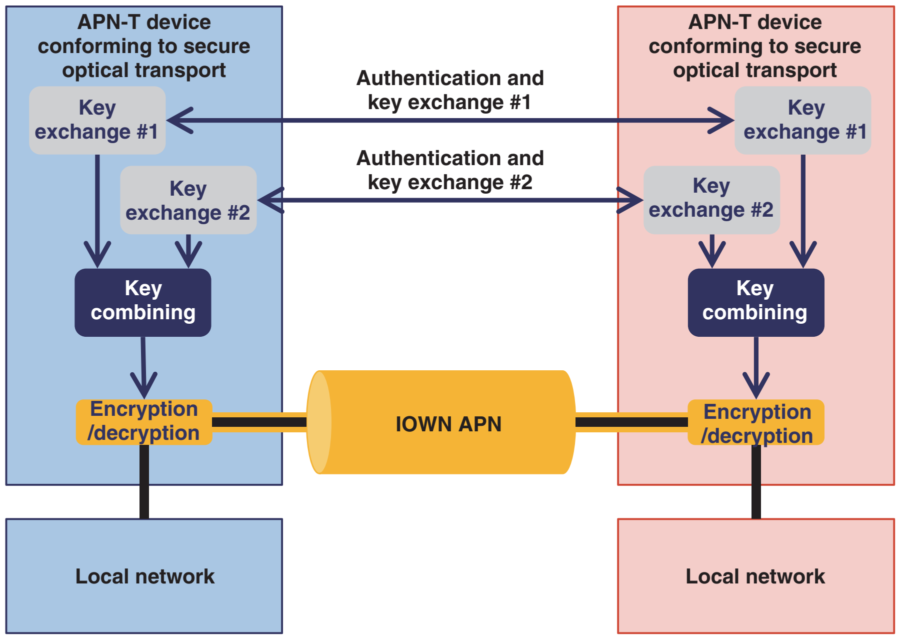


Fig. 4. Specific example of MFS.

6.2 Secure optical transport network technology

Promising applicable fields of the APN include finance, healthcare, and other areas where protection of systems and information systems are critical. One possible way to further improve APN security is to address crypto agility [3, 4]. Crypto agility is a concept proposed by National Institute of Standards and Technology (NIST), and its major aim is to minimize the impact of migration of the cryptographic algorithms of networks and systems. This will be accomplished by switching the cryptographic algorithm in a short or no maintenance window in preparation for compromise or adoption of new cryptographic algorithms.

NIST has also promoted a standardization of post-quantum cryptography (PQC), a cryptographic algorithm based on the difficulty of mathematical complexity as the basis for its safety, which even quantum computers cannot solve effectively at present. PQC is expected to be implemented in the future. However, PQC is a work in progress, and it is quite possible that new attack vectors will be discovered and compromised.

NTT Social Informatics Laboratories and NTT Network Innovation Laboratories are engaged in research and development of secure optical transport network technology [5, 6] as a crypto-agility-enabled system to provide continuous secure operation while taking advantage of APN features. This technology adds an encryption function, which is considered secure even in the quantum-computer age, to the communication between two points, such as APN-Ts. Elastic key control technology is one of the features that enhances the security level of the encrypted communication. It switches flexibly between any combination of cryptographic algorithms used for key exchange, such as conventional cryptography, PQC, and pre-shared key (PSK). This technology enables us to maintain security even if one of the cryptographic algorithms operating simultaneously will be compromised, and to switch to new cryptographic algorithms easily. Secure optical transport network technology enables these operations without a maintenance window of the network or system.

The IOWN Security (IOWNsec) Taskforce, which was formed in the IOWN Global Forum, is currently discussing ideal frameworks and use cases of quantum-resistant security required for IOWN in the quantum-computer era. It is proposing a concept called Multi Factor Security (MFS) that enables quantum secure E2E communication. Elastic key control technology is one of the conceptual implementations based on the MFS concept (**Fig. 4**).

7. Future prospects

We introduced the APN-C, which is the basic technology for quickly implementing IOWN services using the APN and value-added functions. With the aim of creating a network that can be designed and operated by multiple vendors and carriers, we will continue to study further operational sophistication and advance research and development to achieve the APN, which is fully disaggregated.

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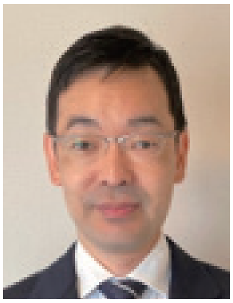

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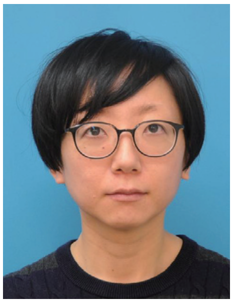

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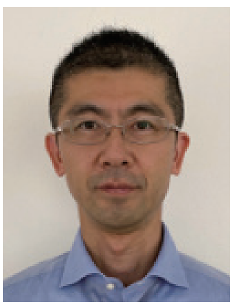

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Data-centric Infrastructure for Supporting Data Processing in the IOWN Era and Its Proof of Concept

Ryosuke Kurebayashi, Teruaki Ishizaki, Sampath Priyankara, Christoph Schumacher, and Shintaro Mizuno

Abstract

"Data-centric infrastructure" is an information and communication technology infrastructure for highly efficient processing of data scattered over a wide area, and in a data-driven society, it is expected to be used as the foundation of large-scale cyber-physical systems (CPSs). The concept of a data-centric infrastructure, which effectively uses accelerators and the All-Photonics Network to provide a data-processing pipeline, is outlined in this article. A step-by-step demonstration of the concept is introduced by using video analysis as a use case concerning a CPS.

Keywords: data-centric infrastructure, disaggregated computing, accelerator

1. Towards creation of a data-driven society

Owing to recent improvements in sensing technology and advances in Internet of Things, digital transformation, and artificial-intelligence (AI) technology, the data-driven society is upon us. The data-driven society aims to address social issues and create new value by distributing and combining various types of data in physical space (i.e., the real world) and cyberspace (i.e., the online world of the Internet, computers, etc.) across a wide range of industries and fields. One of the core systems supporting this data-driven society is a cyber-physical system (CPS). A CPS analyzes vast amounts of data obtained from physical space in cyberspace and feeds the analysis results back to the real world for optimal control in the real world. CPSs have begun to be used in specific fields, such as constructing smart factories and traffic optimization. In the data-driven society, these various CPSs must be scaled up, applied to all fields, and interconnected.

While various technical issues need to be addressed before a large-scale CPS can be implemented, this article focuses on the information and communication technology (ICT) infrastructure responsible for data processing. It had been sufficient to process data in individual CPSs siloed by purpose and processing method. In contrast, a large-scale CPS will lead to two capabilities: (i) high-speed distribution of data among far-more-numerous and geographically dispersed entities (humans, systems, devices, etc.) that distribute more data than is currently possible and (ii) analysis of a much larger variety and volume of data. The ICT infrastructure to support such a large-scale CPS must provide a network connection with high quality of service (QoS) between geographically dispersed entities, sufficient computational resources responsible for analysis, and a highly efficient data-processing pipeline without bottlenecks to meet the enormous computing-resource demands.

2. Data-centric infrastructure

Focusing on an ICT infrastructure that can meet the

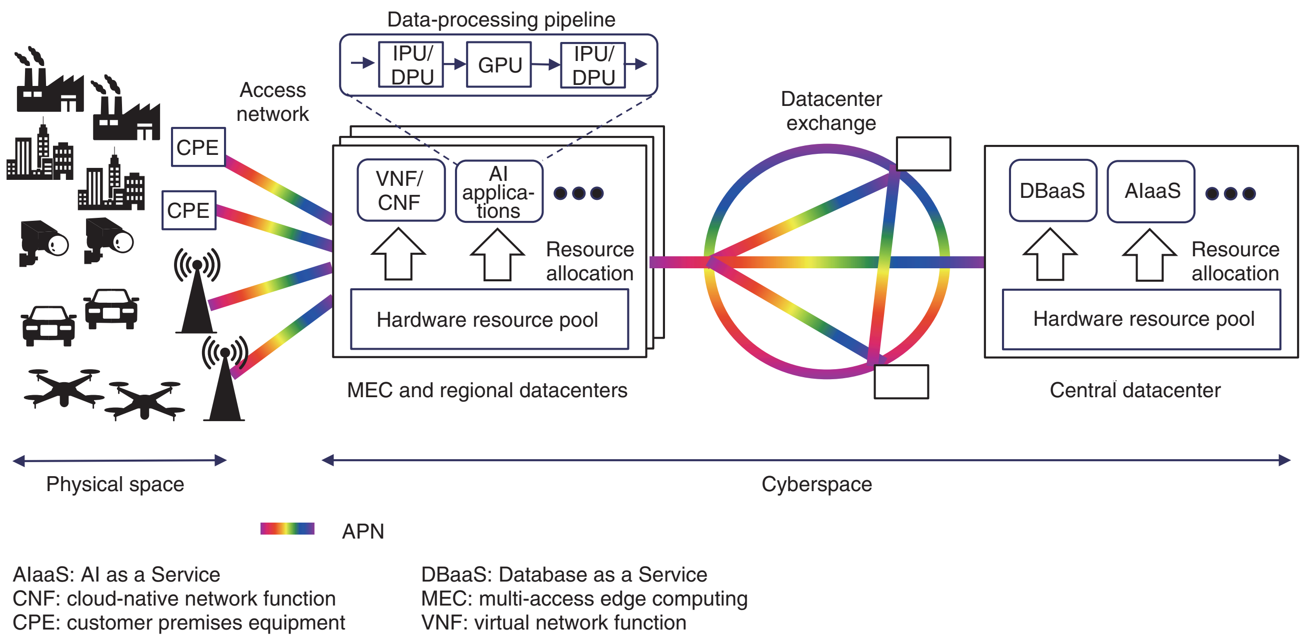

Fig. 1. Illustration of implementation of CPS using DCI.

requirements of a large-scale CPS, NTT is considering a data-centric infrastructure (DCI) subsystem that uses the Innovative Optical and Wireless Network (IOWN). The DCI is an ICT infrastructure that efficiently processes data scattered over a wide area in physical space and cyberspace by optimally combining widely distributed computing resources. The implementation configuration of a large-scale CPS based on the DCI is shown in **Fig. 1**. The main features of the DCI are listed below and explained hereafter.

- Highly efficient data-processing pipeline using accelerators
- Integration with the All-Photonics Network (APN)
- Formation of an open ecosystem

2.1 Highly efficient data-processing pipeline using accelerators

The first feature of the DCI is a highly efficient data-processing pipeline that uses accelerators. Conventional data processing is focused on software processing on a host central processing unit (CPU). Various accelerators have been used in areas where computational costs are high. Typical examples of accelerators are graphics-processing units (GPUs) for AI and media processing and smart network-interface cards (NICs), infrastructure-processing units (IPUs), and data-processing units (DPUs) for network processing. These accelerators provide highly efficient parallel processing in specific areas and use hardware such as application-specific integrated circuits (ASICs) and field-programmable gate arrays (FPGAs) to increase processing speed. The DCI actively uses these accelerators to increase the efficiency of the data-processing pipeline.

The challenge with using accelerators as an extension of conventional technologies is to reduce bottlenecks caused by the host CPU. As shown in **Fig. 2(a)**, a host CPU is required as an intermediary to manage data transfers even when an accelerator is used during data processing. This intermediary communication handling results in a bottleneck on the host CPU and limits the number of accelerators that can be effectively handled.

Accordingly, as shown in **Fig. 2(b)**, the DCI shifts from a data-processing pipeline involving the host CPU to a mechanism by which data are transferred between accelerators in a more-autonomous manner and further processed. To create this mechanism, we are investigating remote direct memory access (RDMA), which can arrange data on remote memory without intervention by the host CPU, communication-protocol-based processing by hardware using ASICs, FPGAs, etc., and direct data transfer between accelerators. We are also investigating methods to

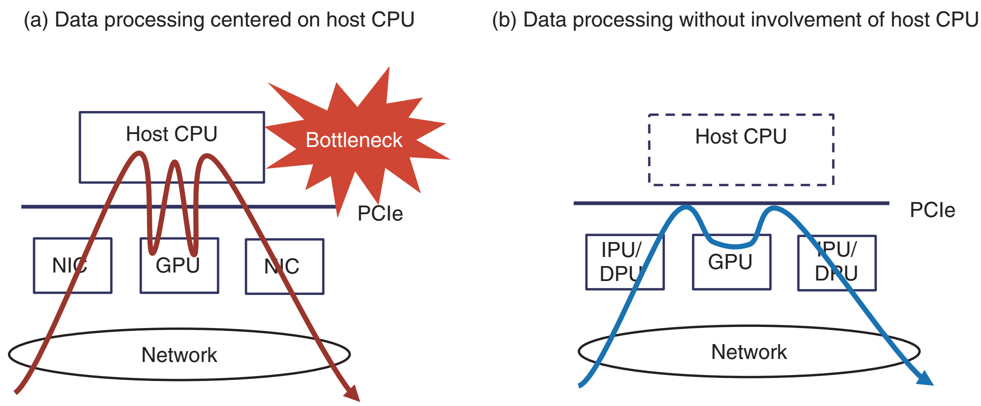

Fig. 2. Data processing without involvement of host CPU.

offload execution control, such as data-arrival detection and start-instructions processing, to the accelerators.

For an accelerator-based data-processing pipeline, it is essential to select and combine the right accelerators for a certain workload. However, the type and number of accelerators required also depends on the workload. As a result, the conventional configuration of infrastructure—which is based on servers as the basic unit—results in many wasted accelerators. In other words, when servers with uniform configurations of accelerators are arranged, depending on the workload, some accelerators will be used and others will be unused. To accommodate all workloads, however, it is impractical to have a large number of servers with different patterns of accelerator configurations in advance.

In response to the above issues, as shown in **Fig. 3**, the DCI uses a hardware resource pool, which pools the multiple devices (including accelerators) that conventionally comprise a server by connecting them via a high-speed interconnect. The optimal number of devices for a given workload are then selected from the pool and allocated. Devices that are no longer needed can be returned to the pool and made available for reuse or turned off. Therefore, the use of a hardware resource pool allows accelerators to be flexibly selected and reused in a manner that dramatically increases device utilization compared with that in the case of the conventional infrastructure configured in units of servers.

A hardware resource pool can be configured at several different layers. On the first layer, a bare-metal server is formed at the hardware level (Fig. 3(1)). Composable disaggregated infrastructure (CDI) products that extend the Peripheral Component Interconnect Express (PCIe) standard as an interconnect and link arbitrary devices to the host CPU are beginning to be commercially offered [1]. As the next-generation interconnect standard Compute Express Link (CXL) [2] becomes more widely used, it is expected to unify standards and expand functions. On the second layer, under the assumption that bare-metal servers that are connected to a collection of devices required for specific applications or tenants, workloads and/or data flows on the devices are appropriately managed at the software level on a finer-grained basis (Fig. 3(2)). As data-processing pipelines that do not involve a host CPU become mainstream, the effective size of the accelerator that can be handled by a single host CPU will increase. Consequently, the importance of resource management at the software level, as shown in Fig. 3(2), is expected to increase. The DCI will be implemented by flexibly combining these layers in accordance with use cases and diffusion of the technology.

2.2 Integration with the APN

For the DCI, the high-speed, high-quality APN is used for the access network that connects physical and cyberspace and for the connections between datacenters (which form a datacenter exchange). This feature helps configure data-processing pipelines that span wide areas between devices and datacenters without forming bottlenecks. It is envisioned that optical networking technologies, such as the APN, will be applied to not only wide-area networks but also intra-datacenter networks and interconnects in hardware resource pools.

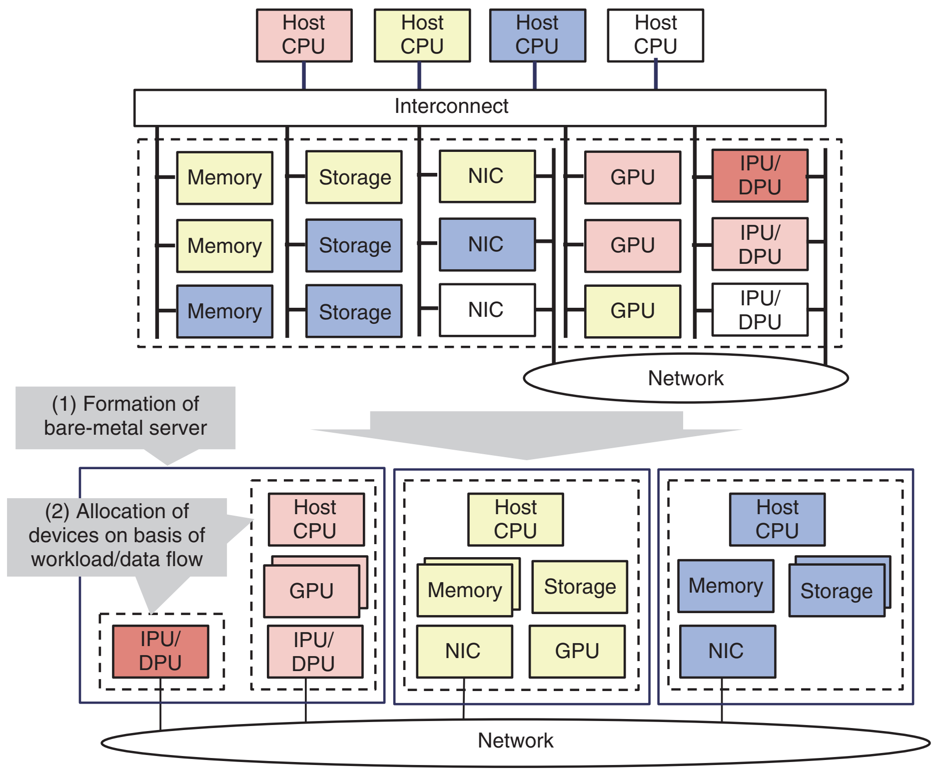

Fig. 3. Concept of hardware resource pool.

2.3 Formation of an open ecosystem

The implementation of the DCI requires a restructuring of technology that spans a wide range of disciplines—from networking to computing and from hardware to software. It is therefore important to establish an open ecosystem in which many companies can participate and pool their knowledge. For that reason, the DCI is being discussed within the global community, at bodies such as the IOWN Global Forum (IOWN GF), and its embodiment is being promoted through steady consensus building. Discussions of the DCI at IOWN GF have focused mainly on efficiency and management of hardware resources. In particular, IOWN GF is considering the formation of logical service nodes (typically corresponding to bare-metal servers in Fig. 3(1)), which are a set of devices allocated for specific applications, and the allocation of network resources among logical service nodes in consideration of QoS. The application of RDMA technology over the open APN to speed up data transfer between logical service nodes is also being discussed. The second edition of the document that summarizes these results, DCI Functional Architecture, has been published [3].

3. Proofs of concept

NTT Software Innovation Center is researching and developing disaggregated computing as one of the technologies to implement a highly efficient data-processing pipeline using accelerators, which is a feature of the DCI. To increase the scale of a CPS, we are progressing step by step with proofs of concept (PoCs) for disaggregated computing. The following two PoCs concerning real-time video analysis with a CPS are introduced hereafter (**Fig. 4**).

- PoC-1: Video-analysis pipeline using various accelerators
- PoC-2: Disaggregated computer controller to implement the “as a service” model

3.1 PoC-1: Video-analysis pipeline using various accelerators

In this PoC, we demonstrate the effectiveness of a data-processing pipeline that combines various accelerators. Specifically, the video-analysis unit shown in Fig. 4, in which eight 4K cameras are used for detecting people, is the focus. The power consumption is then reduced by optimally configuring the data-processing

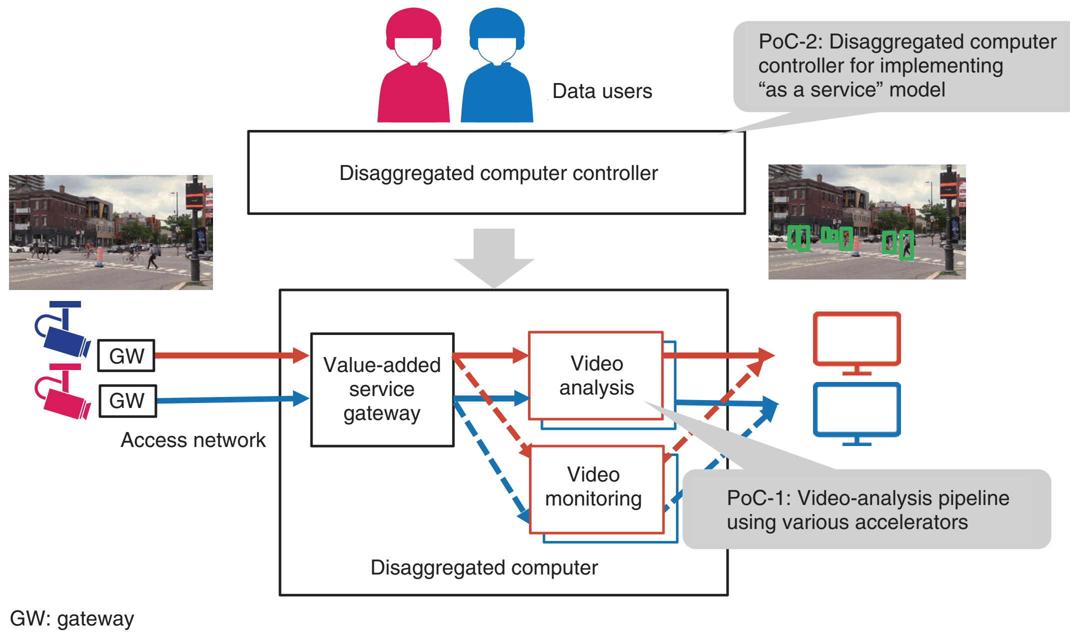

Fig. 4. Proof of concept using disaggregated computer.

pipeline for detecting people in accordance with changes in the flow of people during the day and night. This PoC is officially recognized by IOWN GF as a PoC conducted in accordance with the PoC Reference for the DCI [4].

The configuration of the video-analysis unit considered in this PoC is shown in **Fig. 5**. Camera images from the distribution servers are first input into FPGAs and decoded. For pre-processing by FPGAs, the images are then filtered and resized, and the resized images are subjected to video inference on GPUs to detect the presence of people. For the video inference, it is assumed that advanced inference and lightweight inference are used as follows.

- Advanced inference: For cameras that have captured people in previous frames, the video images are subjected to highly accurate person detection, which prioritizes detection accuracy and infers a person’s presence from high-quality images at high frame rates.
- Lightweight inference: For cameras that have not captured people in previous frames, the video images are subjected to low-power-consumption, rough person detection, which prioritizes power efficiency and infers a person’s presence from low-quality images at low frame rates.

During the daytime, more people are present in the scenes, so more cameras execute advanced inference; in contrast, at nighttime, fewer people are present, so more cameras execute lightweight inference. Thus, the daytime and nighttime workloads vary, so the data-processing pipeline is configured in accordance with the processing and computational load required for each scene (daytime or nighttime). The upper and lower parts of Fig. 5 show the data-processing pipelines for daytime and nighttime scenes, respectively. To demonstrate the concept of using a variety of accelerators, the data-processing pipeline of the video-analysis unit uses FPGAs and GPUs. To execute data processing without the aforementioned CPU intermediary, the FPGAs are equipped with NIC functions and proprietary circuits specialized for data transfer. That is, the FPGAs are used for decoding and pre-processing, and the GPUs are applied for inference processing. A high-performance GPU (NVIDIA A100) is used for advanced inference, and a power-saving GPU (NVIDIA T4) is used for lightweight inference. As shown in Fig. 5, the data-processing pipeline for daytime scenes is allocated more FPGAs (four) for advanced inference at higher frame rates, while the data-processing pipeline for nighttime scenes is allocated fewer FPGAs (two) for lightweight inference at lower frame rates.

The scheme used for communication between accelerators is described next. The video-coding stream from the cameras is input to the decoding

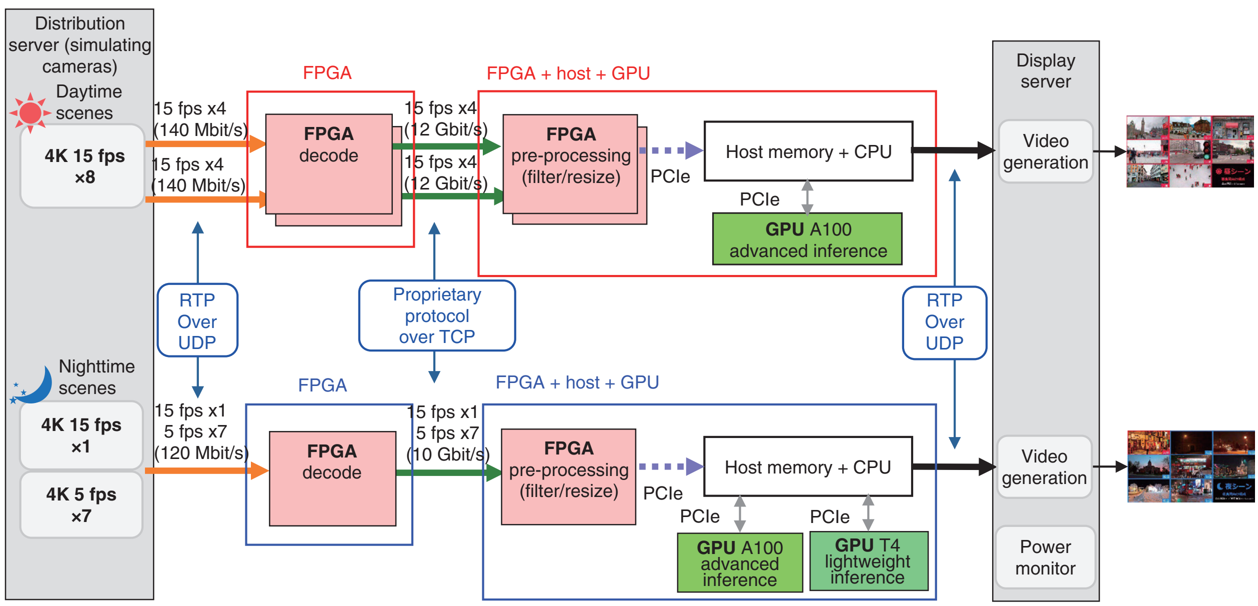

Fig. 5. Configuration diagram of video-analysis unit of disaggregated computer.

processor using the Real-Time Transport Protocol (RTP) over the User Datagram Protocol (UDP). The decoded video is then transferred to the pre-processing section at a later stage using a proprietary protocol over Transmission Control Protocol/Internet Protocol (TCP/IP). The protocol processing is terminated by the FPGAs, and the payloads are directly deployed on the memories for the user circuits of the FPGAs. This scheme achieves the effect of hardware offloading of protocol processing. In particular, the FPGA that executes the decoding process completes a series of processes from video reception to decoding and transmission within the FPGA; in other words, data processing becomes autonomous without the need for a host CPU. Data transfer from the FPGAs, which execute pre-processing, to the GPUs, which execute inference processing, is also executed on a proprietary-DMA basis with little overhead on the host CPUs, although the data are transferred through the host memory.

The power consumption of the video-analysis unit was measured. A conventional configuration (a typical configuration in 2020 was assumed) and the configuration of the video-analysis unit in Fig. 5, as well as their respective power consumptions, are compared in **Fig. 6**. Comparing the power consumptions of the video-analysis unit of the disaggregated computer and the conventionally configured computer for daytime scenes reveals that the power consumption of the former decreased from 2626.8 to 990.6 W (approximately 62% lower). This reduced power consumption is due to the fact that the video-analysis unit is highly efficient in terms of selecting the optimal accelerator, including hardware evolution (from NVIDIA T4 to A100), using accelerators in a wider range, including decoding and pre-processing, and transferring data efficiently between accelerators. Furthermore, comparing the power consumptions in the daytime and nighttime scenes confirms that the power consumption decreased from 990.6 W (daytime scene) to 696.7 W (nighttime scene). In other words, flexibly reconfiguring the pipeline in accordance with the scene can reduce power consumption from 2626.8 to 696.7 W (approximately 73% lower) compared with that of the conventional configuration.

Note that the video-analysis unit is intended for PoC and is subject to the following restrictions.

- The original circuit on the FPGA is a prototype implementation, and its power consumption can be further reduced by improving the implementation.
- Daytime and nighttime scenes are switched statically offline. In practical use, it will be necessary to upgrade the system for dynamic switching.

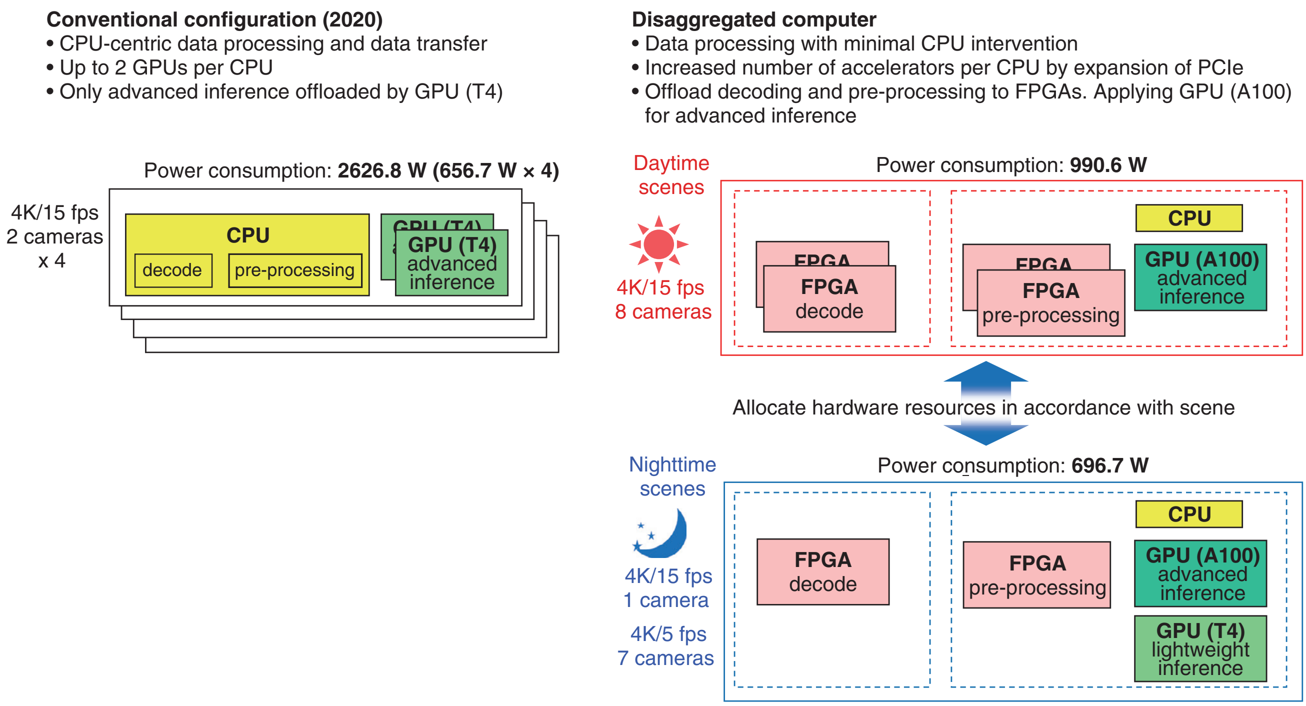

Fig. 6. Comparison of power in cases of conventional computer configuration and disaggregated-computer configuration.

3.2 PoC-2: Disaggregated computer controller that implements the "as a service" model

In PoC-2, we demonstrate that by using a disaggregated computer controller (DCC), data users without advanced expertise can easily configure data-processing pipelines that take advantage of accelerators. This PoC was exhibited at NTT R&D Forum 2023.

For this PoC, the data-processing pipeline shown in Fig. 4 is generated or reconfigured in response to requests from data users. The daytime scenes analyzed in PoC-1 are used as the video-analysis function in this PoC. Moreover, the video-monitoring unit forwards the video images appropriately for the observer. In this PoC, it is assumed there are multiple tenants. The value-added service gateway [5] aggregates and distributes the video images captured with the cameras, and a secure connection between the cameras and video-analysis and -monitoring units is provided for each tenant. In other words, generic routing encapsulation (GRE) tunnels are created and used to connect the cameras so that images can be separated for each tenant. The video data are then appropriately duplicated and distributed to the following processing units, namely, video analysis and video monitoring, in response to requests from the data users of each tenant. For this distribution, the GRE tunnels are converted to virtual local area networks.

The DCC plays an important role in this PoC. When the DCC receives a request from a data user to generate a data-processing pipeline or change the configuration of an existing pipeline, it automatically builds a data-processing pipeline for the video-analysis and video-monitoring units and changes the relevant setting, including that of the value-added service gateway unit. At that time, the data user can describe a blueprint of the requested data-processing pipeline in a YAML file that abstracts the details of the accelerator. The DCC is also responsible for software-level resource management (as shown in Fig. 3(2)). That is, it is assumed that many accelerators are already connected to the bare-metal server. According to the data-user request, the necessary accelerators are then allocated to the data-processing pipeline. The DCC is implemented by extending Kubernetes, namely, the de facto container orchestrator. Kubernetes custom resources are then used to manage the accelerators on the worker nodes (i.e., the bare-metal server mentioned above) and the connections between them.

Conventionally, the actual construction and operation of a data-processing pipeline using accelerators requires a high level of expertise and a great deal of time. The DCC appropriately hides this work and allows it to be provided as a service. This service allows data users to enjoy the benefits of accelerator-based data-processing pipelines while remaining focused solely on the functional aspects of data analysis.

4. Conclusion and future directions

We validated the concept of the DCI through a PoC using disaggregated computing. This PoC used video analysis via a CPS to demonstrate the effectiveness of data-processing pipelines using accelerators and the usefulness of the DCI as a service. In the future, we will promote practical application of the DCI by expanding its various operational functions while promoting its cooperation with the APN, which is another feature of the DCI. We will also expand the DCI to other use cases that use video and use cases other than video processing.

These results utilize technology under study in a joint research and development project with Fujitsu Limited [6].

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Photonics-electronics Convergence Devices Enabling IOWN—Development of Second- and Third-generation Devices

Shin Kamei and Yuzo Ishii

Abstract

This article presents second- and third-generation photonics-electronics convergence devices developed at NTT Device Innovation Center. The target applications and technical requirements for each generation of the devices are described. The advantages that can be obtained from photonics-electronics convergence devices and the technical points to achieve such advantages are also explained.

Keywords: photonics-electronics conversion, silicon photonics, co-packaged optics

1. Second- and third-generation photonics-electronics convergence devices

Second-generation photonics-electronics convergence devices are designed for use in digital coherent optical transceivers, which play an important role in optical communication network systems. By using a new optical technology called silicon photonics, we developed photonics-electronics convergence devices that make it possible to miniaturize optical transceivers and reduce their power consumption, and put them into practical use. In the first half of this article, the progress of digital coherent optical transceivers, advantages of silicon photonics, and features of photonics-electronics convergence devices we developed are described.

Third-generation photonics-electronics convergence devices are intended to provide short-distance optical connections between racks and printed circuit boards (PCBs) in datacenters. With the increase in wide-bandwidth applications such as artificial intelligence, machine learning, augmented reality, and extended reality, network traffic in datacenters is increasing, and the accompanying increase in power consumption is a major challenge. In the second half of this article, our approach to address this challenge, which focuses on a new packaging technology called co-packaged optics (CPO), is described.

2. Miniaturization of optical transceivers and application of silicon photonics

Digital coherent optical transmission technology can compensate for signal degradation in optical transmission by using powerful compensation on the basis of digital signal processing and has been developed for transmission over long distances, namely, from several-hundred kilometers to several-thousand kilometers. Digital coherent optical transmission technology is also being applied to relatively short-distance (about 100 km) transmission, such as datacenter interconnects (DCIs), for which growth in traffic is particularly noticeable.

The Optical Internetworking Forum (OIF) [1], an industry organization that develops technical standards for devices for optical transmission, stipulates requirements for power consumption and size of optical transceivers for digital coherent optical transmission. Every few years since 2012, OIF has published a new specification for digital coherent optical

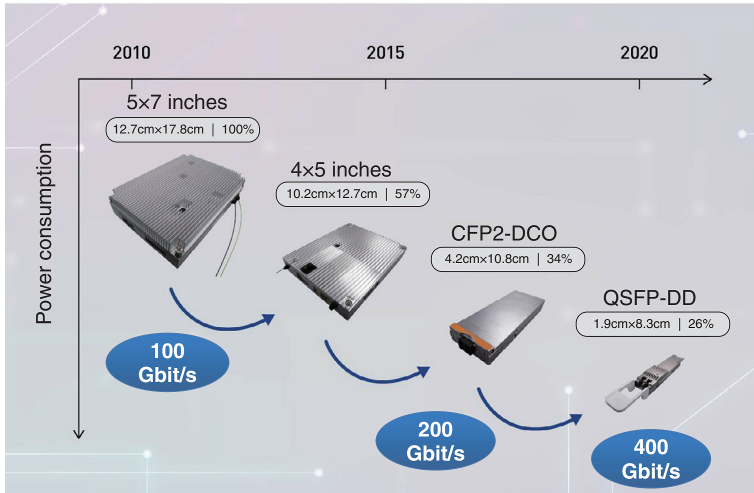


Photo courtesy of NEC Corporation

CFP2-DCO: Centum (100)-gigabit form-factor pluggable 2 digital coherent optics

Fig. 1. Trends in digital coherent optical transceivers.

transceivers requiring a reduction in size. As shown in **Fig. 1**, such transceivers are becoming smaller, lower power consuming, and have faster transmission speed. The size of the transceiver has recently been reduced from 5 × 7 inches (12.7 × 17.8 cm) in 2012 to about 2 × 8 cm today (quad small form-factor pluggable double density (QSFP-DD) [2]), and over that period, its transmission speed has increased from 100 to 400 Gbit/s while its power consumption has decreased by about 75%.

The need for smaller, lower power consumption, and higher-speed digital coherent optical transceivers is driven by the need for high-density installation of such transceivers in datacenters and other facilities. The demand for optical transceivers continues to grow annually, and the need for change to improve their cost performance and producibility is also growing.

A digital coherent optical transceiver consists of a digital signal processor (DSP), analog electronic circuit (driver), which amplifies electrical signals, and optical modulator, which converts electrical signals into optical signals and outputs them, on the transmitter side; an optical receiver, which receives optical signals and converts them into electrical signals, and analog electronic circuit (trans-impedance amplifier (TIA)), which amplifies electrical signals, on the receiver side; and a laser-light source that serves as the local light source for transmitting and receiving.

In conventional optical transceivers, optical devices such as optical modulators and receivers in the above-described configuration have been fabricated as individual packaged devices using optical material systems most suitable for their functions. For example, lithium niobate and indium phosphorus are used as materials for optical modulators. However, limitations on device size have made it impossible to miniaturize optical transceivers as required, so attention has turned to miniaturization and integration of optical devices through silicon photonics.

We at NTT Device Innovation Center recognized the potential of silicon photonics early on and have continued researching and developing it. The advantages of silicon photonics have long been considered its contribution to device miniaturization and high productivity based on the mature semiconductor fabrication process. However, it is difficult to implement a light-source function with silicon photonics, and functions such as optical wavelength filters (which require precise control of the phase of light) are not suited to silicon photonics. Its characteristics also depend on the polarization of light (i.e., high polarization dependence).

However, silicon photonics is a good match for digital coherent technology. The circuit configuration of the optical device of a digital coherent optical transceiver is shown in **Fig. 2**. The optical modulator consists of four modulation circuits and a polarization-beam combiner rotator, while the optical-receiver circuit consists of a polarization-beam splitter

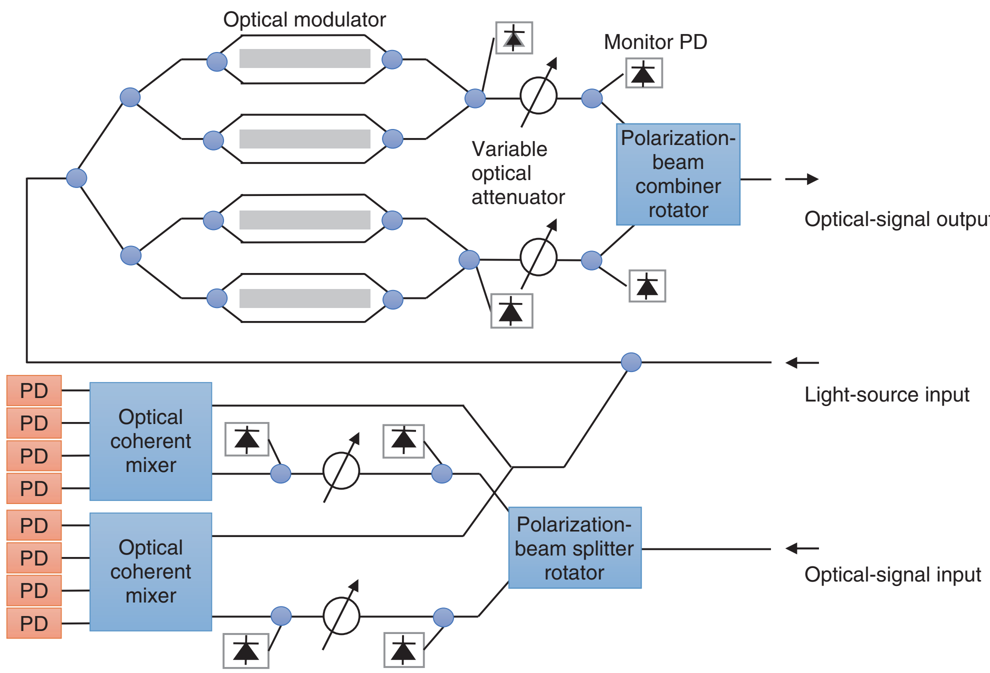


Fig. 2. Circuit configuration of optical devices for optical transceivers.

rotator, two optical coherent mixers, and eight photo detectors (PDs). Monitor PDs for monitoring optical-signal power for transmission and reception, and variable optical attenuators are also needed. These circuits do not require precise control of the optical phase, and their polarization dependence is not a problem because the polarization is processed separately. Silicon photonics, which has a large polarization dependence, is also suitable for circuits that control polarization such as a polarization-beam combiner rotator (splitter rotator). In conventional material systems, different optical components are integrated in the package to fabricate a polarization controller; in contrast, silicon photonics has the advantage in that different optical components can be integrated on a single chip. The integration of a large number of PDs with silicon photonics is also relatively easy.

Taking advantage of the above-described features of silicon photonics, we developed a silicon-photonics chip for optical transceivers by integrating all optical circuits other than the light source. All the components shown in Fig. 2 are integrated on a single silicon-photonics chip.

3. Second-generation photonics-electronics convergence device: coherent optical subassembly

Second-generation photonics-electronics convergence devices use silicon photonics and are intended for application to small optical transceivers. We developed a coherent optical subassembly (COSA) [3] and put it into practical use as a second-generation photonics-electronics convergence device. The configuration and external appearance of our COSA are shown in **Fig. 3**. In addition to a silicon-photonics chip that integrates optical circuits, a driver that drives the optical modulator, and TIA that converts the output current of the receiving PD into a voltage signal and amplifies it are mounted in a single package. The development of our COSA has made it possible to fabricate a simple and compact optical transceiver with only three key devices: a DSP, COSA, and laser source.

Our COSA was initially intended for use in DCIs between distributed datacenters, which at the time were beginning to attract attention as an application for digital coherent communications. The standardization of optical transceivers for DCIs was promoted as a transmission distance of 80 to 120 km, transmission speed of 400 Gbit/s, and QSFP-DD as the form

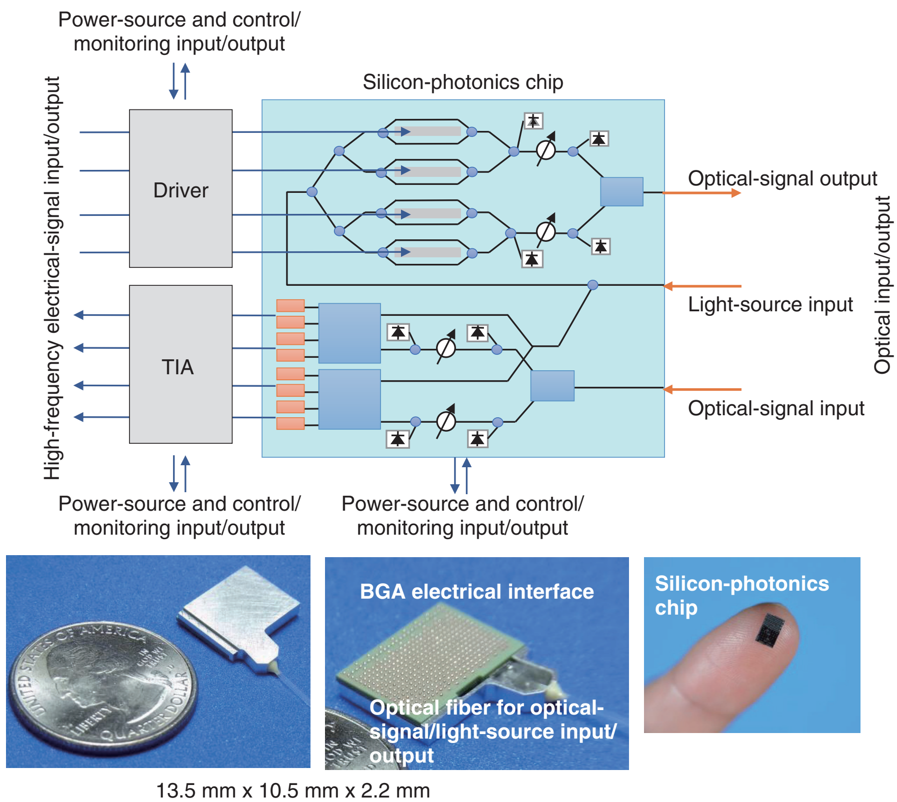
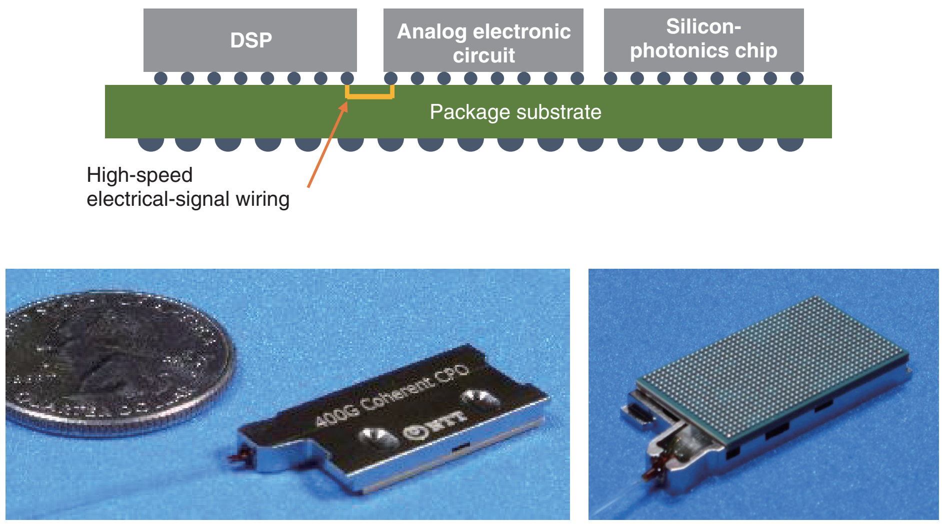


Fig. 3. Configuration and appearance of our COSA and the silicon-photonics chip on which it is mounted.

factor (approx. 2 × 8 cm), which is considerably smaller than conventional transceivers. We developed our COSA as a second-generation photonics-electronics convergence device for embodying such a compact optical transceiver. As shown in Fig. 3, the size of the mounted silicon-photonics chip is approximately 4 × 6 mm, and the size of the package of our COSA is 13.5 × 10.5 × 2.2 mm, which makes it small enough to be mounted inside a transceiver with the QSPF-DD form factor.

The factors that make it possible to downsize our COSA from the conventional package of optical devices include the omission of the temperature-control unit and the fact that the package of our COSA does not need to be hermetically sealed. These factors are the result of achieving temperature-independent characteristics and moisture resistance by applying a unique optical-circuit design while taking full advantage of the material stability of silicon. The non-hermetic packaging also enables a simple configuration in which the end face of the optical fiber is directly connected to the silicon-photonics chip, contributing to miniaturization and high productivity.

In addition to the above advantages, our COSA offers excellent ease of use and producibility when mounted on a PCB of an optical transceiver. Our COSA uses (i) a ball grid array (BGA) as the electrical-signal interface and (ii) optical fiber as the optical-signal interface as with conventional packages, but the optical fiber is directly bonded to the silicon-photonics chip and is configured with materials that can withstand reflow soldering temperature (approximately 250°C). Most conventional optical devices require individual mounting processes after mounting other electronic components on the package substrate by solder printing and reflow. In contrast, thanks to its BGA interface and improved heat resistance, the components of our COSA can be mounted by solder printing and reflow automatically and simultaneously with other electronic components. This fabrication process of our COSA represents a revolutionary change in optical or photonics-electronics convergence devices. Our COSA can be mounted on an automated assembly line like other electronic devices in a manner that greatly simplifies and streamlines the assembly process of an optical



21.9 mm x 11.5 mm x 2.3 mm

Fig. 4. Configuration and appearance of coherent co-package.

transceiver. It became commercially available in 2020 and is currently being used in many compact digital coherent optical transceivers.

4. Second-generation photonics-electronics convergence device: coherent co-package

During the development of the second-generation photonics-electronics convergence devices that will follow our COSA, we have been promoting further integration of devices. Our COSA is a photonics-electronics convergence device that integrates a silicon-photonics chip, i.e., optical circuits, a driver, and TIA, i.e., analog electronic circuits, in a single package. We have further advanced this photonics-electronics conversion technology by mounting a DSP and a COSA in a single package (coherent co-package).

The configuration and appearance of a coherent co-package are shown in **Fig. 4**. In addition to a silicon-photonics chip and an analog electronic circuit supporting a transmission speed of 400 Gbit/s, the same as that of our COSA, a DSP is also mounted on a single package substrate, which results in a package size of 21.9 × 11.5 × 2.3 mm. It is small enough to be mounted inside a QSPF-DD-form-factor transceiver with room to spare. Like our COSA, it uses a BGA interface, and components can be mounted through the automated solder printing and reflow.

Since signal speeds are continually increasing, the performance of the high-speed electrical-signal wiring connecting the DSP and a COSA is particularly important. The aim with the coherent co-package is therefore to maximize the performance of the wiring by incorporating it into the package substrate and reducing its length, as shown in Fig. 4. This eliminates the need to design high-speed wiring to connect the DSP and a COSA in an optical transceiver, so the development period for the optical transceiver can be shortened. Having become commercially available in 2023, coherent co-packages providing a transmission speed of 400 Gbit/s are expected to be used in compact digital coherent optical transceivers.

5. Third-generation photonics-electronics convergence devices

In a datacenter, which must handle large amounts of traffic, a large number of server racks are connected in a two- or three-tier tree-like configuration using switches. Graphics-processing-unit clusters are often set up to execute dedicated processing for artificial intelligence and machine-learning applications, and large-scale clusters are connected via switches.

Many optical transmission devices, including high-capacity switches, have an array of pluggable optical transceivers on the front panel. As shown in **Fig. 5(a)**, the application specific integrated circuit (ASIC) and pluggable transceiver in the body of the switch are connected by electrical wiring on the host PCB. As

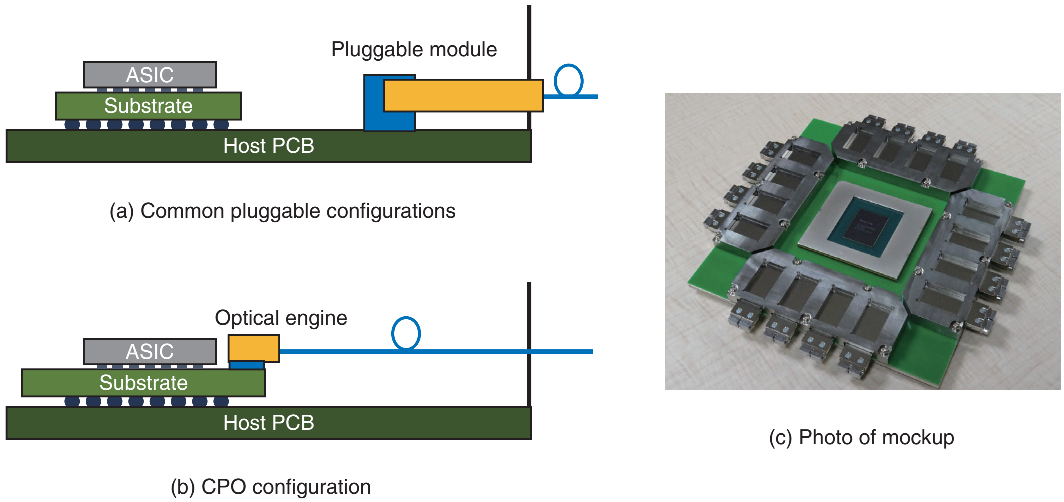


Fig. 5.   Switch with CPO configuration.

signal speed increase, transmission loss on the host PCB increases rapidly, so advanced signal-compensation circuitry for accurate signal transmission is required, and power consumption is thereby increased. The power consumption of large-capacity switch ASICs is more than 500 W, 30% of which is accounted for by input/output circuits for high-speed electrical-signal-wiring transmission. To reduce this power consumption, it is effective to place the optical transceiver as close to the switch ASIC as possible, and a new packaging approach called near package optics (NPO) or co-packaged optics (CPO) is attracting attention for that purpose (**Fig. 5(b)**). Although the transceiver cannot be plugged into or unplugged from the front-panel side, it is expected to reduce the total power consumption of the switch and accommodate more optical fibers at the front panel.

Distinguished from conventional front-panel pluggable transceivers, optical transceivers used in NPO or CPO are called optical engines. A mockup of the prototype optical engine we are developing, mounted around the switch ASIC, is shown in **Fig. 5(c)**. On the basis of the specifications established by OIF, the optical engine measures about 50 × 20 × 7 mm and has a transmission speed of 3.2 Tbit/s. Silicon photonics, which has begun to be used in second-generation photonics-electronics convergence devices, is used in the optical engine; however, the main difference is that the optical circuits for PAM4 (4-level pulse amplitude modulation) transmission are integrated in multiple channels instead of coherent circuits.

The optical engine accommodates up to just under 70 single-mode optical fibers. For a 51.2-Tbit/s switch using 16 3.2-Tbit/s optical engines for input and output, approximately 1000 optical fibers are accommodated in the switch. Since the fiber routing for this configuration is complicated, the optical engine should have an optical connector interface so that the optical engine and optical fiber can be mounted separately.

Multi-fiber push-on (MPO) connectors are commonly used as multi-fiber optical connectors; however, 70 optical fibers cannot be accommodated in the 20-mm width of a single connector. Thus, we are developing our own multi-fiber compact connectors [4]. These in-house connectors use the attractive force of the magnet as a pressing force between the plug and receptacle, so springs and housing parts, which are indispensable components of MPO connectors, can be omitted, and the connector can thereby be significantly miniaturized. As shown in **Fig. 6**, we constructed a prototype of this magnetic connector to verify the principle of this connector and confirmed that its size (volume ratio) is one-tenth that of a conventional MPO connector. The image on the right of Fig. 6 visualizes the magnetic field around the prototype and shows that the magnetic force is efficiently confined.

6. Future developments

We are developing second-generation photonics-electronics convergence devices to achieve even

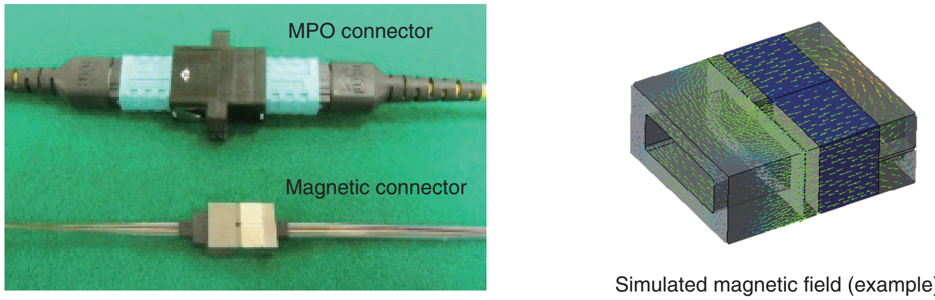


Fig. 6. Photo of prototype magnetic connector and example of simulated magnetic field.

higher transmission speeds. OIF is currently discussing the next generation of coherent optical transceivers with transmission speeds of 800 Gbit/s. We have also started developing a silicon-photonics chip for supporting this higher-speed transceiver and we developed a prototype chip [5]. As the next step, we are currently researching the technology for a coherent co-package that can support a transmission speed of 800 Gbit/s.

For the development of third-generation photonics-electronics convergence devices, we will not only develop silicon photonics and optical connectors but also create an ecosystem to promote the transition to CPO.

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Artificial Neural Network Trained for Sound Recognition Exhibiting Human-like Sensitivity to Sound Amplitude Modulation

Takuya Koumura

Abstract

Amplitude modulation (AM) is one of the most important sound physical dimensions for auditory perception. Human listeners can detect subtle AM in such a way that their sensitivity to AM depends on the stimulus parameters. Why does the auditory system exhibit such a form of AM sensitivity? How does the brain conduct AM detection? To answer these questions, my research colleagues and I conducted a computational study. We trained an artificial neural network (NN) model for sound recognition and simulated AM-detection experiments in the model. We found the emergence of human-like AM sensitivity in the model. The AM structure in the sounds for model training was essential for this emergence. The layers exhibiting human-like AM detection had AM-related properties similar to the neurons in the auditory midbrain and higher brain regions. These results suggest that AM sensitivity in humans might also be a result of the adaptation of the auditory system to sound recognition and that the auditory system might detect AM using neural activities in the auditory midbrain and higher brain regions.

Keywords: auditory perception, amplitude modulation, artificial neural network

1. Background

Sounds in our everyday life (e.g. speech, music, and environmental sounds) exhibit rich patterns of amplitude modulation (AM) (**Fig. 1**). AM is a slow change in sound amplitude. It is one of the most important sound features for auditory perception. Different patterns of AM evoke different hearing sensations such as pitch and roughness [1]. Humans can recognize a sound only with its AM cue [2, 3]. AM is often characterized by its rate (or speed) and depths (or magnitude) (Fig. 1, right panel). Originally, it referred to conveying a signal as a form of slowly changing amplitude, but in the context of auditory research, it is often used in the aforementioned sense.

Perceptual sensitivity to sound AM is considered an important property reflecting auditory perception because it quantifies the ability of the auditory system to detect subtle AM cues in the sound stimulus. It has been investigated under multiple experimental conditions in several independent studies [4–7] and has been shown to depend on stimulus parameters such as the AM rate, carrier bandwidth, and sound duration. In the previous experiments, a modulated and non-modulated sound are presented in succession to a human listener. When the listener is asked to identify which sound is modulated, the answer is generally correct when the modulated stimulus has a deep AM, but the discrimination is more difficult when the AM is shallower. Therefore, we can define an AM-detection threshold as the minimum depth required for discriminating a modulated sound from a non-modulated one.

Understanding this stimulus-parameter dependency

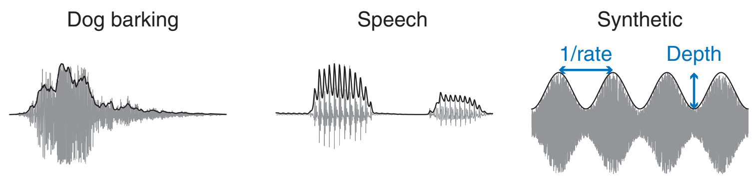

Fig. 1. Examples of sound AM, shown as black lines, in dog barking, speech, and synthetic sounds.

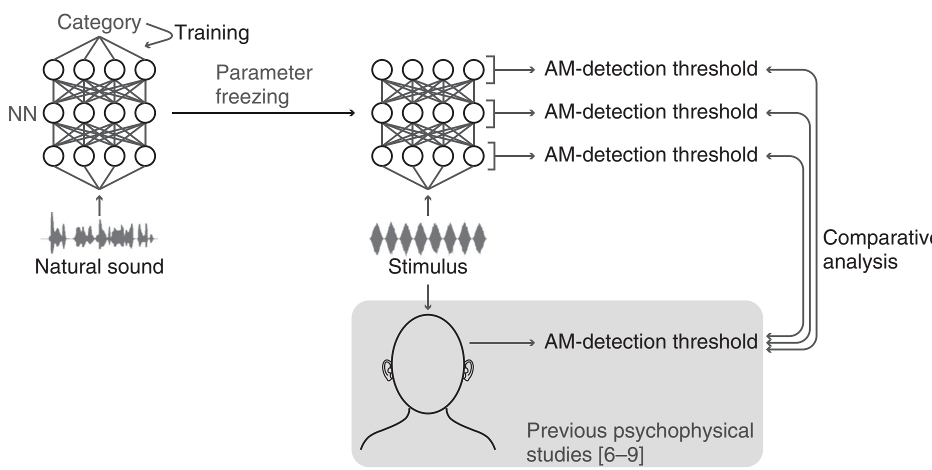

Fig. 2. Overview of the procedure of model construction and analysis.

is critical in the research of auditory perception because those parameters vary greatly in the sounds in our everyday environment and affect our sensitivity to AM cues, which in turn influences our perception. Therefore, it is important to consider the following fundamental questions: why such a stimulus-parameter-dependent sensitivity has emerged in the auditory system, and how it is actualized in our brain. The "why" question is scientifically important because it incorporates an understanding of the evolutionary and developmental process (or the "origin") of the auditory system. However, it requires considering the long time scale of our evolution and development, which makes it difficult (albeit not impossible) to address experimentally. In such a case, computational modeling can be effective. If we assume that an increase in evolutionary fitness is the primary factor in shaping the auditory system and that better sound-recognition performance yields better evolutionary fitness, we can computationally simulate this adaptation process using machine-learning techniques. After constructing a model by training it for a biologically relevant task such as sound recognition, we can simulate psychophysical or neurophysiological experiments and compare the emergent properties with those in the auditory system to gain insights into the effect of the adaptation to sound recognition on shaping the auditory properties. Several studies have been conducted along this line including ours that demonstrated the emergence of neuronal AM-related properties in an artificial neural network (NN) trained for sound recognition [8]. The "how" question has often been addressed by neuroscience, but this computational paradigm should help us understand those experimentally elucidated mechanisms from the perspectives of their emergence.

2. Simulating psychophysical experiments in a neural network trained for sound recognition

In our present study, we applied this paradigm to the AM-detection threshold [9]. This study involved the following two steps: constructing a computational model of the auditory system and simulating psychophysical experiments in the model (**Fig. 2**). We used an artificial NN as the computational model. The

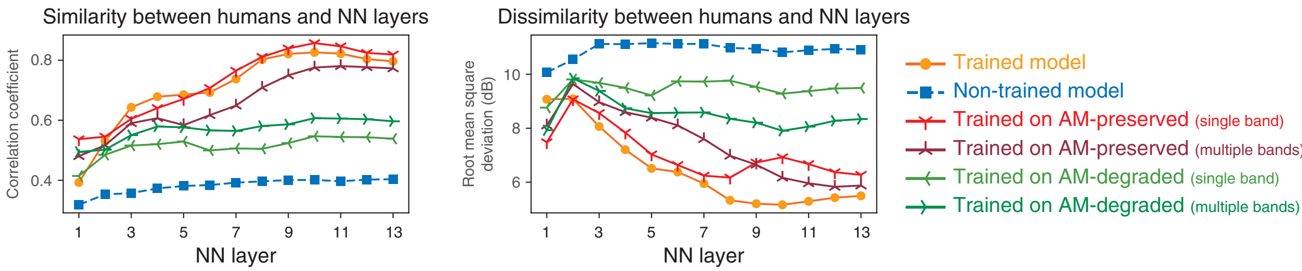

Fig. 3. Similarity and dissimilarity between the AM-detection threshold in humans and that in NN layers.

model architecture was almost the same as in our previous study [8]. We used a multi-layer (or deep) convolutional NN that takes a sound waveform as an input and outputs the estimated category of the input. The model parameters were adjusted to match the estimated categories to the true categories (Fig. 2, left). This process is called "training" in machine learning. The training objective was the classification of everyday sounds or of phonemes in speech sounds.

After the training, we froze the model parameters and simulated psychophysical experiments (Fig. 2, right). We delivered a modulated or non-modulated stimulus to the model and measured how accurately the model discriminated them. Specifically, we attempted to estimate whether the stimulus was modulated from the time-averaged model activity in response to the stimulus. The stimulus parameters were the same as in psychophysical studies [4–7]. This enabled the direct and quantitative comparison of our results with those in humans. The AM-detection threshold was defined as the depth at which the discrimination performance was 70.7% (again, same as in the psychophysical studies). This threshold was measured in each layer in the NN. We conducted the same simulation in the non-trained model (i.e. the model with random parameter values before training for sound recognition).

3. Emergent AM detection threshold in the model

We first quantified the similarity of the AM-detection threshold in the model and that in humans (**Fig. 3**, orange circles for the trained model, blue squares for the non-trained model). This comparison was done for each NN layer. We compared the stimulus-parameter-dependent AM-detection threshold in an NN layer and humans in terms of their overall patterns of stimulus-parameter dependency and their specific values. To compare their overall pattern, we quantified the relative similarity using the correlation coefficient (Fig. 3, left panel). To compare their specific values, we quantified the absolute dissimilarity using the root mean square deviation (Fig. 3, right panel). The upper layers in the trained model showed high similarity and low dissimilarity with humans, whereas the lower layers and the non-trained model showed low similarity and high dissimilarity. This indicates that the human-like detection threshold emerged in the upper layers as a result of training for sound recognition.

We then wanted to determine the essential factors for the emergence of the human-like detection threshold in the model. Since the similarity to humans was largely different between trained and non-trained models, we hypothesized that the training procedure is an important factor. To test this, we trained the model on degraded sounds and compared the emergent detection threshold with humans. We tested two types of degraded sounds: sounds with degraded AM components and those with degraded faster components (i.e. faster change in their amplitude than AM components). In the latter sounds, AM components were preserved. The model trained on AM-degraded sounds did not exhibit a human-like detection threshold (Fig. 3, green < and > shapes), whereas the model trained on AM-preserved sounds showed a detection threshold somewhat similar to humans (Fig. 3, red Y and inverse Y shapes). The results indicate that the AM structure in the training data is essential for the emergence of a human-like AM detection threshold.

Finally, to gain insights into how AM detection is conducted in the brain, we estimated the brain regions responsible for AM detection. Figure 3 indicates that layers around the 9th, 10th, and 11th layers exhibit the human-like AM detection threshold. We estimated the corresponding brain regions to these layers by using a method developed in our previous study for

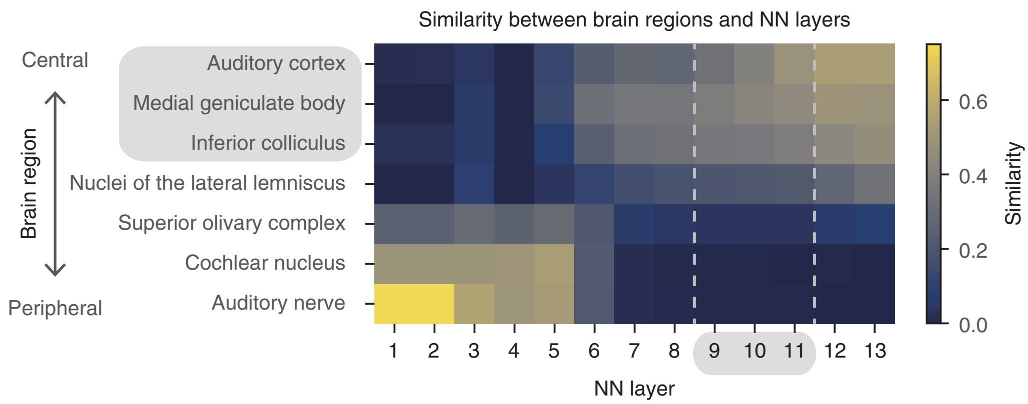

Fig. 4. The similarity of neuronal AM-related properties in the NN layers and those in the auditory brain regions.

calculating the similarity between an NN layer and brain region in terms of neuronal AM-related properties [8]. Applying this method to the present model revealed that these layers were similar to the inferior colliculus, medial geniculate body, and auditory cortex (**Fig. 4**), which are included in the auditory midbrain and higher regions. This means the 9th, 10th, and 11th layers would respond to AM stimuli similarly to neurons in these brain regions. This suggests that, if we calculate the AM-detection threshold as in our analysis from the time-averaged neural activities in these brain regions, we would obtain an AM-detection threshold similar to that observed in the psychophysical experiments. A human brain might also use time-averaged neural activities in these brain regions when a human listener is performing AM detection.

4. Conclusions

We simulated psychophysical AM-detection experiments in an NN model trained for sound recognition. We observed the emergence of the human-like AM detection threshold in the upper layers in the trained model, suggesting that the detection threshold in humans might also be a result of the adaptation of the auditory system to sound recognition during evolution and/or development. This provides an answer to the question of why the auditory system exhibits the present form of the AM detection threshold. We demonstrated that the AM structure in the training data is an essential factor for the model to exhibit the human-like detection threshold. Mapping of the NN layer and brain regions suggests that psychophysical AM detection might be a result of neural activities in the auditory midbrain and higher brain regions. This provides an answer to the question of how AM detection is performed in the auditory system.

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Release of NTT IOWN Technology Report 2023

Tomoyuki Kanekiyo, Daisuke Shirai, and Suzuyo Inoue

Abstract

NTT Research and Development Planning Department released the NTT IOWN Technology Report 2023, which summarizes its vision for the Innovative Optical and Wireless Network (IOWN), the concept of which was unveiled in 2019, and technologies intended to make the world a better place for everyone. This article provides an overview of this report.

Keywords: technology, future vision, IOWN

1. Text structure of NTT IOWN Technology Report 2023

Since unveiling the concept of the Innovative Optical and Wireless Network (IOWN) in 2019, we have diligently advanced research and development (R&D) efforts to make it a reality. In March 2023, we finally commenced the deployment of the APN IOWN1.0 service, marking the transition from concept to implementation. In NTT IOWN Technology Report 2023, we use the keywords “light” and “AI” to consider a future society achieved with IOWN. We review the formation of the concept of IOWN and introduce the status of initiatives that are moving into the implementation phase and that of initiatives to use artificial intelligence (AI), which is closely related to IOWN. We also discuss the All-Photonics Network (APN) and photonics-electronics convergence devices, which are the two pillars that support IOWN, and Digital Twin Computing (DTC), which is being implemented as value creation using IOWN. Finally, we envision what services and solutions will be possible and how our lives will change in 2030, when these technologies develop and IOWN becomes more widespread, based on discussions among experts in each field.

2. Kickstart IOWN

2.1 Disruptive surge in data and energy consumption

To address the multifaceted challenges our society faces today, we must reconsider our approach to information processing. Even though digital technology has offered solutions to many of our problems, the current information-processing environment is rapidly approaching its limits. Consider the exponential growth in the volume of data we handle each year. As data volume escalates, so does the energy consumption of datacenters. Digitalization entails the generation and utilization of vast quantities of data, inevitably accompanied by the energy needed for data processing and storage. Unless we address this issue, we will not be able to reap the full benefits of a digital society and AI.

These issues compelled us to turn to optical technology. Electrical circuits consume immense energy when processing great volumes of data, particularly over extended transmission distances. To process a large amount of data within the same timeframe, higher operating frequencies become necessary, causing energy consumption to increase even further. In contrast, light requires minimal power consumption, even with increased transmission distances or operating frequencies. Our extensive research into information processing via light spans several decades, dating back to our pioneering role as the world's first commercial producer of optical fiber for data transmission. Once optical technology transformed how we transmit data, we then began exploring its potential application in processing it. Thus, the concept of IOWN was born.

As a next-generation communication network paradigm, IOWN will harness light for all facets of information, from transmission to processing. By using optical devices and embedding optical technology in everything from network infrastructure to terminal processing, IOWN promises three significant advantages: high capacity, low latency, and low power consumption. In terms of capacity, transmission capabilities could increase by a factor of 125, while latency measured by end-to-end delay could diminish to 1/200th of present durations. Regarding power consumption, complementing fiber optic cables with optical (wavelength) through-transmission devices and photonics-electronics convergence elements within the information-processing infrastructure could lead to 100-fold efficiency gains. Following the unveiling the concept of IOWN in 2019, we have diligently pursued R&D, culminating in the launch of the APN IOWN1.0 service in March 2023. IOWN is progressing from the conceptual phase to tangible applications.

Services are primarily tailored to specific industries and contexts. However, as AI and robotics are introduced into more and more applications, industry collaboration via IOWN is poised to accelerate. Domestically, IOWN is expected to encourage digitalization and data utilization not only in manufacturing, urban development, healthcare, and finance but throughout government services, education, and many other social applications and industries. This trend is not confined to domestic industries; IOWN's impact will extend around the world, as it fosters flexible collaboration across borders through DTC.

2.2 IOWN's vital role in spreading AI

To ensure the well-being of individuals, we must comprehend the diverse values held by a broader spectrum of people. As society confronts increasingly complex and dire challenges, we need to absorb and analyze information on an unprecedented scale to forecast future developments. Therefore, AI plays a pivotal role.

The surging expectations for AI seen across the world today are highly relevant to IOWN. Centralized collection is an impractical approach to the diverse array of data sources, encompassing not just vehicles and factories but also individuals and the environment, and countless other sensors. Therefore, asynchronous distributed learning, wherein AI systems in diverse domains collaborate and share knowledge, is expected to make strides. IOWN will serve as the communication infrastructure for such systems, enabling AI to process vast amounts of information and enhance their interactions.

This shift is particularly relevant to our longstanding commitment to the R&D of natural-language-processing technology, which enables AI to understand and generate everyday human language. We are leveraging our expertise to accelerate R&D of our own large language model (LLM) in anticipation of AI making even greater inroads in society. LLMs are a rapidly evolving branch of natural language processing. LLMs, such as OpenAI's GPT-4, are gaining widespread adoption in Japan and are expected to have substantial impact on business. Although such LLMs exhibit remarkable capabilities, they still have difficulty in seamlessly collaborating with humans or growing alongside us as partners in our life. We aspire to develop an AI cognitive engine capable of natural collaboration with people across various environments that can contribute to the well-being of each individual. Leveraging AI models that have the same interfaces as humans, we aim to create versatile software robots capable of interactive collaboration with humans.

3. Two pillars supporting IOWN

3.1 Network: APN

Networks and computing are the two pillars that support IOWN as we begin to deploy it. Regarding networks, we are developing an innovative network technology called the APN. The APN is a new network foundation that makes use of optical communication technology. By transmitting information in the form of light, optical communication technology allows more information to be transmitted in a shorter time than electronic signals. By converting all connections to direct optical paths, we will be able to construct networks that have far higher capacity, lower latency, and are more secure than ever before. It should also be noted that multiple networks can be created over a single optical fiber by altering the wavelength. This means the APN could be used to create distinct networks for different purposes, such as one using conventional Internet Protocols alongside another using dedicated medical protocols. The APN currently provides 100-Gbit/s private connections, and users have exclusive use of optical wavelengths from end to end. This on its own leads to a 200-fold reduction in latency and makes it possible to visualize and adjust latency. The APN uses three types of equipment: APN terminal equipment, APN-G (gateway), and APN-T (transceiver). Sales of these devices are now underway.

Many applications that do not tolerate delays, such as telemedicine, autonomous vehicles, and real-time financial transactions, will be enabled by APN low-latency communications. These applications are becoming increasingly important in the digital world. Low-latency communications can also encourage the development of new applications. For example, real-time virtual reality/augmented reality, real-time AI, and real-time robot control. These applications require networks capable of low-latency communications, so we are currently co-creating with partner companies in various fields through the APN. The APN will also have a significant impact on the datacenter business. NTT has an extensive track record of colocation, in which it operates datacenters for numerous companies, with the third-largest share in the global market. By linking datacenters through the APN, we will be able to construct an ultra-high-speed, ultra-high-capacity network on a global scale. This network will reinforce data logistics worldwide and increase the accessibility of cloud services. Datacenters must become more varied and complex due to the need to decentralize datacenters to balance disaster risk and safely manage data close by to respond to various problems. The introduction of the APN will not only enhance our datacenter capabilities but also usher in a novel approach to crafting unique communication environments tailored to the diverse needs of various companies.

3.2 Computing: Photonics-electronics convergence devices

On the computing side, the core pillar is our development of photonics-electronics convergence devices. Such devices integrate electronic and photonic elements into a single system to increase the speed of data transfer and improve energy efficiency. The introduction of these devices inside the APN components is expected to further reduce power consumption of the APN and increase its capacity.

In discussing the deployment of photonics-electronics convergence devices, we should not ignore the role of disaggregated computing. This computing model physically separates computing resources (central processing units, memory, storage, etc.) from physical servers and allows these components to be freely combined and used over the network. This enables more efficient resource use and greatly increases system scalability and flexibility. Disaggregated computing is playing an important role in enabling new computing paradigms such as cloud computing and edge computing. It could also be useful for applications that need to process large amounts of data at high speed such as AI and big data analytics. Demand for disaggregated computing is expected to manifest particularly in large-scale datacenters and cloud environments. Because many users simultaneously perform a variety of tasks in these environments, resource demands are highly dynamic. Disaggregated computing is capable of flexibly responding to these demands. We are also developing a computing platform for disaggregated computing with commercial deployment targeted for 2026. To this end, we are also developing operating systems, controllers, and applications that can run on this platform, which is expected to be part of the infrastructure underlying IOWN.

In June 2023, NTT Innovative Devices Corporation was established as a manufacturing company specializing in photonics-electronics convergence devices to expedite the transformation from concept to reality. To enhance the progress of R&D and the practical application of IOWN-related technologies, including the 6th-generaion mobile communication system, we are committing approximately 100 billion yen to the overall IOWN R&D efforts for FY2023. Our ongoing and future financial investments will drive the development of servers such as the disaggregated computing platform, as well as the advancement of services such as DTC.

4. DTC is a new platform for urbanism

DTC is one of the applications being developed to create value through the use of IOWN. This is a system that enables users to freely combine multiple digital twins to precisely reproduce comprehensive simulations of people and vehicles in an urban environment that were not previously possible, thereby enabling future predictions and personalized services. Real-world objects, such as automobiles and factory machinery, have been digitally reproduced to improve real-time situational awareness and detect anomalies. DTC will combine these models in countless ways to reproduce the real-world at large scale and high precision. It will even go beyond the reproduction of the physical world to entail virtual representation of interactions with the internal aspects of

Fig. 1. A scene during a discussion.

humans.

There are numerous potential use cases for DTC, but we are currently rolling out services and conducting experiments mainly in offices and commercial facilities. Among these, APN IOWN1.0 is already being deployed in a major development being undertaken by Tokyu Land Corporation in Shibuya. This collaborative project between Tokyu Land Corporation, NTT, NTT DOCOMO, and NTT EAST aims to integrate cutting-edge convenience and sustainability into urban development in ways that address environmental and other social concerns. Once DTC is extended to commercial facilities as well as office spaces, remote concierge support and shopping using extended-reality technology could enable highly satisfying shopping experiences tailored to the tastes and preferences of each individual. Foreign visitors to Japan would be able to communicate using real-time translation, and entertainment such as e-sports will become more popular across Japan and abroad.

5. Envisioning the world of 2030 through IOWN

As we introduce IOWN, the proliferation of services and applications harnessing IOWN is poised to shape the future. What sort of world will emerge on the horizon? How will conventional industries and businesses transform? To explore the societal landscape of 2030, we have gathered experts from three distinct areas: a versatile business platformer, healthcare-transforming startup, and researcher re-evaluating the AI-human connection (**Fig. 1**). We invite you to imagine the societal landscape of 2030 through conversations with these three experts by reading their conversation in NTT IOWN Technology Report 2023 online [1].

6. Conclusion

NTT Research and Development Planning Department will continue to release a summary of technology trends and the activities of NTT R&D. NTT IOWN Technology Report 2023 can be downloaded from NTT R&D's website [1].

Reference

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https://www.rd.ntt/e/download/

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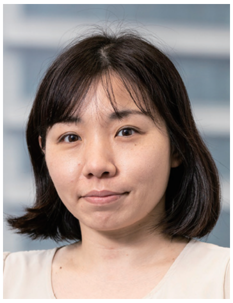

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Growth Record of Kanagawa Prefectural Yokosuka Senior High School Students Becoming Sports Analysts—Introducing NTT Human Informatics Laboratories' Contribution Activities to the Local Community

Kaori Kataoka, Masato Shindo, and Ryosuke Aoki

Abstract

NTT Human Informatics Laboratories has been engaged in collaborative research with students from Kanagawa Prefectural Yokosuka Senior High School under the research theme of "Let's experience being sports analysts" since 2022 as part of its support for the school's Super Science High School program. This article introduces interviews with NTT researchers who have been involved in local-community-contribution activities aimed at nurturing young researchers along with the lead teacher from Kanagawa Prefectural Yokosuka Senior High School.

Keywords: local-community-contribution activities, sports analyst, motor-skill transfer technology

1. Introduction

The Ministry of Education, Culture, Sports, Science and Technology has implemented the Super Science High School (SSH) program with the aim of nurturing science and technology talent capable of international contributions through advanced education in mathematics and science at high schools. Kanagawa Prefectural Yokosuka Senior High School (Yokosuka High School) has been designated as an SSH school since fiscal year (FY) 2016 and has developed a unique curriculum to foster students' exploratory activities.

Yokosuka High School's SSH program is structured as a mandatory course throughout the three years of high school. One particularly distinctive feature is that the first-year students engage in exploratory activities alongside researchers working at the forefront of research. Yokosuka High School collaborates with multiple research institutions, including universities and companies in the surrounding area. On the basis of research themes proposed by these institutions, students choose a research institution that piques their interest and carry out exploratory activities. NTT has also been supporting exploratory activities for first-year students since Yokosuka High School was designated an SSH school in FY2016.

Since FY2022, NTT Human Informatics Laboratories (hereafter, the Laboratories) has accepted first-year students under the research theme "Let's experience being sports analysts." The Laboratories has also begun supporting the SSH program by positioning this theme as collaborative research. In this research, the Laboratories not only facilitates students'

Table 1. List of achievements.

[Baseball team]
• Poster presentation at Science Festival for Everyone 2023 in Yokosuka City Museum (Jan. 2023)
• Short presentation at Technical Committee on Media Experience and Virtual Environment, The Institute of Electronics, Information and Communication Engineers (Mar. 2023) *Received MVE Award K. Kameyama, M. Shindo, R. Ogawa, D. Kondo, M. Kurozumi, and R. Aoki, "[Short Paper] Preliminary Investigation of Batting Form in Response to Slow and Steady Pitching Strategies Utilizing VR Systems and Motion Capture in Baseball," IEICE MVE, MVE2022-70, 2023 (in Japanese).
[Swimming team]
• General presentation at Technical Committee on ME and Bio Cybernetics, The Institute of Electronics, Information and Communication Engineers (June 2023) Y. Ogata, M. Kobayashi, T. Kageyama, M. Kurozumi, G. Nakagawa, M. Shindo, and R. Aoki, "Preliminary Investigation of Swimming Form Analysis Using Dry-Lan Training Tool for Swimming," IEICE MBE, MBE2023-11, 2023 (in Japanese).
• Poster presentation at the international conference EMBC (July 2023) Y. Ogata, M. Kobayashi, T. Kageyama, M. Shindo, and R. Aoki, "Study on Front Crawl Form Analysis Using a Dry-Land Training Tool and a Motion Capture System," 45th Annual International Conference of the IEEE Engineering in Medicine & Biology Conference, 2023.
[Track and field team]
• Poster presentation at Science Festival for Everyone 2023 in Yokosuka City Museum (Jan. 2023) *Received Today's Good Prize
• Poster Presentation at Kanagawa Exploration Forum (Mar. 2023)
• General presentation at Technical Committee on ME and Bio Cybernetics, The Institute of Electronics, Information and Communication Engineers (June 2023) H. Aoki, M. Shindo, K. Wada, Y. Kitamura, M. Kurozumi, G. Nakagawa, and R. Aoki, "Preliminary Investigation of the Effects of Load Distribution of Upper and Lower Limbs on and Initial Acceleration and the "Set" Position Posture in the Sprint Start," IEICE MBE, MBE2023-12, 2023 (in Japanese).
• General presentation at Global Link Singapore 2023 (July 2023) *Received Fine Work Prize

exploratory activities but also promotes research endeavors in which the ideas of high school students contribute to the academic achievements supporting the advancement of motor-skill-transfer technology conducted by the Laboratories. Some of the research results have received high academic acclaim, culminating in presentations at gatherings attended by leading researchers (**Table 1**).

This article introduces interviews with NTT researchers involved in recent community engagement activities focused on nurturing young researchers (Ryosuke Aoki and Masato Shindo), along with the lead teacher from Yokosuka High School for FY2022 (Mika Kurozumi, currently a teacher at Kanagawa Prefectural Shirosato Senior High School).

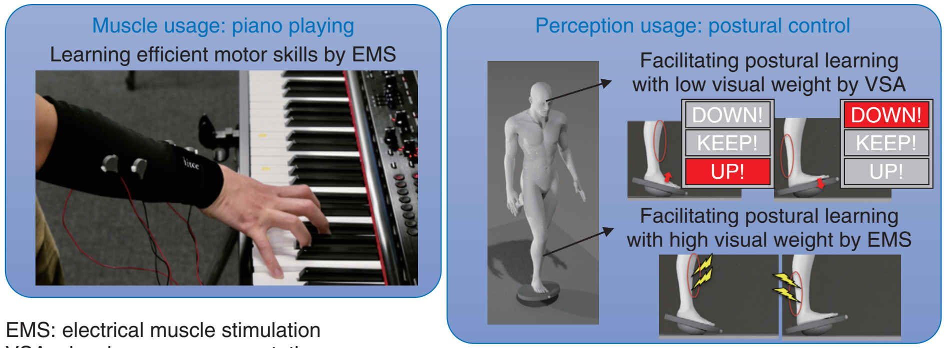
2. Motor-skill-transfer technology and experimental facilities of the Laboratories

The Laboratories is conducting research and development (R&D) on motor-skill-transfer technology and studying how to directly transfer motor skills of experts, which are generally difficult to convey with words or video, by external sensory stimulations such as electrical stimulation [1]. With postural control while standing [2] and piano-playing techniques [3, 4] as areas of investigation, researchers at the Laboratories are researching techniques for transferring motor skills, such as the use of muscles and sensory perception, by combining involuntary and voluntary movements using external stimulations such as electrical muscle stimulation (**Fig. 1**). They are also conducting research on quantifying motor skills and motor habits to expand the range of applications of such technologies. The Laboratories has measurement systems for supporting learning motor skills and motion-analysis equipment for providing external stimulations at Yokosuka R&D Center (**Fig. 2**).

Ryosuke Aoki, introduced in this article, oversees the entire research on motor-skill-transfer technology. Masato Shindo, also introduced here, is in charge of motion analysis and learning motor skills related to postural control to prevent loss of ability due to conditions such as aging.

3. Background of research theme settings to elicit high school students' interest

The theme proposed by NTT to Yokosuka High School, "Let's experience being sports analysts," aims to inspire students to identify habitual movements in their respective sports activities and uncover the techniques used by skilled individuals. The objective



EMS: electrical muscle stimulation
VSA: visual sensory augmentation

Fig. 1. Example of research on motor-skill-transfer technology. This technology was developed to directly transfer motor skills through external sensory stimulations such as electrical stimulation.

Fig. 2. Experimental facilities (measurement systems certified as medical equipment): VICON motion capture (11 cameras), DELSYS electromyography sensors, AMTI force plates, etc.

is for students to leverage these insights to improve their performance.

Even though basic research on motor analysis generally concentrates on gait and posture, Aoki decided to target sports-club activities instead to encourage students to maintain their interest outside the classroom and create a cycle through which students can put into practice their respective sports activities what they have questioned in class. Shindo, who was a student of another high school's SSH program, also understood the challenges of maintaining interest and felt that this approach will be effective.

As anticipated by Kurozumi, this theme setting and Aoki's presentation, which were designed to spark interest from the students' perspective, resulted in a significantly higher number of students applying for this theme than the expected limit of 20. The high school adjusted by selecting students with clear reasons for applying to meet the set capacity. However, there were students with a compelling desire to conduct research specifically with NTT, so the final participant count reached 22. This underscores how compelling both the theme and presentation were.

The NTT SSH class ended up consisting of 3 students from the baseball team, 3 from the track and field team, 3 from the swimming team, 3 from the badminton team, 4 from the tennis team, 1 from the archery team, 1 from the soccer team, 2 from the basketball team, 1 from the volleyball team, and 1 from the Sports Chanbara (a modern Japanese martial art) circle. For students who were the only student of their respective sports, NTT researchers highlighted the challenges of working alone. Although the researchers encouraged them to form groups to investigate common movements in their sports such as jumping, the students rejected the suggestion due to the distinct processes involved in each sport, even if the movements were similar. The NTT researchers respected this and accommodated their preferences.

4. Flexible lesson design to sustain high school students' interest in weekly SSH classes

In the weekly SSH classes, various strategies were implemented to sustain the interest of high school students. Thanks to these efforts, Kurozumi mentioned that students were excited and their eyes sparkled.

During the opening 5 to 10 minutes of each class in the beginning stage, Aoki explained the relationship between subjects typically studied in high school and the connection between physical activity and muscle use. This approach was aimed at redirecting students' attention to their immediate surroundings.

The curriculum design also incorporated flexible elements at the beginning stage. The initial plan was for students to investigate literature and explanatory videos related to the evaluation of sports they found interesting, leading to hypothesis construction. However, observing challenges with this approach, the focus shifted towards helping students understand how their chosen sports were represented through actual data. By measuring and observing waveform graphs that changed in conjunction with their movements, students gained a new perspective on analyzing body movements, gradually clarifying initially vague issues. Reflecting on the process, Shindo mentioned that if too much time had been spent on researching peripheral technologies or specifying measurement details, such significant results (Table 1) would not have been achieved within the short span of one year.

Special attention was also given to how assignments were given to the students. If they were instructed in the same manner as NTT researchers, such as "investigate current research and consider what measures you want to take," it is conceivable that they might struggle to generate ideas due to a lack of research experience. Recognizing that too much freedom might hinder the students from taking action, while being too focused might stifle their initiative, the researchers and Kurozumi devised assignments with a scope that enabled students to act independently. They encouraged the students to carry out tasks within the assigned parameters. The first assignment initially involved searching for "what is generally said in the world" and "what your coach says." However, even with these constraints, students found it challenging to narrow down measurement items. Consequently, the researchers and Kurozumi modified the assignment to focus on determining measurement items by examining body movements they wanted to measure. This included repeatedly confirming measurement data in the lab while changing measurement conditions each time.

Kurozumi also took measures to ensure that students remained motivated. Kurozumi understood the challenge of maintaining students' motivation if they were only assigned SSH tasks once a week as homework. To prevent the weekly sessions with the NTT researchers from being unproductive, she actively engaged with the students by referencing what they wrote in their review cards submitted after each lesson. When passing them in the hall, she would ask questions such as, "Have you investigated XX?" Responses such as "Oh no, I haven't! I'll do it!" prompted the students into action. The students' awareness that their teacher paid attention to their progress heightened their motivation and sustained their interest. The students received support not only during classes but also through Kurozumi's behind-the-scenes encouragement such as reaching out to them outside of class.

5. NTT researchers' experience of challenges and delight during measurements and analysis

The NTT researchers faced difficulties in interpreting the measurement data collected by high school students but were experiencing joy that surpassed those difficulties.

Both Aoki and Shindo were tackling sports-analysis and motor-learning research perspectives for the first time in any sport. Thus, they did not have prior knowledge or expertise in current research for each sport. Both were exploring the measurement targets and visualization content in a trial-and-error manner. Even with information gathered from students in various sports clubs, not all students could clearly articulate what they wanted to measure. It was more of a sensory awareness. Respecting this awareness, both researchers engaged in multiple discussions with the students, drawing on their own research insights and personal athletic experiences. They initially decided on measurement conditions and parameters somewhat vaguely, prioritizing the quantification and visualization of those aspects over the development of novel hypotheses. This approach was aimed at articulating the sensory aspects through discussions, leveraging the researchers' knowledge and their experiences in movement.

As visualizing measurement data solely in graph form posed challenges for high school students to interpret, the NTT researchers decided to provide guidance by proposing comparative elements. In preparing these considerations, it was necessary to change their mindset to organize results for each sport due to the completely different experimental tasks, measurement content, and verification criteria in each sports club. Shindo recalled that this was the most difficult part. Kurozumi expressed great appreciation for the efforts of both researchers as they individually measured and visualized movements for all sports clubs, finding it truly impressive.

The challenges faced by the two researchers as they repeatedly considered these activities for all ten sports clubs must have seemed unsurmountable. Particularly for Shindo, who was in his third year at the company at that time and was already grappling with the demands of paper publication for his own research, handling and guiding high school students proved to be challenging. Aoki fondly recalled that during this time, Shindo, despite being in his third year at the company, would occasionally express his challenges while dealing with high school students, but he persevered. However, as the two researchers delved into experiments based on the ideas of high school students, the excitement of unexpected results seemed to outweigh the difficulties. According to Kurozumi, the students, who may not have immediately grasped the interesting aspects of the results, were envious of the genuine enjoyment demonstrated by both researchers. This envy motivated the students to seek and experience the same excitement in their endeavors.

6. Struggles and growth in Yokosuka High School students in interpreting visualized measurement data

The NTT researchers shared the visualized data. It was now time for the students to show their abilities. The students needed to compare the visualized data under different conditions, reflect on their sensory awareness while making regular observations, and consider whether additional experiments were necessary. This section introduces the challenges and growth of Yokosuka High School students and teachers, which were unknown to the NTT researchers.

Kurozumi assisted in setting up the personal computers for students to use the analytical software MATLAB, and Shindo shared the visualized data. However, the students found the data challenging to interpret. Some students expressed frustration such as, "I don't want to look at the data anymore," "I can't take it anymore," and "I don't understand what I don't understand." To help students clarify their vague comments, Kurozumi dedicated time outside of SSH class for discussions. During these sessions, they collectively examined what they did not understand and worked to clarify areas of confusion. Kurozumi would prompt students with questions like, "I don't know either, so can you tell me what you don't understand?" This approach encouraged students to articulate their uncertainties, such as, "This graph is telling me something, but what is the meaning of this number here?" This effort facilitated the verbalization of their questions and, through patient repetition, enabled students to clarify their thoughts to some extent. Subsequently, during SSH class time, students engaged in discussions with the NTT researchers about their questions. Kurozumi's support played a crucial role in sustaining the students' motivation and enhancing the quality of the limited discussion sessions with the researchers. Aoki and Shindo expressed gratitude to Kurozumi for enabling this support, considering the constraints on the time they themselves had available for assistance. As students began to comprehend the visualized data, they proactively approached the researchers, asking, "Is it possible to create such a graph?" Some students sought guidance on generating more detailed graphs as they correlated movements to graphs and learned the outputs at specific times.

The strong collaboration between Kurozumi and the NTT researchers helped the students overcome obstacles. It can be truly said that the growth of the students lay in the relationships of trust between the researchers and Kurozumi and the students. Kurozumi, Shindo, and Aoki confirmed students' progress together by reviewing their comment cards after each class. They also carried out attentive care of students who were not making expected progress.

7. Chain of growth

As Aoki and Shindo proceeded to investigate the results of the ten different sports, the outcomes of some teams appeared to be worthy of academic discussion. For the baseball and swimming teams, in particular, it was deemed valuable to report on case studies even at the stage of setting research issues. Therefore, the NTT researchers were encouraged to present these findings at domestic research conferences and academic meetings.

The baseball team was the first team to present their findings at a domestic research conference. Talk of presenting at an academic conference alongside researchers from companies and universities naturally spread throughout the school, and some students became interested in participating. Following the baseball team, while preparing for the submission of the swimming team's outcomes, students from the track and field team approached, inquiring about what was needed for them to present at an academic conference.

When Aoki told the students that their current research findings were not sufficient for discussion at research conferences and that they needed to conduct more experiments to dig deeper into the initial results, the students took the initiative in revising their experimental plan with Shindo. They conducted the experiments, asking classmates on the track and field team to assist and participate. When the researchers told them about items that should be investigated on the basis of the visualized measurement data, the students found time to meet and discuss on their own, gathering during lunch and after school.

The SSH students acquired the ability to interpret measurement data. Motivated by the prospect of presenting at conferences, they started to experience the thrill of research and became deeply engrossed in data analysis. This independent thinking and proactive approach align with the qualities of researchers, embodying the perspective of a sports analyst that Kurozumi and the NTT researchers had aimed for the students to develop.

Finally, it took less than two months from Aoki's comment when the track and field team submitted their poster to the conference. One can easily envision the tremendous efforts invested by the students to accomplish their tasks within this relatively short timeframe. Simultaneously, the researchers undertook numerous behind-the-scenes responsibilities, including assessing the protection of personal information, making adjustments on the basis of feedback from NTT's ethics committee, reviewing research literature to articulate the experiment's novelty, and meticulously planning the experiments and analysis. I believe the two researchers demonstrated exceptional responsiveness to the students' enthusiasm.

8. Comment by the interviewer (Kaori Kataoka)

The baseball, swimming, and track and field teams have already given presentations at public conferences. The first-year students in other sports teams also presented posters at the school in March [5]. Although all participants could present their results at the end of the school year, in March, it was challenging for small groups of one or two students to continue when the SSH students became 2nd-year students. After finishing their poster presentation, some students approached Kurozumi and said, "I worked hard, didn't I?" The presence of peers who can support each other in the same position is significant. Due to the rules, adding personnel is challenging, and the sports teams that are currently continuing consist of three or more members. However, there were comments in the final reflection cards stating, "I now understand what research is," and I can imagine that this was a rewarding moment for both Kurozumi and the NTT researchers. When faced with questions from researchers that might initially seem critical, such as "What do you think about this? Why did you write that?" the students candidly reflected, wondering why they wrote what they did and taking it as an opportunity for introspection. I was impressed by how they saw it as a chance for growth.

To all readers, I hope that through the introduction of NTT's local-community-contribution activities, I can deliver a bit of inspiration for tomorrow.

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External Awards

Young Scientist Award of the Physical Society of Japan

Winner: Katsumasa Yoshioka, NTT Basic Research Laboratories
Date: October 24, 2023
Organization: The Physical Society of Japan

For pioneering terahertz spectroscopy techniques for investigating ultrafast local and nonlocal responses.

Fellow

Winner: Jun-ichi Kani, NTT Access Network Service Systems Laboratories
Date: October 30, 2023
Organization: Optica

For achievements and leadership in advancing optical access architecture and technologies.

Top Committer

Winner: Akihiro Suda, NTT Software Innovation Center
Date: November 8, 2023
Organization: Cloud Native Computing Foundation

For his contributions as a maintainer of several projects, including containerd and Lima.

Excellent Presentation Audience Award

Winner: Takayuki Ogasawara, NTT Basic Research Laboratories
Date: November 12, 2023
Organization: The Japan Society of Mechanical Engineers

For "Score Prediction Using Postural Tremor during Aiming in Archery."

CANDAR Workshop Best Paper

Winners: Aoi Yamashita, Keio University; Masahiro Tanaka, Keio University; Yutaro Bessho, NTT Computer and Data Science Laboratories; Yasuhiro Fujiwara, NTT Communication Science Laboratories; Hideyuki Kawashima, Keio University
Date: December 1, 2023
Organization: The Eleventh International Symposium on Computing and Networking (CANDAR 2023)

For "Improving Raft Performance with Bulk Transfers."
Published as: A. Yamashita, M. Tanaka, Y. Bessho, Y. Fujiwara, and H. Kawashima, "Improving Raft Performance with Bulk Transfers," Proc. of CANDAR 2023, Matsue, Shimane, Japan, Nov./Dec. 2023.