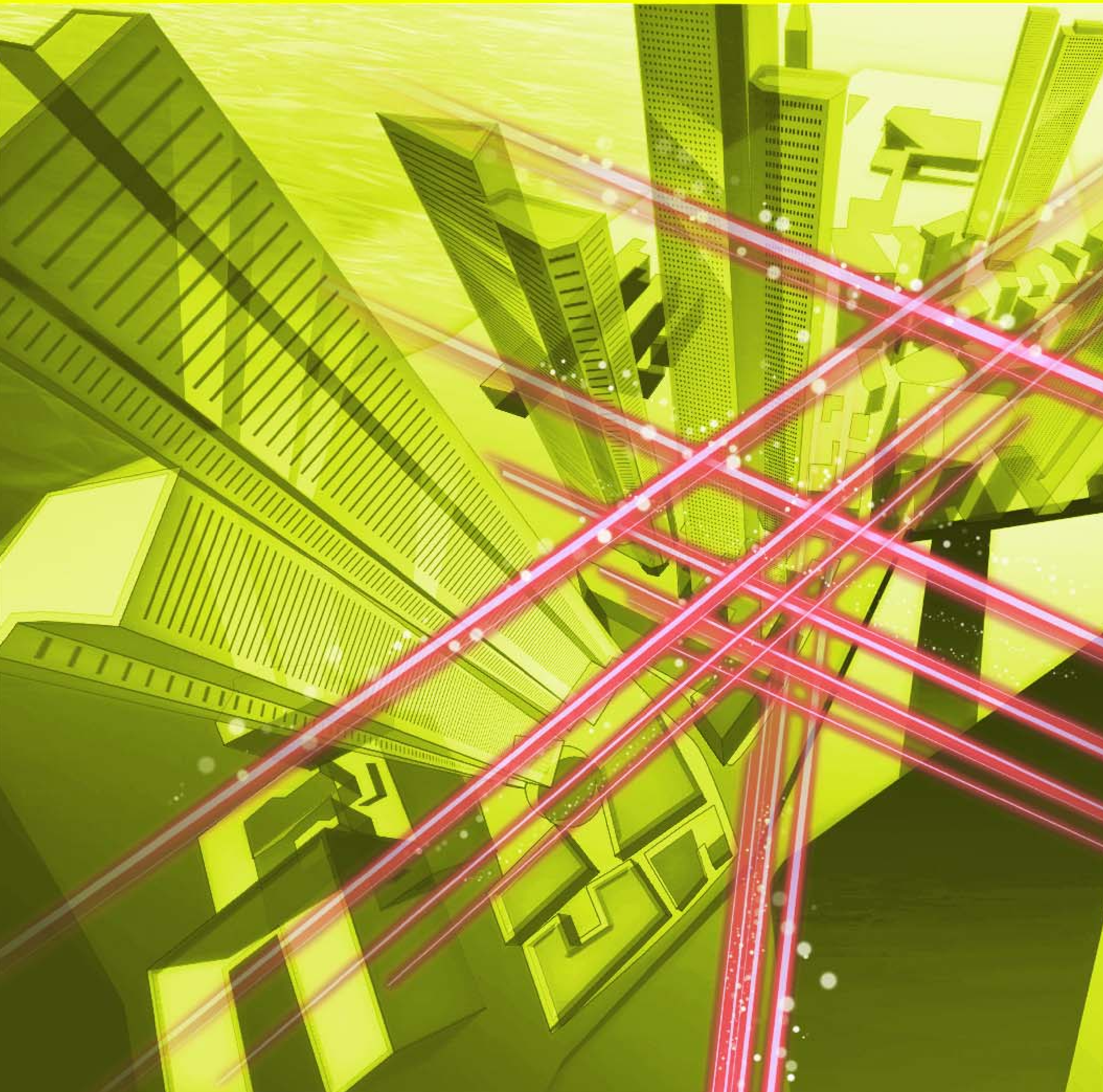
NTT Technical Review

9
2023



September 2023 Vol. 21 No. 9

NTT Technical Review

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NTT Anode Energy Aims to Become a Leading Company in Smart Energy Business to Help Society Achieve Carbon Neutrality

Teruyuki Kishimoto
President & CEO, NTT Anode Energy

Abstract

Under thorough environmental, social, and corporate governance management, NTT Anode Energy maximizes the potential of renewable energy and promotes Earth-friendly economic activities. As a new player in the energy field, the company is driving the NTT Group's efforts to reduce its environmental impact. We interviewed Teruyuki Kishimoto, president & CEO, NTT Anode Energy, about the company's core businesses and his mindset as a top executive.

Keywords: renewable energy, carbon neutrality, local production for local consumption of energy

Connecting the ICT and electric power businesses

—It has been a little more than a year since you took office as president and CEO of NTT Anode Energy. Looking back over the past year, could you tell us about your feelings and the current status of NTT Anode Energy?

I left NTT WEST, where I spent 23 years, to become president & CEO of NTT Anode Energy in June 2022. The business I oversee has shifted significantly from telecommunications to electric power, and the speed of change, scale of investment, and nature of capital investment differ from the factors in the telecommunications industry where I worked for many years, so I do feel like I've changed jobs. While making the most of my knowledge and experience in the telecommunications facility business that I had been in charge of at NTT WEST, I am keeping my ear to the ground and studying trends in the electric power business and society as a whole.

The environment surrounding the energy and electric power business is changing dramatically as exemplified by the global trend toward decarbonization, unstable energy-resource prices, and reforms to power systems owing to the increased introduction of renewable energy and the decline in thermal-power generation. In Japan, a law for promoting the smooth transition to a decarbonized growth-oriented economic structure, called the Green Transformation (GX) Promotion Law, came into effect in June 2023 to accelerate GX initiatives aimed at both achieving a stable energy supply and decarbonization, including that of the power system.

Under these circumstances, NTT Anode Energy, as an expert group in the field of energy and electric power in the NTT Group, intends to play a role in bridging between the information and communication technology (ICT) and electric power businesses.

Focusing on our four core businesses (explained later), we are promoting decarbonization and local production for local consumption of energy in cooperation with NTT Group companies and partners. This initiative takes into account the creation of a circular-economy society, as stated in NTT's new medium-term management strategy announced in May 2023, and aims to help achieve carbon neutrality in Japan by 2050. We are expected to contribute to the NTT Group and society as a whole by achieving the NTT Group's environment and energy vision and creating a smart energy business in Japan and overseas. Although we are under a lot of pressure, I find it very rewarding.

—What is the current situation of the energy and electric power industry? And how is NTT Anode Energy approaching this situation?

Over the last 10 to 20 years, the energy and electric power industry has faced many challenges. Telecommunications is evolving not day by day, but minute by minute. The energy and electric power business too has undergone major changes. In preparation for power shortages in summer and winter in Japan, electric power companies are requested to ensure stable power supplies; in fact, some experts are calling for planned power outages. The form of power generation has been required to change to renewable energy, and deregulation, including the separation of power generation, transmission, and distribution and the liberalization of the retail markets for electricity and city gas, has progressed. The electric power industry needs to address these challenges and create new businesses that are environmentally responsible.

To address these situations, about 3000 energy and electric power experts within the NTT Group joined NTT Anode Energy. In addition, specialists from outside the Group around the world were hired mid-career. NTT Anode Energy is truly an organization that embodies diversity and inclusion, and as a compass that guides all employees in the direction in which they can work together, we have set up our company's purpose as the "Anode Way," namely, "Creating a new common sense in energy through technology and inquisitiveness." Created by our employees, the Anode Way is written in simple Japanese with easy-to-understand explanations.

We also compiled "Our Story," which is our history to be shared with all employees. Tracing the footsteps of our predecessors, we discovered the fact that in 1962, they installed a small solar-power generator on a public telephone box and tested it for practical use. After the Great East Japan Earthquake in 2011, they supplied electricity through large-scale solar-power generation, which we later launched as a business. These examples gave us the opportunity to realize that what our predecessors have endeavored and built have become our great assets.

Developing a smart energy business with a value chain consisting of four core businesses

—It has been four years since the foundation of NTT Anode Energy, and its identity has been steadily established. Could you tell us about the businesses you are focusing on?

We are currently operating four businesses: Green Power Generation Business, Local Grid Business, Consumer Energy Business, and Construction/Maintenance Operation Business. We have built a value chain through these businesses and are developing it as a smart energy business.

In the Green Power Generation Business, we are developing renewable-energy power plants, such as solar, wind, geothermal, biomass, and hydropower, to meet the green power needs of customers and NTT Group companies. We intend to build power plants without causing large-scale deforestation and other issues to protect ecosystems and living environments. In August 2023, we acquired shares in Green Power Investment Corporation in collaboration with JERA Co., Inc.

In the Local Grid Business, we promote energy independence and local production for local consumption of energy by using stable, local renewable-energy sources. Since each region faces different challenges, we will address these challenges in a way that matches local circumstances and contribute to the circulation and revitalization of local economies while achieving the goal of carbon neutrality. Seven municipalities supported by NTT Anode Energy have been selected as leading decarbonization regions by the Ministry of the Environment.

In the Consumer Energy Business, we supply corporate customers with green power generated by our power plants. We are particularly interested in corporate power purchase agreements (PPAs) and believe that off-site PPAs, which are not subject to physical constraints of the customer's location and equipment and are able to flexibly meet increases or decreases in power usage, will prove even more valuable in the future.

In the Construction/Maintenance Operation Business, we provide construction, maintenance, and monitoring services of electric power equipment for various facilities such as solar-power plants and large-scale datacenters. With highly skilled technicians who monitor and control equipment at two operation centers located in eastern and western Japan, and technicians at maintenance stations throughout Japan, we provide design, monitoring, and maintenance of NTT Group's telecommunications power-supply equipment and our leading-edge technical capabilities.

—So these four businesses will make decarbonization and local production for local consumption of energy a reality, right?

We have begun specific efforts in collaboration with various local governments and partner companies. In 2023, we have been working with NEC Corporation to achieve a decarbonized society. NTT, with its environment and energy vision (NTT Green Innovation toward 2040), and NEC, with its NEC Environmental Policy and the Course of Action for Climate Change Toward 2050, have joined forces in this new initiative to reduce environmental impact. In addition to reducing NEC Group's Scope-2 greenhouse-gas emissions as NEC purchases green power from the NTT Group, we aim to reduce NTT Group's Scope-3 emissions as NEC manufactures and supplies its products to the NTT Group by using green

power, thereby promoting environmental management for both companies.

In collaboration with NTT DOCOMO and NTT Smile Energy, since May 2023, we have been conducting field experiments on household solar-power generation and storage batteries to build a decarbonized society. NTT DOCOMO, which aims to achieve carbon neutrality by providing the docomo Denki Green retail electricity service, and NTT Smile Energy, which has knowledge of solar-power generation and storage batteries, are collaborating to provide home energy services using solar-power generation and storage batteries for limited areas. Customers can install solar panels and storage batteries in their homes at a fixed monthly fee and no initial cost. NTT DOCOMO is supporting sales of this service and investigating future collaboration with the docomo Denki Green service through data analysis while NTT Smile Energy is conducting usage analysis as a provider of this service. NTT Anode Energy is investigating the expansion of its services as an electricity retailer and the future possibility of cooperation in the field of supply-and-demand adjustment.

Inspiring myself and colleagues toward goals and sharing the joy of achieving them

—In the previous "View from the Top" interview (2020), you told us about the importance of passing on tacit knowledge. How do you pass on tacit knowledge in an organization employing diverse people as NTT Anode Energy does?

For example, different industries use different systems and terminology. Since we bring together employees from a variety of backgrounds, mutual understanding of terminology and contexts is one type of passing on tacit knowledge. After COVID-19 was downgraded to a Class 5 infectious disease in Japan in May 2023, the office-attendance rate increased to about 50%, and hybrid communication combining remote and face-to-face communication has become crucial. Verbal communication between people in face-to-face meetings accounts for 20 to 30% of communicated information, and non-verbal communication, such as the shared atmosphere, accounts for the majority of the communicated information. Therefore, I would like employees to try to understand such atmosphere in communicating with one another.

We have employees in their 60s, who have been active on the front lines for many years, and young employees in their 20s and 30s; thus, this age difference of 30 to 40 years represents a huge experience gap. Under these circumstances, to pass on tacit knowledge of senior employees, we have created a system through which senior employees can teach young employees in an easy-to-understand manner by simplifying the language. Young employees ask questions of senior employees who have been responsible for maintenance and inspection of equipment and facilities so that tacit knowledge can be passed on in their daily work. In fact, today (the day of the interview), our senior employees were being bombarded with questions from our young employees over lunch. Through these efforts, we hope to create a virtuous cycle in which young employees become aware of the knowledge and qualifications they must acquire, voluntarily improve their skills, and pass these skills on to ones junior to them. When this cycle is created, tacit knowledge becomes explicit knowledge. Toward the upcoming Innovative Optical and Wireless Network (IOWN) era, I want to communicate the areas in which NTT Anode Energy should focus on and the work we should engage in. In addition to the cycle of knowledge, I want to create a grand design of new electric-power equipment and facilities by making full use of ICT.

—What do you value as a top executive? And what is your message to everyone?

As in the past, I value decision making and execution. I also value communication and action for myself to become the source of such execution. I designated the following statement as my purpose, "I will become an 'energy source' that provides vitality to the NTT Group and local communities." To achieve this purpose, I declared, "I will play a role as a guiding light in creating a safe and secure culture in which people can look ahead and keep moving forward, inspire myself and colleagues toward goals, and share the joy of achieving them. I will also keep communicating with my colleagues, who are bound by bonds, respect each other's goals, and embody and put into practice those goals to grow together." I have also asked executives of NTT Anode Energy to set their purpose as well.

I try to keep inspiring employees and bringing them together, even if it is little by little every day. To that end, I want to overcome the physical distance between our head office in Tamachi, Tokyo and the field to minimize the disparity in feelings and information as much as possible. Therefore, I visit each prefecture to listen to the voices of our employees and energize them.

I also want to communicate with people other than employees and send the following messages.

To researchers and engineers. As a global leader in the development of IOWN, I hope that you will carry your marketing ideas with you as you move toward practical application. I also expect you to value diversity and create innovation through contact with others outside the NTT Group. We cannot advance a smart energy business alone. We will continue to be in charge of operations of such business, and I would like you to conduct research and development that contributes to those operations.

To customers. We want to faithfully meet your expectations for the brand image of NTT. In this era of rapid technological progress in areas such as storage batteries and hydrogen power generation, let's work together to create something new. To that end, we welcome requests from the viewpoint of customers and will leverage the knowledge that NTT has cultivated to provide services in the energy field.

Interviewee profile

■ Career highlights

Teruyuki Kishimoto joined NTT in 1986 and became president and CEO of NTT Field Techno in 2014. In 2017, he became a member of the board of NTT WEST, senior executive manager of Kansai Regional Headquarters, and general manager of the Osaka Branch. In 2019, he became executive vice president and concurrently executive manager of Network Department, Plant Headquarters, NTT WEST. He assumed his current position in June 2022.

Pursuing Both Basic Research and International-standardization Activities to Make Technology Useful to Society

Noboru Harada
Senior Distinguished Researcher, NTT Communication Science Laboratories

Abstract
As remote conferencing is becoming commonplace and the term “metaverse” is frequently appearing in the media, society’s attention is increasingly focused on communication using video and audio. Although the role of video in such communication tends to gain greater interest, the role of audio—for example, in creating a sense of immersion—is also significant. Noboru Harada, a senior distinguished researcher at NTT Communication Science Laboratories, has been researching speech and acoustic communication for more than 20 years and is currently focusing on research and standardization of natural and highly functional speech and acoustic communication technology to achieve, for example, selective transmission of sounds you want to convey and sounds you want to hear. We interviewed him about his research accomplishments, standardization activities, and attitude as a researcher.

Keywords: speech/audio coding, immersive communication, semantic segmentation

Contributing to society through basic research and international standardization of speech and acoustic communication

—Would you tell us about the research you are currently conducting?

In 2022, I set a new research theme “research and standardization of natural and highly functional speech/acoustic communication technology,” and I’m researching technologies to (i) achieve highly functional immersive communication that supports multipoint conferences that are natural to people and selectively conveys only the sounds people want to hear or convey to others and (ii) create a speech and acoustic communication environment in which the quality of experience (QoE) is naturally and automatically improved according to individuals and situations.

When people are having a face-to-face conversation, even in the presence of ambient noise, they selectively hear the voice of the person they are

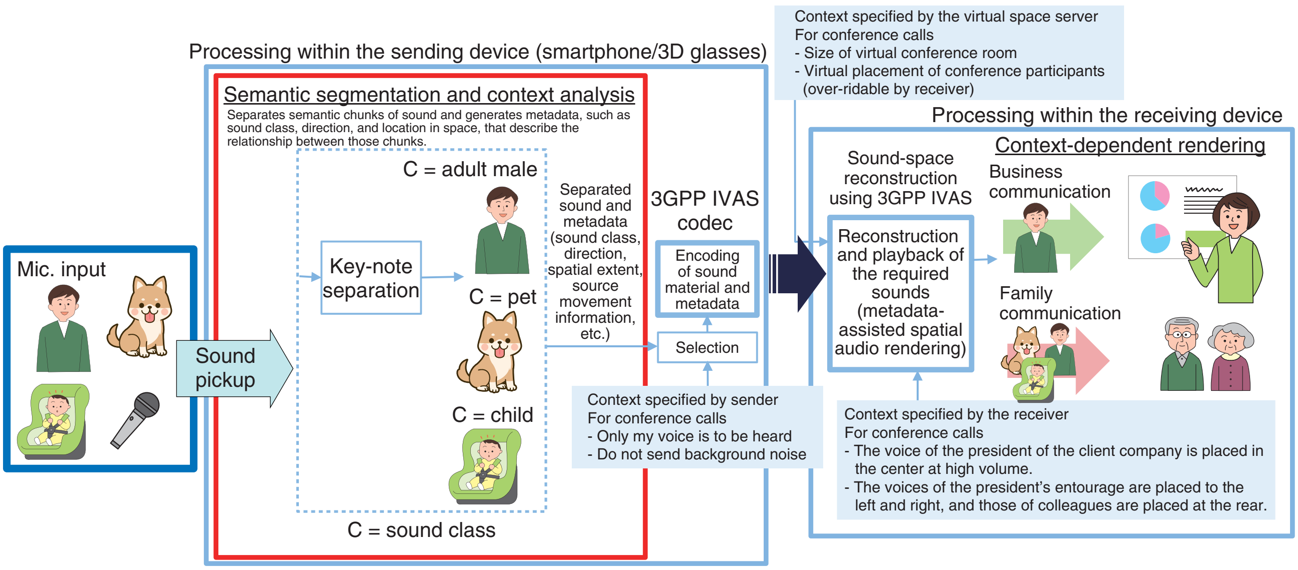


Fig. 1. Example applications of semantic-segmentation technology to immersive communication.

talking to. When people are participating in remote conferences at home, however, the microphone faithfully picks up ambient sounds that the speakers do not want to be heard, and those sounds are played through the loudspeakers of the other participants. Conversely, when family members (such as parents and grandchildren) who live far apart are remotely communicating, these ambient sounds enhance the intimacy of the communication. In other words, in communication, we want to convey and hear certain sounds.

Certain communication methods are used for remote environments, and others are used for "real" (i.e., face-to-face) environments. The use of remote environments was accelerated by the COVID-19 pandemic, but with the end of the pandemic, many situations that mix remote and real environments have emerged. Therefore, developing communication methods for such a hybrid environment is an issue.

We can address the above issues by selectively communicating only the sounds we want to convey or hear in accordance with the purpose and situation. To achieve such highly functional immersive communication, it is necessary to understand the semantic structure of input acoustic signals and extract acoustic objects (i.e., semantic chunks of sound, including metadata) by applying technologies for understanding the sound environment such as acoustic-event detection and sound-source-direction estimation. The key technology to meet this requirement is to automatically acquire representations for executing such extraction from data.

Reconstructing the extracted acoustic objects and applying them to, for example, transmission and virtual-reality (VR) and augmented-reality (AR) playback is being investigated. For VR/AR communication, "semantic segmentation" is an important technology to separate acoustic objects from multiple mixed sound inputs and output them with class and spatial information (**Fig. 1**). Since some use cases do not necessarily require high quality or the extraction of all acoustic objects, highly functional immersive communication is implemented by (i) estimating QoE in accordance with the use case (by modeling the sound-quality-evaluation criterion on the basis of human-auditory perception) and (ii) automatically improving and tuning the sound quality and acoustic objects to be extracted to meet the criterion.

I believe that these technologies for highly functional immersive communication can be used for not only conference calls but also remote medical care, monitoring the elderly, remote control of heavy machinery, and other use cases where sound is heard remotely. With these use cases in mind, I'm aiming for practical application of these technologies through international standardization and other means.

—Before setting this new theme, what type of research have you conducted thus far?

Since joining NTT in 1997, with the exception of a period of development work at an operating company and research management, I have worked on speech/acoustic signal processing, coding, and its international standardization. Recently, I have specialized in self-supervised learning and other representation learning techniques and in applying these techniques to understand sound environments such as acoustic-event detection and anomalous-sound detection.

An achievement representing that work includes the technical proposal and standardization of MPEG-4 Audio Lossless Coding (ALS)*, a lossless coding method for acoustic signals. MPEG-4 ALS is implemented in encoder equipment manufactured by NTT Electronics and used for high-resolution music distribution and other applications. In 2018, in cooperation with NTT DATA and other operating companies, we practically applied our technology to detect anomalies from sounds made by machines and other equipment. This technology is being used to (i) monitor vehicle abnormalities by analyzing train-running sounds recorded on the ground and (ii) identify and detect damage and deterioration of equipment in facilities such as power plants.

I have contributed to international standardization through the following activities. At MPEG in ISO/IEC, I helped standardize the MPEG archive format in audio coding as a chair of the MPEG-Audio Ad Hoc Group and helped standardize MPEG-4 ALS as an editor. At IEC, I helped establish the IEC61937-10 transmission standard as a project leader and editor, and at the International Telecommunications Union - Telecommunication Standardization Sector (ITU-T), I served as an editor on the audio coding standard, ITU-T Recommendation G.711.0. At the Internet Engineering Task Force, I served as an editor on RFC 7655, which specifies payload formats in the Real-time Transport Protocol.

At the 3rd Generation Partnership Project (3GPP), an international standardization body for mobile communications, I also contributed to the international standardization of Enhanced Voice Services (EVS), a high-quality audio-coding technology that is now implemented in all smartphones and adopted by NTT DOCOMO's VoLTE HD+ (Voice over Long-Term Evolution High Definition+) service. I'm currently working on the international standardization of IVAS (Codec for Immersive Voice and Audio Services), which aims to achieve high-quality multi-point telephone services using audio-object coding that enables immersive two-way communication (**Fig. 2**).

In 2020, I served as general chair of Detection and Classification of Acoustic Scenes and Events (DCASE), a major international conference on understanding sound environments, where our team proposed a model for describing the sound on the basis of the distance between language and sound and won first place in the DCASE Challenge Task 6: Automated Audio Captioning task.

Practical application of basic research results through international standardization

—You have been involved in a wide range of activities from basic research to international standardization. In this context, could you tell us what you value as a researcher?

In my research, I find a research topic (technology) with real-world applications in mind, carefully observe the constraints and requirements, and create a reasonable hypothetical model by comprehensively examining the observation results from physical, psychological, mathematical, and informational perspectives. By using this model, I devise the functions necessary for practical use and the methods to implement them and make proposals to international standardization conferences and organizations toward the goal of our technology being used in society. This model can be created as a precise and complex model or as simple and easy model in accordance with the situation, so I find the appropriate model representation in consideration of accuracy and other requirements for practical use cases.

When considering the requirements from a practical standpoint, for example, in noise detection, I also tried to change my way of thinking. In general, music or voice is a target signal and background noise is an unwanted noise. In anomalous-sound detection, however, it is necessary to construct a model by treating strange noise made by machines as a target signal and normal machine sounds as noise. In terms of how to model the phenomenon of interest, the basic idea is

* MPEG-4 ALS: A lossless compression method standardized as part of MPEG-4 Audio by the Moving Picture Experts Group (MPEG) in International Organization for Standardization/International Electrotechnical Commission (ISO/IEC). It is a data-compression method with which the volume of data before compression and the volume of data that are compressed then decompressed can be completely equal.

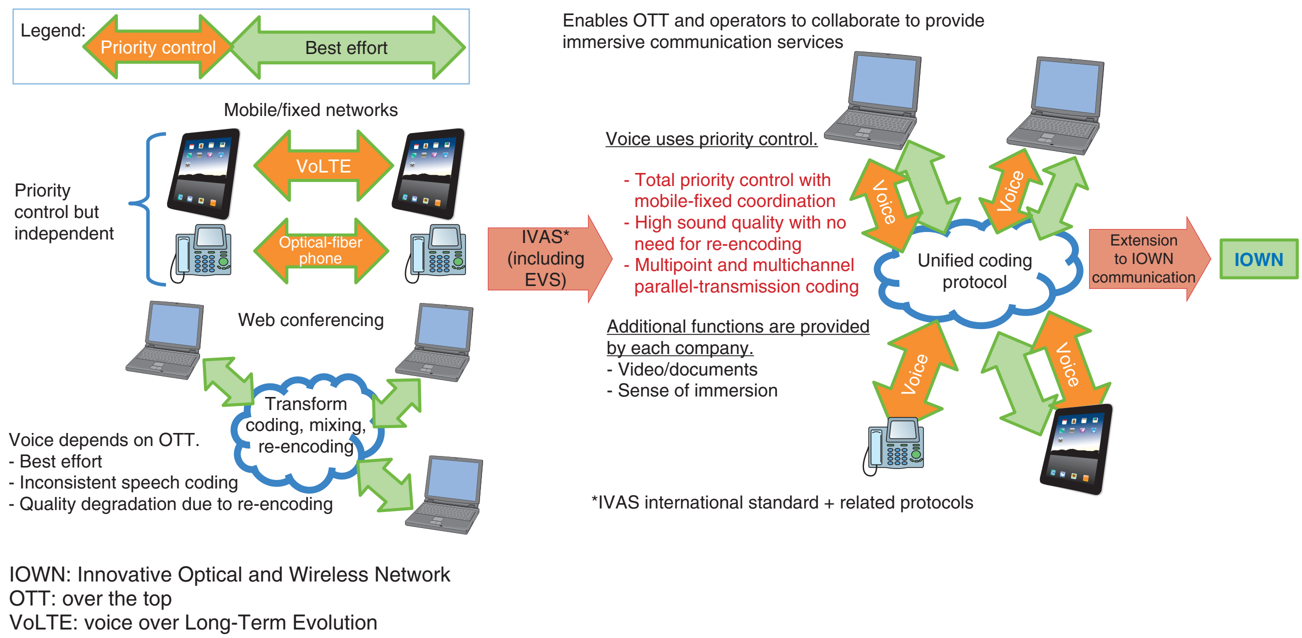


Fig. 2. Aim of 3GPP IVAS standardization at NTT.

the same as the technology used in lossless coding and EVS.

As a corporate research institute, NTT Communication Science Laboratories is engaged in everything from basic research to practical applications, and our desire is to advance research that is useful to society and ultimately contribute to humanity in some form or another. We have therefore set themes that are at the intersection of needs and new technologies or seek to find that intersection. As basic researchers, however, we must also be aware of competition with other researchers. Therefore, there is only so much one person can do, so I believe it is important to focus on what only we can do, rather than trying to do everything by oneself. It is therefore important to work as a team with organic cooperation and division of roles or collaborate with outside parties.

—Is the world of international standardization established through the consensus of participants different from that of basic research?

In the world of international standardization, being useful to society is of paramount importance. Otherwise, there would be no point in establishing an international standard. Therefore, participants in international standardization will make proposals toward this goal and build consensus in the course of discussions. In discussions, conflicts of opinion sometimes arise; even so, the roles of the chairperson, rapporteur, and others, who are basically elected, are to bring those in conflict together and increase the number of supporters to reach a consensus. To fulfill these roles, they need to be trusted by the participants and have broad and deep technical expertise in the field.

My subject technology is only a small part of the international standardization arena, but I still find it frustrating when our technology is not adopted, so I will make every effort to get it adopted. Even if our technology is not adopted directly, I believe that demonstrating it as a competing technology leads to the adoption of easier-to-use and more valuable technology, thereby contributing to humankind.

As for research, each researcher has their own area of expertise and phase of expertise within phases from theme setting to practical application. Even if the themes and goals of different researchers are close, different approaches will result in different time frames. I believe this time-frame difference is one element of the competitiveness in research.

I have a position as both a researcher and contributor to international standardization; however, I am engaged in research with the aim of making practical use of technology, so I am not conscious of each role being a separate entity. As I mentioned earlier, I am always aware of the intersection of needs and new technologies, so issues and requirements discussed in international standardization become needs, which in turn become research themes in terms of pursuing new and basic technologies for satisfying those needs. On the contrary, we may propose the new technology resulting from our research to international-standardization bodies, where discussions can lead to the formation of new methods for applying that technology.

To cite a recent activity, I've been fostering a community at DCASE through the anomalous-sound-detection challenge that I am organizing with other researchers. Through this challenge, we have increased the number of researchers in the field of anomalous-sound detection and have created a platform that enables us to refer to new technologies that emerge from this challenge and eventually gain insights that we can use in our business. Participants in the community are also using this platform to advance their research. Although this challenge differs from international standardization, I believe it will greatly accelerate the process of making a technology useful to society.

Effectively communicating the value of research

—Could you give a message for younger researchers?

In many cases, researchers research a topic that is of interest to them, which can be fun. Such research can be undertaken by convincing those around you—sponsors, customers, partners, operating companies, supervisors, colleagues, and rival researchers—of its value. To get people to understand that value, you need to show them evidence. It is necessary to explain what you aim for, what you want to do, why it is important, and how you will solve the problem then provide evidence to support these elements. However, the people to whom this evidence should be presented—sponsors, customers, partners, operating companies, supervisors, colleagues, and rival researchers—are not all experts, and some are not researchers or engineers. You should effectively communicate the value of your research so that people from various walks of life will understand it. To this end, I believe it is necessary to be aware of the environment surrounding your research.

In the field of basic research, however, disruptive technology that is too advanced to keep up with can suddenly emerge. In such cases, you should not be distracted by what others say; instead, strive forward on the path you believe in. If, as a result of your research, you can demonstrate strong evidence that no one can refute, those around you will eventually be forced to understand. Of course, I think everyone should make an effort to be understood whatever amazing technology you have developed.

■ Interviewee profile

Noboru Harada received a B.S. and M.S. from the Department of Computer Science and Systems Engineering from Kyushu Institute of Technology, Fukuoka, in 1995 and 1997 and later received a Ph.D. from University of Tsukuba, Ibaraki. Since joining NTT in 1997, he has been researching lossless audio coding, high-efficiency coding of speech and audio, and their applications. He is an editor of ISO/ IEC 23000-6:2009 Professional Archival Application Format, ISO/ IEC 14496-5:2001/ Amd.10:2007 reference software MPEG-4 ALS and ITU-T G.711.0 and has contributed to 3GPP EVS.

Transmission Technology for Space-division Multiplexing Supporting Next-generation High-speed, Large-capacity Communications beyond Existing Limits

Takashi Matsui
Distinguished Researcher, NTT Access Network Service Systems Laboratories

Abstract
Recent years have seen remarkable developments in information and communications technology and a dramatic increase in communications traffic. The capacity limit in existing optical fiber supporting such communications is about 100 Tbit/s per optical fiber, and it is predicted that transmission systems using this optical fiber will reach this limit in due time. In this interview, we talked with NTT Distinguished Researcher Takashi Matsui about his research on solving this transmission capacity problem by greatly expanding optical transmission capacity using "optical fiber transmission line technology for space-division multiplexing."

Keywords: optical fiber, space-division multiplexing, multi-petabit class

Optical fiber transmission line technology for space-division multiplexing for achieving a multi-petabit-class transmission infrastructure

—Dr. Matsui, what exactly is "optical fiber transmission line technology for space-division multiplexing" for solving the transmission capacity problem?

Optical fiber transmission line technology for space-division multiplexing (SDM) prepares multiple light paths within optical fiber to perform communications and achieves far more transmission capacity than existing technologies. In recent years, the usage scenarios of information and communications technology (ICT) have become quite diverse producing a sharp rise in the demand for transmission capacity. For example, the core network that bundles and transmits communications signals over long distances between prefectures in Japan currently implements an optical transmission system having a transmission capacity of 16 Tbit/s per optical fiber, which represents an increase of about 1000 times over the last 20 years. The capacity limit of optical fiber now in common use is predicted to be about 100 Tbit/s per

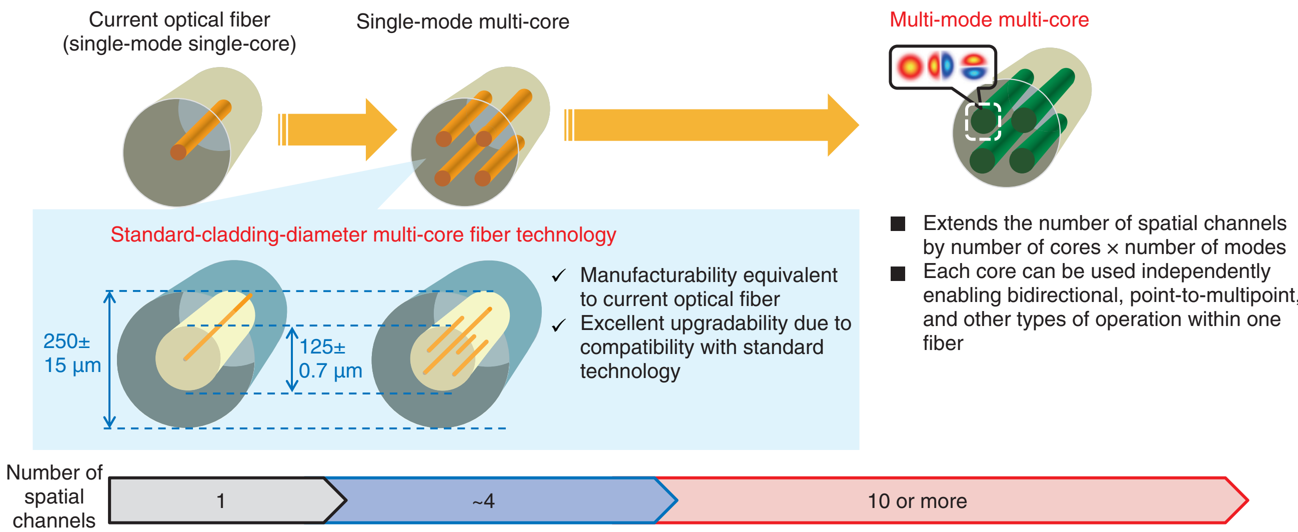


Fig. 1. Evolution of optical fiber technology.

optical fiber, so we can expect the current optical transmission system to reach its limit around 2030 due to the rapidly rising demand for communications.

The solution to this problem in next-generation transmission capacity is SDM optical fiber transmission line technology. The mainstream form of optical fiber used in today's optical transmission system is single-mode fiber that transmits signals through only one path per optical fiber. In contrast, SDM optical fiber transmission line technology transmits signals through multiple, independent paths per optical fiber. Since increasing the number of paths by n times increases transmission capacity by approximately n times, it becomes possible to dramatically expand transmission capacity beyond comparison with existing technology.

To increase the number of optical paths in a single optical fiber, we research SDM optical fiber transmission line technology mainly from two perspectives: the part of the fiber that passes light called a "core" and the way in which light propagates through a core called a "mode." There are three specific approaches here: multi-core fiber that incorporates multiple cores, multi-mode fiber that sets multiple modes in a single core, and multi-mode multi-core fiber that combines the above two technologies. In the case of multi-core fiber that is as thin as current optical fiber, the maximum number of single-mode cores is four. On the other hand, multi-mode multi-core fiber enables light to propagate in multiple spatial modes per core, which makes for excellent extendibility. As an example, establishing three modes within each of four cores means that light can propagate through $3 \times 4 = 12$ paths (spatial channels), which opens up the possibility of expanding transmission capacity by a significant amount. In addition, combining this feature with technology for expanding wavelength bands in optical fiber is expected to greatly expand transmission capacity beyond what ever could be achieved by conventional technologies (**Fig. 1**).

—What are some of the difficulties that have to be overcome in SDM optical fiber transmission line technology?

In multi-core fiber having multiple cores in a single optical fiber, a phenomenon called "crosstalk" arises in which light leaking into a neighboring core creates interference. This crosstalk can significantly reduce transmission capacity to an extent that prevents transmission capacity to be increased by n times by increasing the number of paths by n times. At NTT, we are working to solve this problem by attempting to fit as many cores as possible into a single optical fiber while making the inter-core distance large enough to prevent the generation of crosstalk. Of course, making the diameter of the optical fiber larger would enable the number of cores to be increased. However, thicker optical fiber creates problems in relation to physical properties such as making it hard to bend the fiber when laying and making it difficult to handle the fiber cable overall. On top of this, making the diameter of optical fiber larger means increasing the amount of glass material used, which can greatly degrade the manufacturability of optical fiber. When setting out to deploy optical fiber in actual facilities, these problems in physical properties and ease-of-handling and in manufacturing cost take on great importance. So researching without taking these problems into consideration can lead to a result in which no one would be able to use the optical fiber. It is for this reason that searching for an optimal number of cores while maintaining the conventional diameter of optical fiber has become a key research issue.

In parallel with this research, we are also researching the expansion of wavelength bands in optical fiber. At present, systems are configured with optical fiber in which signals are packed into a region limited to a bandwidth of about 35 nm called the C-band in the 1.5-µm range. If this wavelength band can be expanded so that a wide range of wavelengths can be used, a quantum leap in transmission capacity should become possible. We are therefore conducting research with the aim of expanding the wavelength band to the 1.6-µm band, for example, to support the need for greater transmission capacity with NTT's vision of the Innovative Optical and Wireless Network (IOWN) in mind. In the design of optical fiber, the task is to find a wavelength band in which sufficient transmission quality can be obtained by controlling changes in the refractive index and optical characteristics of optical fiber. However, two key technical problems in SDM optical fiber are "crosstalk increases when expanding the upper wavelength limit (to longer wavelengths)" and "light can easily leak when expanding the lower wavelength limit (to shorter wavelengths)." In optical-fiber structures up to now, shortening the lower wavelength limit and lengthening the upper wavelength limit have had tradeoffs, so we are exploring new optical-fiber structures and manufacturing methods that can significantly increase transmission capacity while searching out wavelength bands that can be used.

—What have been some of the achievements of SDM optical fiber transmission line technology to date?

As one achievement of SDM optical fiber transmission line technology, our research group successfully performed a relay transmission experiment exceeding a transmission capacity of 100 Tbit/s per optical fiber in cooperation with industry, academia, and government in 2017. We did this by using a transmission line that interconnected 4-core multi-core fibers fabricated by multiple vendors. We have also been researching the number of cores and modes that can fit within a certain fiber thickness for which the optical fiber breakage rate can be sufficiently tolerated. In 2018, we demonstrated a 10-mode, 12-core multimode multi-core fiber thereby achieving the world's highest number of spatial channels at 120.

In research reports on SDM optical fiber up to now, extremely diversified structures have been proposed in terms of the number of cores, thickness of the optical fiber, and other parameters. However, when actually making optical fiber into a product and using it in communications facilities, connectivity between optical fibers and compatibility with other devices and facilities must be ensured. For this reason, NTT took the worldwide lead in proposing that the thickness of optical fiber be maintained at 0.125 mm as used by existing single/multi-mode fiber and that four cores are optimal in transmission by multi-core fiber.

These research efforts have progressed through collaboration with many experts and individuals from the NTT Group. When arriving at the stage of installing optical fiber, a variety of technologies that are needed to configure a total optical communications system must be studied in addition to connectivity, such as input/output methods, transmission-equipment and system configuration, and operation methods. Our research has been making good progress by receiving feedback from many people.

In view of a 125-fold increase in transmission capacity as a target of the All-Photonics Network in NTT's IOWN vision, we are aiming for a transmission capacity potential of more than 10 times in an optical fiber transmission line as our research target going forward. To achieve this target, the first step in our research plan for SDM optical fiber transmission line technology is to focus our attention on establishing technology for 4-core multi-core fiber having high affinity with existing optical technology. Additionally, while using this 4-core multi-core fiber technology as a basis to work from, we will explore methods of establishing technology that can extend the number of spatial channels in one direction to 10 or more and thereby achieve a transmission capacity potential of more than 10 times in an optical fiber transmission line.

Moreover, taking into account present capacity demands, it is predicted that the demand for transmission capacity will increase to the multi-petabit class from 2040 on. We therefore want to work on

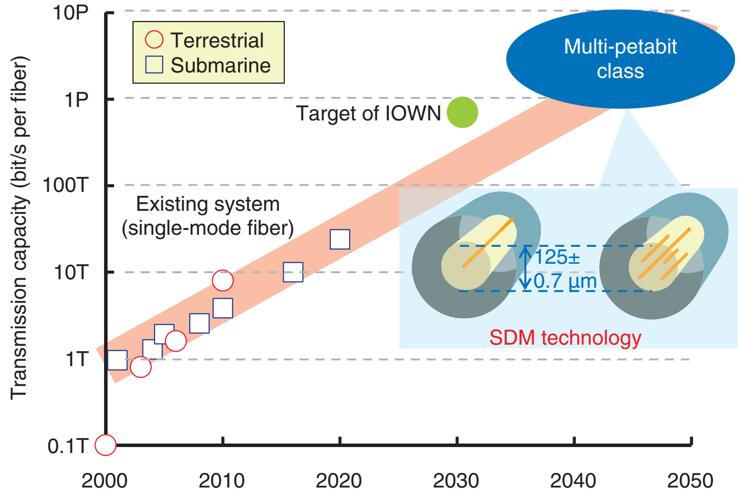


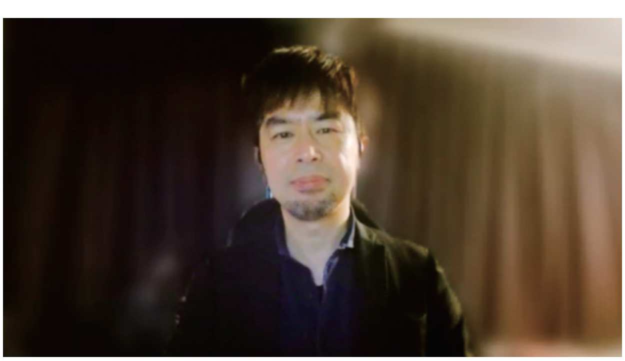
Fig. 2. Research targets toward a new transmission infrastructure.

establishing technology that can also support the future beyond IOWN. Furthermore, in addition to high-density SDM optical fiber starting with multi-mode multi-core fiber, we will also work on technology for controlling wavelength characteristics. Our aim here is to establish new optical fiber transmission technology that can achieve transmission capacity 50 times that of current levels and support transmission capacity of the multi-petabit class (**Fig. 2**).

Placing importance on the user's point of view—flexible thinking builds a new future

—What way of thinking should be valued in research?

In my many years of research, I have often witnessed the appearance of optical fiber and devices based on totally new concepts different from those of the past. At the research stage, this can be quite exciting, but a pitfall here is that a new fiber or device may turn out to be useless when it comes time for actual implementation. Of course, when you are pursuing only the research immediately in front of you, no value is being created. To some extent, I think it's very important to strike a balance between an awareness of how research is to be used in the future and taking up the challenge of new, cutting-edge research, and then set and prioritize themes. No matter how interesting a certain research theme may be, I believe it is meaningless if it comes to be used nowhere in the end. I myself have experienced such a failure any number of times, and to avoid making the same mistake again, I conduct my research while listening to diverse viewpoints and exchanging opinions with experts in other organizations and fields and manufacturers too. In this way, I can expand my field of vision.



In fact, NTT Access Network Service Systems Laboratories that I belong to is in charge of all sorts of technologies that are needed in the network to connect customers with central offices. It deals with a very broad range of technical fields from civil-engineering facilities, optical facilities, and wireless facilities to operations and services. Because it has facilities throughout Japan, it has high technical competence and a great ability to make judgments on the specifications, construction, and operation of those facilities all the way from research and development to implementation and operation. I believe that this is a major strength of NTT Access Network Service

Systems Laboratories. In addition, I feel that the ability to develop and implement technologies while fortifying our ties with NTT Group companies and discussing their needs is very reassuring for researchers. The achievements that have come about through the efforts of senior researchers are also encouraging. Moreover, I have many opportunities to hear what people in standardization organizations and academic societies outside of NTT have to say, and I can conduct my research while exchanging opinions with a wide range of people. Interacting with people in a variety of situations is truly a blessing. I believe that this sort of environment is very important for achieving success in research.

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

Today, technology is progressing, and we are entering an era in which many people, myself included, can feel its benefits. Technology will continue to evolve: communications in our daily lives will become even more convenient through wireless technologies, and cutting-edge services and social innovations will be driven by virtual reality, artificial intelligence, and other types of advanced software. From here on, however, optical transmission facilities will become indispensable to support such high-speed communications and new social developments. Yet, in recent years, it has become difficult to focus on technologies related to the communications infrastructure as they tend to be hidden by software-based technical fields in the digital space. So the communications infrastructure is perhaps a low-profile field, but if new technologies in this field can be released to the world, I think they would have great potential in driving dramatic changes in existing industries and today's society. Going forward, I myself would like to promote top-level research results throughout the world and contribute to the development of new optical communications facilities including the standardization of these results in a form that can provide for practical deployment. In this endeavor, I look forward to everyone's support.

Additionally, while I hope that this will be the desire of people involved in the research of optical communications from here on, there is still much room left for discussion in how this field should continue to develop and in what way new technologies should be pursued. If a flexible way of thinking can be adopted as in the merging of our technologies with technologies in other fields, I believe that the entire optical communications field can be energized and that the future of the communications infrastructure can be made bright indeed. To those who can sow the seeds of such flexible thinking and to readers who find this article interesting, I would say, "Let's work together to build a new future for optical communications."

■ Interviewee profile

Takashi Matsui received his M.E. in electronic engineering from Hokkaido University in 2003 and entered NTT in the same year. He received his Ph.D. in electronic engineering from Hokkaido University in 2008. He has been an NTT distinguished researcher since 2022. He is engaged in the research of optical fiber transmission line technology for space-division multiplexing toward a dramatic expansion of space and wavelength resources. He is a recipient of the Japanese Ministry of Economy, Trade and Industry (METI) International Standardization Contributor Award in 2021, SPIE Photonics West 2021 Best Technical Paper Award, and OECC/PS 2019 Best Paper Award among other awards. He has been a visiting professor at the College of Engineering, Ibaraki University since 2022.

APN Service-provision Activities

Junichiro Saito and Yukiko Chaki

Abstract

In March 2023, NTT EAST and NTT WEST launched APN IOWN1.0, the first-version service of the All-Photonics Network (APN), which is one of the major technology areas that comprise the Innovative Optical and Wireless Network (IOWN). APN IOWN1.0 provides ultra-low latency and enables the visualization and adjustment of latency with microsecond granularity. This article describes the position of the newly introduced APN service within the IOWN concept and the value the service provides. It also presents typical use cases and an overview of the service.

Keywords: APN IOWN1.0, ultra-low latency, visualization and adjustment of latency

1. Introduction

On March 16, 2023, NTT EAST and NTT WEST launched APN IOWN1.0, the first-version service of the All-Photonics Network (APN) of the Innovative Optical and Wireless Network (IOWN) [1].

The APN is one of the major technology areas comprising IOWN. It implements photonics-based technology everywhere from terminals to the network, thereby providing end-to-end optical wavelength paths. Its aim is to achieve unparalleled low-power-consumption, high-quality, high-capacity, and low-latency transmission.

With this capability, the APN will address network issues, such as ever-growing traffic volume, network complexity, and latency due to congestion. It will also address energy-consumption issues, such as increases in power consumption at datacenters. The APN will make it possible to provide customers with new experiences and value, such as the fusion of real and online activities that will be required in response to changing lifestyles.

Although the target year for implementing IOWN is 2030, we decided that the value of ultra-low latency can be provided by combining technologies and products currently available. Thus, we studied the possibility of launching the APN service in March 2023, ahead of 2030. The intention was that the early introduction of the APN service would enable us to work with customers to accelerate the creation of new use cases and new value.

The efforts to implement APN IOWN1.0 were led by NTT EAST and NTT WEST in collaboration with the Innovative Technology Office under the NTT Technology Planning Department, whose mission is to commercialize IOWN-related technologies, the IOWN Development Office under the NTT Research and Development Planning Department, which is responsible for promoting research and development of IOWN-related technologies, and NTT laboratories (NTT IOWN Product Design Center, NTT Network Innovation Laboratories, and NTT Network Innovation Center), which are researching and developing APN-related technologies and products (see **Table 1**).

2. APN IOWN1.0 provides ultra-low latency

Of the three performance targets of the APN [2], APN IOWN1.0 offers the value of ultra-low latency with end-to-end latency being 1/200[*1] that of the conventional network. It also features a commercial implementation of “OTN Anywhere,” an optical transport network (OTN) terminal device developed by NTT laboratories that visualizes and adjusts latency with microsecond granularity.

The performance targets of the APN for 2030 are as follows.

(1) 100-times higher power efficiency: We aim to achieve low power consumption by implementing technology that transmits signals all

*1 End-to-end latency being 1/200: Target latency for intra-prefecture video traffic that does not require compression.

Table 1. Organizations involved in the implementation of APN IOWN1.0.

Organization	Role
NTT EAST/NTT WEST	Install equipment and provide service
NTT Technology Planning Department	Promote commercialization of IOWN technology
NTT Research and Development Planning Department	Promote research and development of IOWN technology
NTT IOWN Product Design Center	Promote the implementation of products that adopt IOWN technology
NTT Network Innovation Laboratories	Undertake APN-related research and development
NTT Network Innovation Center	Develop APN-related products

the way through the network to the terminal in optical form as well as by implementing technology of photonics-electronics convergence.

(2) 125-times higher transmission capacity: This will be achieved through the use of new multi-core optical fibers, implementation of high-capacity transceivers, and adoption of high-capacity optical-transmission-system technology.

(3) End-to-end latency being 1/200 that of the conventional network: We seek to achieve ultra-low latency by transmitting information in units of wavelengths, eliminating the need for encoding and compression.

Take video transmission as an example. In a current mainstream Internet protocol (IP) network, it is general practice for a video captured with a camera to be encoded and compressed for transmission over the IP network with the data being decompressed and decoded at the destination before the video is displayed on a monitor. In the APN, however, the OTN*2 protocol is used for high-speed layer 1 communication paths, making optical-wavelength spans end-to-end paths. This eliminates packet queuing at routers and switches in the paths, enabling jitter-free communication with ultra-low latency. Since the APN has high capacity, video can be transmitted without encoding or compression. Thus, the APN reduces latency currently caused by encoding and compression and eliminates jitter that is currently produced by fluctuations in packet forwarding. By using low-latency cameras and monitors, we can minimize latency throughout the entire system.

We provide the capability to visualize and adjust latency with microsecond granularity by connecting OTN Anywhere (**Fig. 1**). This device makes it possible to equalize delays across different locations. This capability is effective and valuable for use cases that require fair timing between different locations, such as e-sports.

3. APN IOWN1.0 use cases

The ultra-low latency provided by APN IOWN1.0 is beneficial not only for e-sports but also for a variety of use cases not achievable with conventional networks, such as the remote operation of surgical robots in areas where doctors are in short supply, remote operation of devices in vast factories and of facilities located high above ground, and remote production in the broadcasting industry through real-time video transmission.

The availability of a network with high performance means that applications in various business fields that have been conventionally processed on-premises can be processed over the network. This will help produce solutions that overturn the conventional way of business (**Fig. 2**).

A typical benefit of ultra-low latency is the ability to perform precise operations and tasks even from a distance (**Fig. 3**). Typical use cases that demonstrate this ability are described below.

3.1 Telemedicine using surgical-support robots

There are concerns over the shortage of surgeons in rural areas and too great a concentration of medical specialists and supervising doctors in urban areas. These concerns have given rise to expectations for telemedicine. Connecting a surgical robot with a remote operator via the APN makes information transmission between them fast and jitter free, facilitating high-quality remote surgical support through stable robot teleoperation. It is also important to provide an environment in which medical personnel at a remote location can feel as if they are in the same room as the patient. Bi-directional communication over the APN enables medical personnel to conduct

*2 OTN: A communication standard for optical transmission networks specified by ITU-T (International Telecommunication Union - Telecommunication Standardization Sector), an international standardization organization.

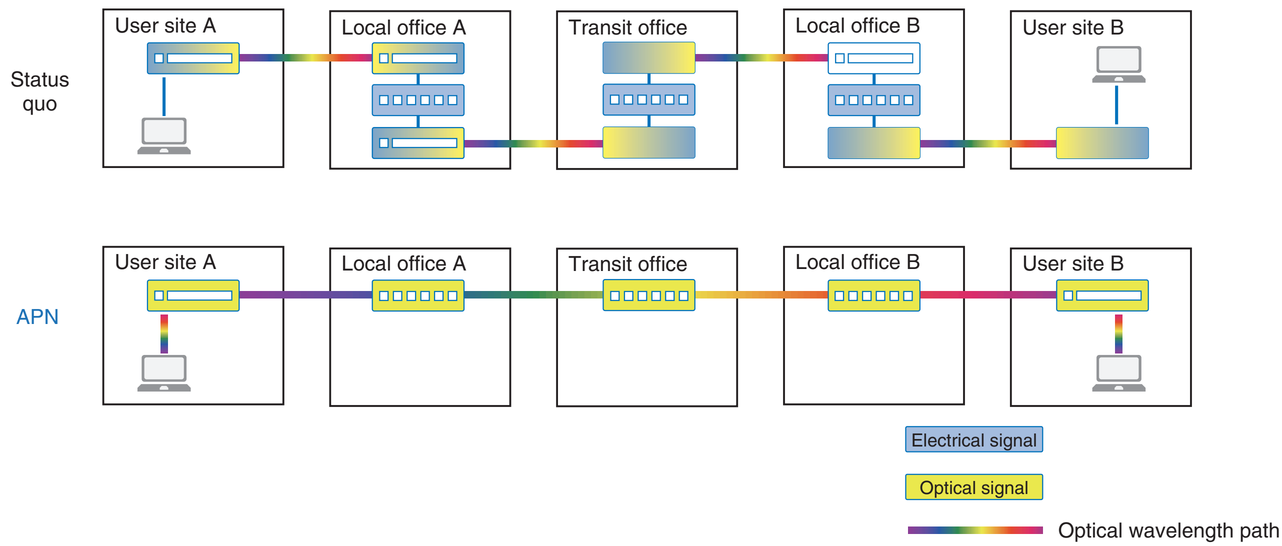
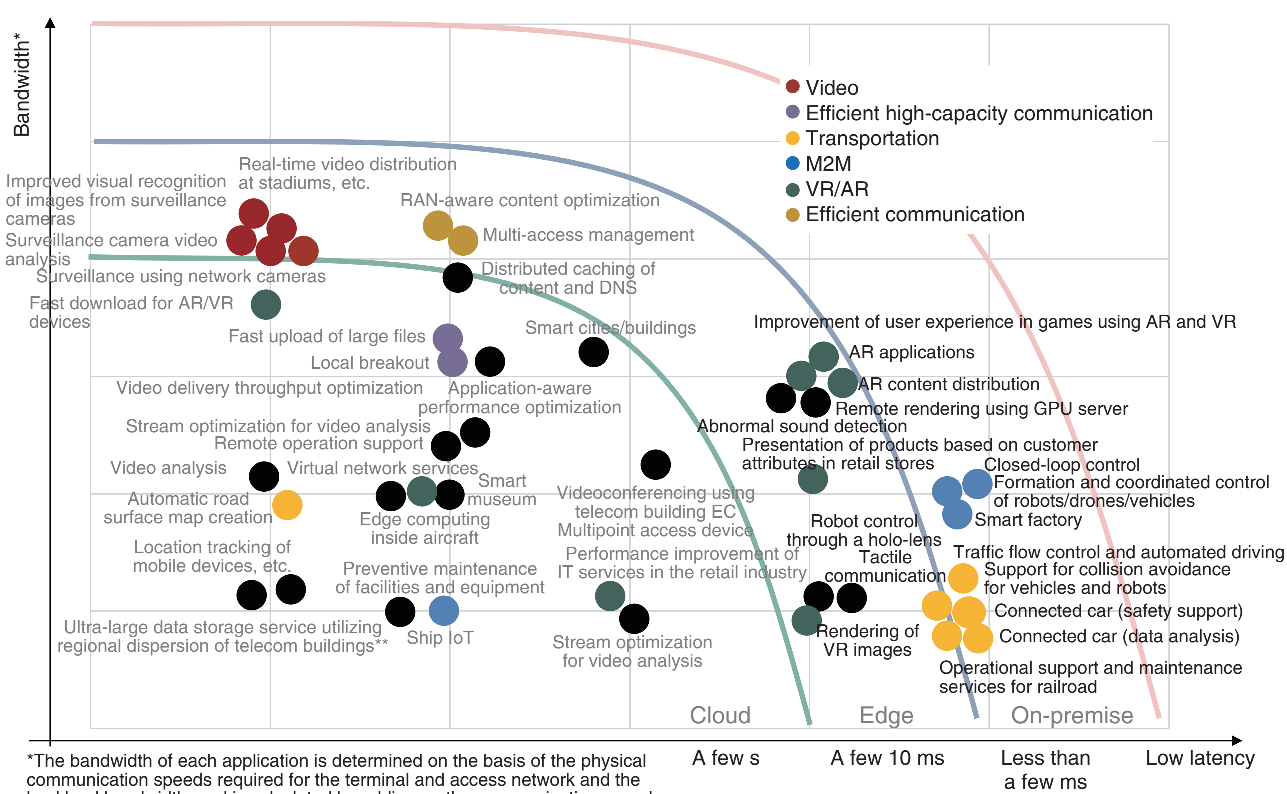


Fig. 1. APN provides ultra-low latency.



*The bandwidth of each application is determined on the basis of the physical communication speeds required for the terminal and access network and the backhaul bandwidth, and is calculated by adding up the communication speed of each terminal multiplied by the number of terminals accessing the edge site.
**The required bandwidth is narrow because storage units are physically delivered.

AR: augmented reality
DNS: domain name system
EC: edge computing
GPU: graphics processing unit
IT: information technology
M2M: machine to machine
RAN: radio access network
VR: virtual reality

Fig. 2. Areas that are expected to benefit from low latency.

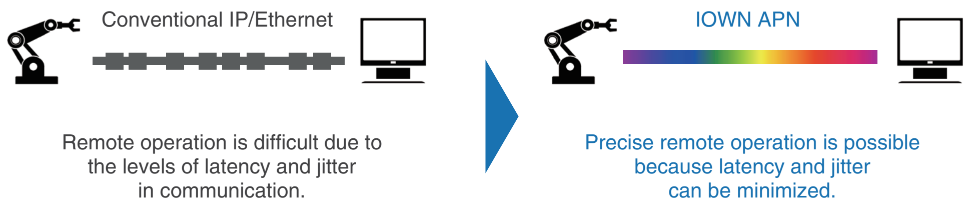


Fig. 3. Image of a use case that takes advantage of ultra-low latency.

surgery while viewing high-resolution images, such as 8K video, of the patient's condition, operating room, and other operational conditions. By supporting telemedicine, we are aiming for further development of regional medical care.

3.2 Smart factories

The low-latency, jitter-free APN makes remote operation possible for a wide range of tasks and maintenance work in vast environments, such as chemical plants and precision-equipment manufacturing plants. Remote fine operations, such as checking equipment and fine-tuning valves located high above ground or in explosion-proof areas, enable skilled personnel to gather in a room in factories and safely perform high-risk tasks. Implementing Internet of Things (IoT) in machines and systems at multiple locations and connecting them via the APN makes it possible to automate manufacturing lines and enables automated remote inspection of products before shipment.

3.3 Remote television production

The broadcasting industry is focusing on remote television (TV) production, a new method of live program production, by which video captured at an event site is transmitted to a program-production site in real time. The high-capacity, low-latency APN enables uncompressed transmission of video between an event site and program-production site. Conventionally, production equipment needs to be brought to the event site, and a program is produced on-site and distributed to broadcast stations. Remote TV production reduces the need to bring equipment and personnel to the event site.

Beyond the examples introduced above, we will endeavor to expand applicable use cases by combining the APN with other IOWN technologies and further evolving the APN. Such attempts include connecting datacenters with the high-capacity and low-latency APN to enable optical disaggregated computing[*3] and applying the APN to mobile fronthaul to rapidly expand the service area of Beyond fifth-generation mobile-communication system (5G)/6G.

4. Overview of APN IOWN1.0

The APN IOWN1.0 service achieves high-speed, high-capacity, low-latency, and jitter-free communication by providing dedicated optical wavelength in all sections of the network and using the optical transport unit 4 (OTU4)[*2], which accommodates multiple optical transmission networks, at APN interfaces. The combined use of OTN Anywhere, which is an APN terminal device, makes it possible to visualize and adjust latency (**Fig. 4**).

(1) Features of APN IOWN1.0

- High speed, high capacity: Dedicated point-to-point 100-Gbit/s paths.
- Low latency, jitter free: Latency 1/200 that of conventional networks, no jitter[*4], and no impact from other users' traffic thanks to the use of a dedicated optical wavelength for each path.

(2) Features of terminal device, OTN Anywhere

- Conversion of information format: The device receives 10-GbE or 100-GbE signals from customer devices, converts them to OTU4, and outputs them.
- Visualization and adjustment of latency: The device visualizes latency by outputting the results of measurements at certain points as an OTN Anywhere log, which can be used to adjust latency with microsecond granularity (8 µs to 20 ms).

*3 Optical disaggregated computing: In contrast to the conventional server-oriented concept in which computers are connected via a network, this concept takes advantage of the transmission characteristics of light by using optical fibers to directly connect computer resources, such as central processing units and memory units, and treats them as a single computer on a datacenter scale.

*4 Latency 1/200 that of conventional networks, no jitter: Time division multiplexing (distinguishing multiple traffic by fixing the time of transmission) is used to reduce traffic-dependent latency and packet loss.

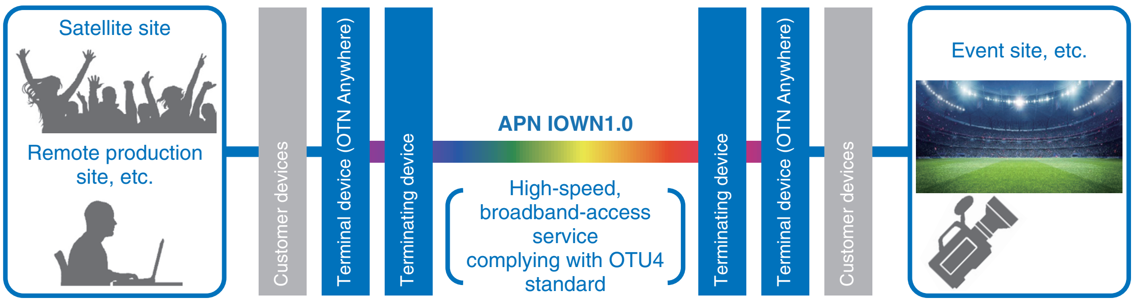


Fig. 4. Overview of APN IOWN1.0 service.

5. Conclusion

We launched APN IOWN1.0 as the first service offering of IOWN. We expect that this early provision of the APN will accelerate the creation of new services in collaboration with external partners as well as the creation of new use cases and value for customers. We will continue to enhance the unique features of the APN, such as low power consumption enabled by photonics-electronics convergence technology and high-quality, high-capacity transmission that uses high-capacity optical-transmission-system technology on the basis of new optical fibers such as multi-core fibers.

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Joining NTT EAST in 2005, he worked as a network planner for regional networks. He was involved in Next Generation Network (NGN) operations from 2007. He was then engaged in the launch of an NGN security task and enhancement in-house systems security until 2021. In his current position, he has been promoting the implementation of services actualizing the IOWN concept.

Yukiko Chaki
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Joining NTT WEST in 2007, she worked as a network engineer, mainly formulating the strategy for network enhancement and performing network operations and maintenance. In her current position, which she has held since 2022, she has been promoting the commercial implementation of IOWN aimed at creating new businesses that take advantage of IOWN technologies.

Road to IOWN at NTT EAST

Takahiro Igarashi and Yuta Takino

Abstract

As the first commercial service of the Innovative Optical and Wireless Network (IOWN), NTT EAST launched the All-Photonics Network (APN) IOWN1.0 service on March 16, 2023. In this article, we introduce our demonstration efforts in taking advantage of low latency, use cases, and future prospects of APN IOWN1.0.

Keywords: IOWN, All-Photonics Network, low latency

1. Significance of NTT EAST's IOWN initiative

The NTT EAST Group aims to become a social innovation company that supports the future of regional communities for building a regional circular society. A regional circular society means expanding the distinctive culture and diversity of the region through information and communication technology and digital technology, completing transportation within the region, producing and consuming energy locally, and distributing data regionally. By promoting such a society, the population, economic activities, and data that are concentrated in urban cities would be dispersed across the region. As a result, we can create new industries and employment locally. The NTT EAST Group promotes the REIWA Project [1] to achieve this society. This is a project that maximizes the use of assets (buildings, equipment, etc.) owned by the NTT EAST Group in the region to solve the problems of regional customers.

We believe that the Innovative Optical and Wireless Network (IOWN) will drive our REIWA Project further. Interconnecting the regional edge clouds with the low-latency and high-capacity All-Photonics Network (APN) enables a seamless ecosystem. By implementing this system in society, we aim to build a sustainable community.

2. Demonstration efforts

The NTT EAST Group conducted a demonstration of a remote concert that used the low latency and large capacity of the APN, which is a technical component of IOWN. Due to the changes in society by the spread of COVID-19, our psychological hurdles to remote communication have been lowered, and new styles of co-creation and appreciation of music, such as online streaming of concerts and remote lessons, are expanding. However, low-latency interactive communication, which has been considered difficult with conventional Internet-based networks, is necessary for remote concerts (**Fig. 1**). We aimed to resolve this problem by incorporating low-latency video-processing technology and low-latency transmission technology, which are elemental technologies of the APN.

We first held a remote concert in March 2022 [2] by connecting Bunkamura Orchard Hall (Shibuya-ku, Tokyo) and NTT Inter Communication Center (Shinjuku-ku, Tokyo). This was the first case of a remote concert with APN-related technology in Japan. Through the concert, we verified that even professional musicians could perform a remote concert stress-free by reducing communication delay with the use of the low-latency video-processing and the low-latency transmission technologies.

We then held another remote concert that created more unity between two venues by connecting Tokyo Opera City (Shinjuku-ku, Tokyo) and Dalton Tokyo Junior & Senior High School (Chofu-shi, Tokyo) in November 2022 [3]. The performances of the encore program "Radetzky March" by the orchestra in Tokyo Opera City and by the snare drum player in Dalton Tokyo Junior & Senior High School were transmitted bi-directionally to establish a remote performance. By bi-directionally transmitting the

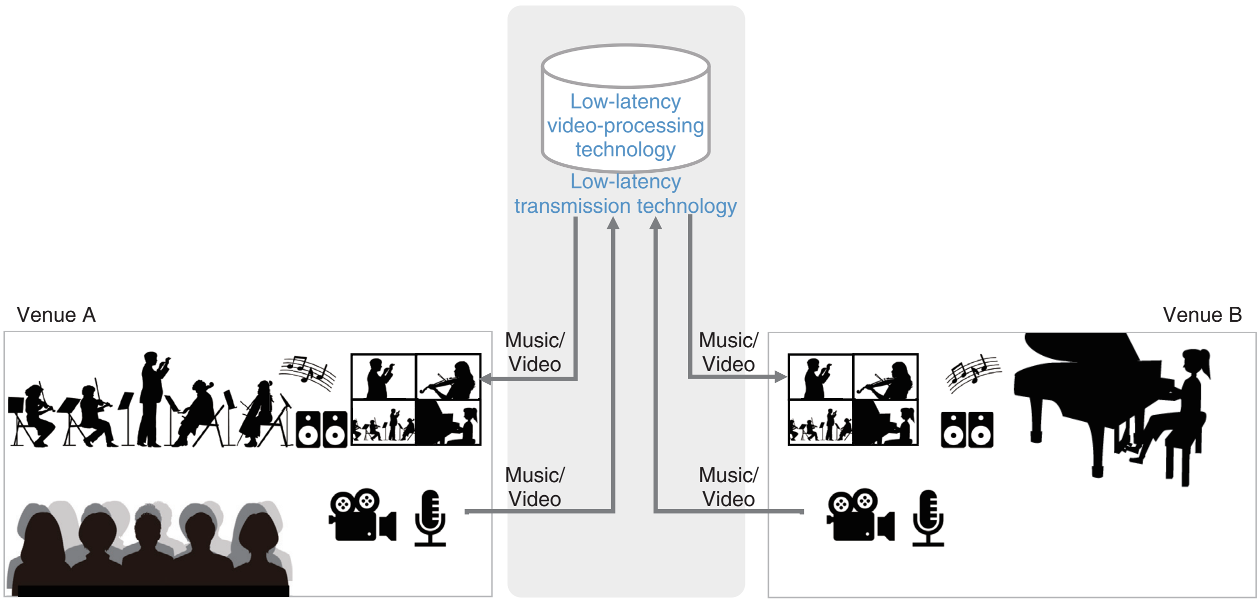

Fig. 1. Remote concert (two venues).

clapping of the audience at both venues along with the music with low latency, we achieved a new music co-creation and appreciation experience in which the audience felt as if they were in the same place even though these venues were about 10 km away.

The third demonstration was a multipoint and long-distance concert [4] held in February 2023 by connecting four locations, Tokyo, Osaka, Kanagawa, and Chiba. The Tokyo and Osaka venues had performers and audiences, the Kanagawa venue had performers, and the Chiba venue had an audience. We could provide an interactive musical experience among these locations. We also verified the feasibility of the network configuration for interconnecting multi-vendor devices in accordance with the standard specifications (**Fig. 2**).

Through these demonstrations, we confirmed the possibility of holding a new style of remote concert with a sense of unity among distant venues. In the future, we will use the data and knowledge obtained through these demonstrations to create new businesses for music performances, events, education, etc. as one of the new co-creation and appreciation models in the field of culture and art.

3. Efforts to create use cases of APN IOWN1.0

NTT EAST launched the APN IOWN1.0 service on March 16, 2023 as the first service of IOWN initiative. APN IOWN1.0 can provide low-latency communication without fluctuations. In addition, APN IOWN1.0 enables unprecedented delay visualization and adjustment functions by being combined with terminal device called "OTN (optical transport network) Anywhere."

Since these functions are effective for e-sports and real-time communication with music and video, an event sponsored by NTTe-Sports was held as a service release event for APN IOWN1.0 [5]. Response speed has a large impact on winning or losing in e-sports. Therefore, the play environment must be precisely prepared. In fact, there are many players who have postponed or hesitated to participate in online tournaments due to concerns about the play environment such as transmission delays. In this event, APN IOWN1.0 was used to connect Miyashita Park (Shibuya-ku, Tokyo: Miyashita) and eXeFelid Akiba (Chiyoda-ku, Tokyo: Akiba) to hold an e-sports exhibition match. No personal computer (PC) was installed on the Miyashita side, and players remotely controlled the Akiba side PC via APN IOWN1.0. The PC on the Akiba side was configured to add the same amount of delay as the transmission delay between Miyashita and Akiba (**Fig. 3**). As a result, we achieved a play environment with no difference in delay between the Miyashita-side and Akiba-side players.

In terms of real-time communication with music

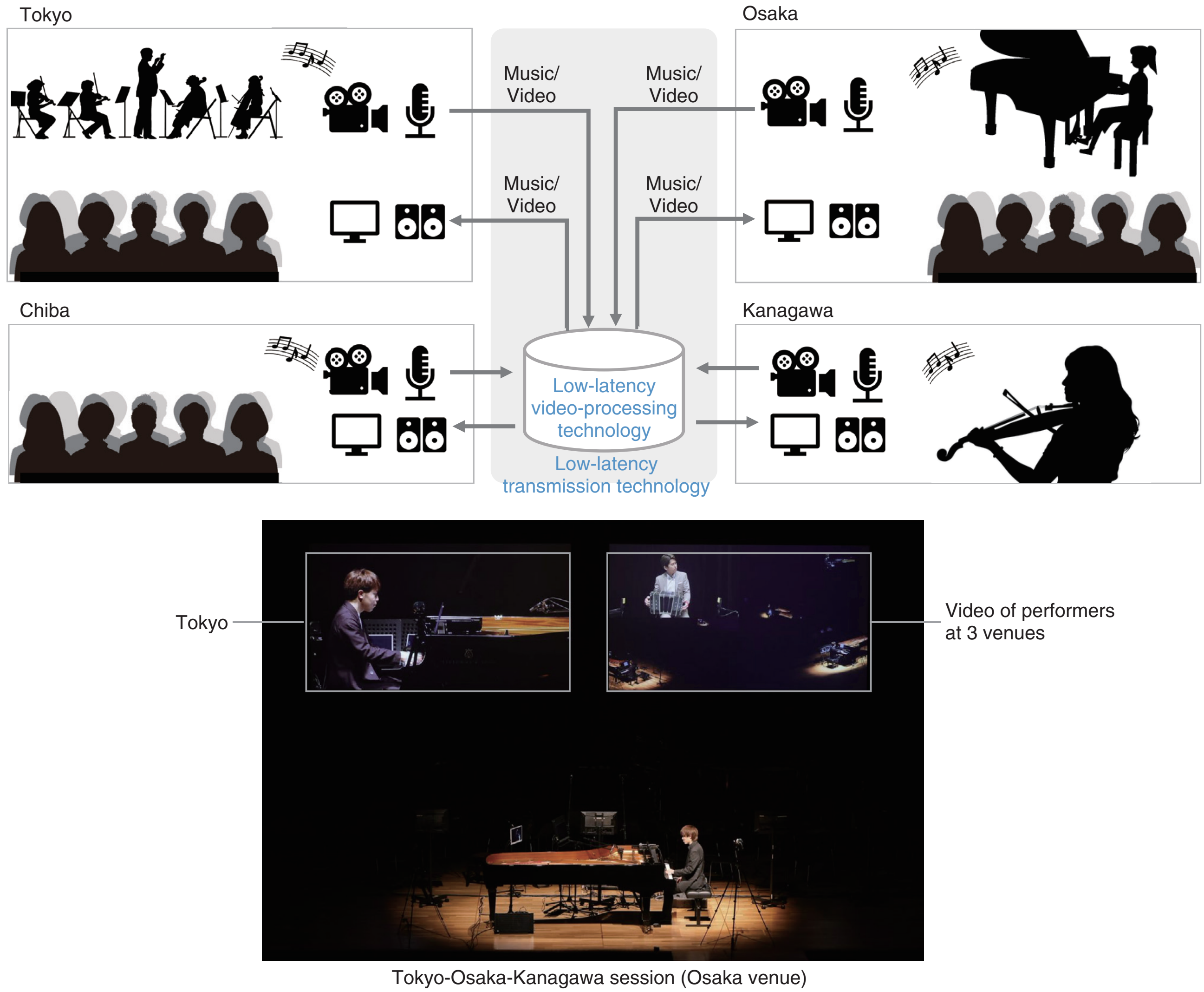

Fig. 2. Remote concert connecting four venues.

and video, we demonstrated remote dance lessons. NTTe-Sports is focusing on these activities because they believe the demand of these remote lessons is high in regional revitalization and the Japanese government policy on transferring the operation of school club activities from schools to the local communities. A dance coach in Akiba instructed students in Miyashita remotely with the background music played at Akiba studio. We confirmed whether the students in Miyashita could perform the lesson without any problems.

The e-sports players, dance coach, and students who participated in these events said that they felt no discomfort and could play and dance as if they were in the same place. We will use APN IOWN1.0 for e-sports competitions at multiple sites in urban and rural areas and for remote instruction such as arts and sports.

4. Efforts toward expansion of use cases and future prospects

We will promote the IOWN initiative through further expansion of use cases of APN IOWN1.0. For example, the APN can be used in remote productions, in which operators in a remote location can switch or edit video sources when sending real-time video data from a venue such as a stadium (**Fig. 4**). The data amount of the video source is generally so huge that it is necessary to compress and convert the video data

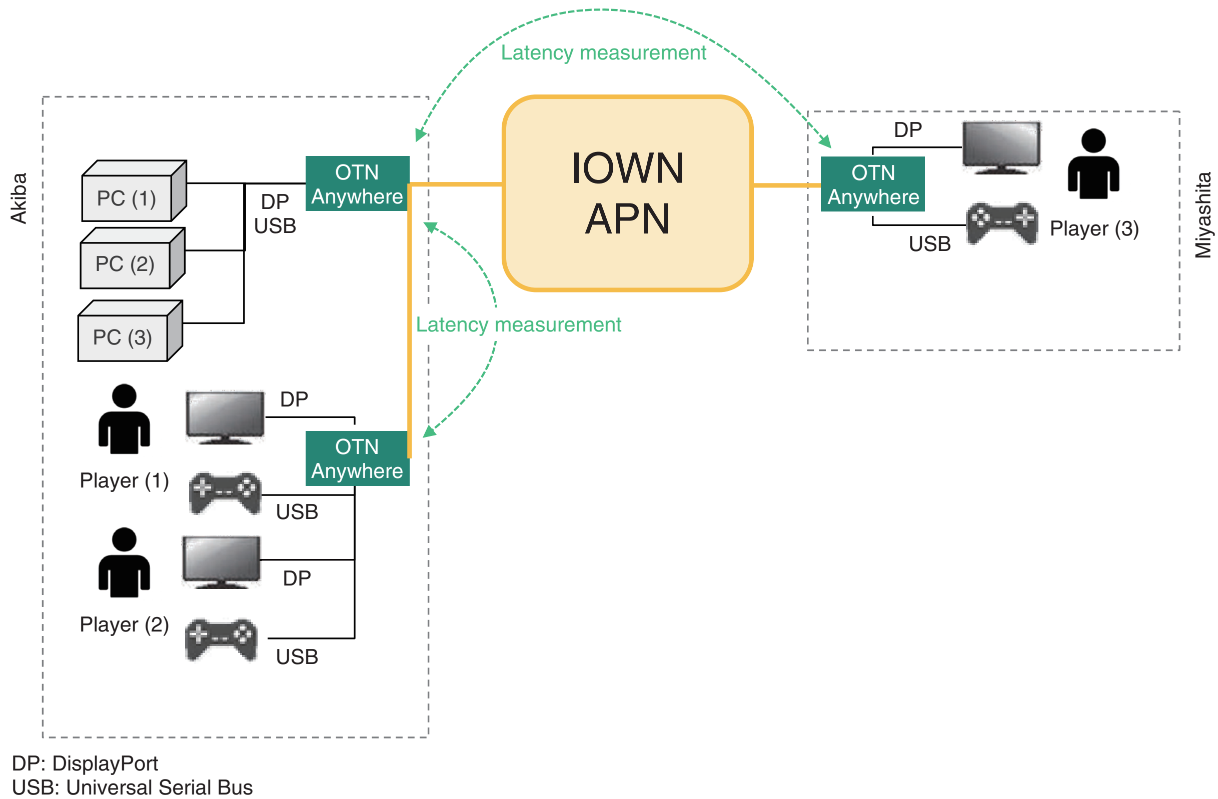

Fig. 3. Structure between Miyashita and Akiba.

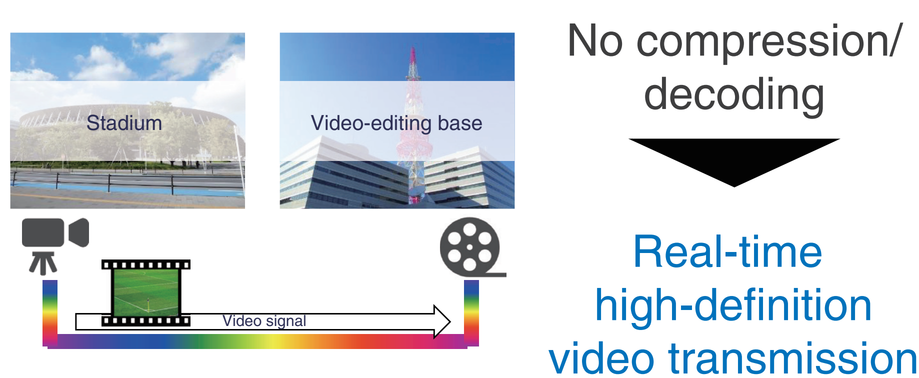

Fig. 4. APN utilization for remote production.

at the venue for transmission and decode them at the video-editing base. However, since the APN can resolve such a problem, we can transmit high-quality images in real time without compressing or decoding the data.

By connecting small and medium-sized datacenters with the APN, they can be operated like one datacenter. With the APN, we can contribute to the decentralization of datacenters by reducing land use and electricity. Furthermore, the APN has the potential to be applied to remote precision-machine operations by taking advantage of the APN's low-latency and zero-fluctuation characteristics, which also leads to local energy production and consumption.

These are just a few examples, and we believe that there are still more value of APN IOWN1.0 that we are not yet aware of. With this service release as an opportunity, we will expand the use cases with our customers.

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He received a B.E. and M.E. from the Tokyo Institute of Technology in 2009 and 2011. In 2011, he joined NTT EAST and has been working as a network engineer.

NTT WEST's Efforts in Providing APN Services

Atsushi Ota, Masayuki Nishiki, Hideaki Kimura, Kenji Matsumoto, Katsuhiro Tanabe, and Shinji Yonesaka

Abstract

With the declared purpose of "'Connecting' then 'opening' the door to the new world," NTT WEST seeks to contribute to the further development of communities and address a variety of challenges posed by changes in society by refining its technologies and wisdom and co-create new value. The entire NTT Group has been working to actualize the Innovative Optical and Wireless Network (IOWN) concept. In this article, we introduce NTT WEST's efforts toward this end, especially related to the development of the All-Photonics Network (APN) in creating use cases and providing the APN commercial service in the form of IOWN1.0.

Keywords: optical transport network (OTN), real-time remote control, remote live

1. Introduction

As society changes drastically, NTT WEST aims to contribute to the revitalization of communities and creation of new value through co-creation with local customers and partners. To address a variety of challenges affecting communities, NTT WEST is using its networks, services, and solutions.

Challenges in a community are becoming more complex. They include the lack of workers in local industries due to declining birthrate and an aging population and the need to maintain transportation systems for the community. To achieve both economic development and solutions to social challenges, lifestyles will need to change drastically. These changes will include the incorporation of information and communication technology systems and other digital technologies that use data, artificial intelligence, and Internet of Things into many aspects of daily life.

The NTT Group has been studying the Innovative Optical and Wireless Network (IOWN) as a technological platform that supports such social transformation and developing specific IOWN solutions and services. An example of such efforts is that NTT WEST is engaged in conducting demonstrations of use cases to connect IOWN's innovative technologies to solutions for various social issues. We are also developing commercial services using IOWN technologies. Some of these services are being rolled out as the first applications of IOWN.

In the following sections, we introduce NTT WEST's co-creation efforts with a variety of partners using the All-Photonics Network (APN) as examples of applying the IOWN concept to solutions for communities. The APN is an element of IOWN and achieves low-power consumption and high-capacity and low-latency communication. We also introduce the features of the APN service in IOWN1.0, launched in March 2023, as the first social implementation of the IOWN concept as well as examples of collaborative enterprises with partners using this service.

2. Remote live event using APN-related technologies

The live-entertainment field is exploring new types

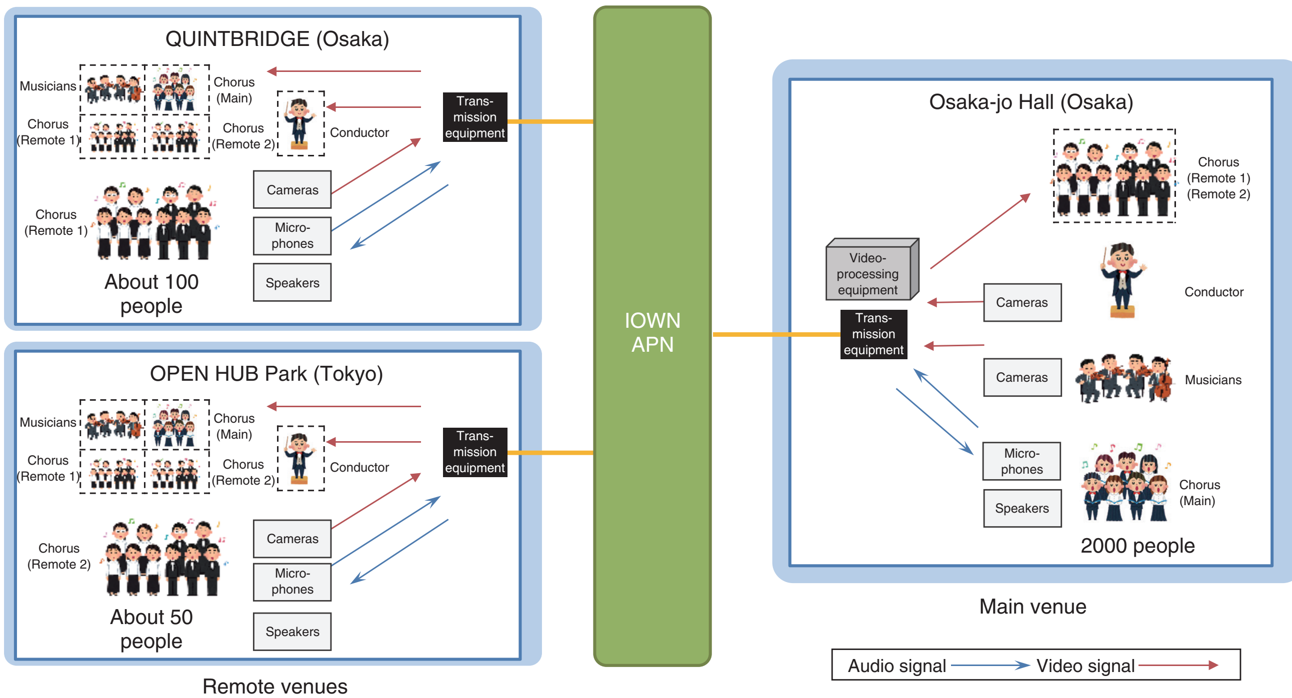

Fig. 1. Demonstration of real-time remote choral performance.

of events that integrate the real world and cyber world, such as audience-less live shows and virtual festivals. Through the development of IOWN APN-related technologies for achieving high-capacity and low-latency communication, the NTT Group is also seeking to create such integration in a variety of fields, including live entertainment. The NTT Group's technologies make it possible to connect multiple locations and enable users to experience them as one space.

With such background, NTT WEST conducted a field demonstration of a real-time remote choral performance connecting Tokyo and Osaka using technologies related to the APN (**Fig. 1**). For the 40th anniversary of the choral concert "SUNTORY Presents Beethoven's 9th with a Cast of 10,000," held in the Osaka-jo Hall and broadcast annually by Mainichi Broadcasting System (MBS) since 1983, NTT WEST connected three locations: Osaka-jo Hall, QUINTBRIDGE (Kyobashi district in Osaka), and OPEN HUB Park (Tokyo), all separated by a total of 700 km of optical fiber. APN-related technologies connected the three different locations, each with a conductor, orchestra musicians, and choral performers. Video latency was kept to 15 ms one way (propagation time of less than 1 video frame at 60 fps), resulting in an experience where video delay was not felt. Audio latency was approximately 4 ms one way. This is the same it takes for sound to travel 3 m in the same space, meaning that this is the same latency musicians experience if they are 3 m apart on the same stage. Thus, with NTT's APN technology, audio from remote locations and audio from 3 m apart at the same space could be received simultaneously, creating a new experience that transcends distance.

Latencies are not just due to data transmission but also internal processing of data in equipment such as cameras and displays. Because the latter has a major impact on latencies, it is important to choose equipment with the shortest internal-processing time possible to achieve low latency. To share the excitement and sensation of you-are-there realism, it is necessary to enhance the experience in remote locations so the audience there can have the same experience as they would at the main venue. There is thus still much research to be done in providing a richer experience.

The benefits of the APN are not just limited to this type of field demonstration. Because there are many cases in which it can contribute to addressing social challenges by bringing people together so they feel they are side-by-side even when separated, we will use the knowledge gained from remote live event to

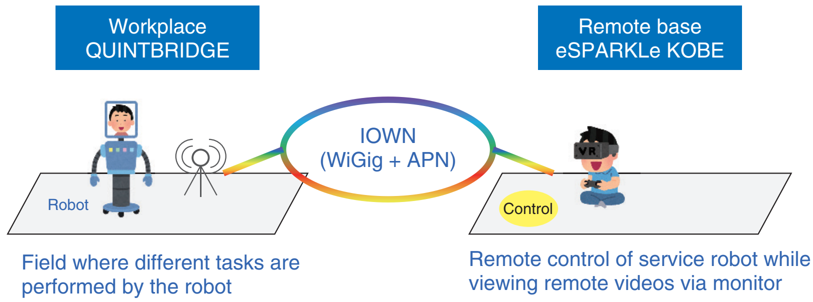

Fig. 2. Real-time remote robot control.

develop applications for the APN.

3. Remote robot control using the APN and high-frequency band radio

In regions with a growing aging population and declining birthrate, the decrease in the working population is a major issue to sustain the local economy. The development of remotely operated robots that can perform necessary tasks anywhere without being limited by physical location or physical characteristics of the operator can be effective for addressing such an issue. However, such development faces the challenge of ensuring sufficient communication bandwidth and low-latency communication, which are necessary for high-resolution video communication and real-time signal exchanges during remote operation. With this background, NTT WEST collaborated with ADAWARP, which provides a platform for remote operation of robots, in a demonstration of real-time remote robot control (**Fig. 2**).

In the demonstration, a service robot in QUINTBRIDGE was controlled remotely from eSPARKLe KOBE, a facility within the NTT WEST's Hyogo branch office, via an APN line. By viewing video from multiple cameras attached to the robot, the robot's operator remotely performed tasks that required detailed operations, such as pressing buttons and opening and closing doors.

Because QUINTBRIDGE is where many workers constantly carry out digital communication exchanges, using a 2.4- or 5-GHz wireless local area network to connect to the robot may lead to operational issues such as throughput degradation due to network-traffic congestion in the facility. Wireless Gigabit (WiGig), which uses the 60-GHz band was thus used to avoid interference with the 2.4- and 5-GHz bands.

High-frequency radio bands, such as the 60-GHz band, cannot penetrate physical objects such as people, walls, and columns, so it is necessary to design base stations that ensure line-of-sight propagation within an area and develop technology to switch between different base stations instantly when a robot moves or rotates to maintain line-of-sight communication propagation with the robot. The first requirement was fulfilled using a direction-diversity scheme, which places multiple base stations along the edges of an area. The second requirement was achieved using NTT Access Network Service Systems Laboratories' site diversity control technology. Specifically, the robot was equipped with two WiGig wireless terminals, each connected to different base stations to ensure communication on two different wireless-transmission channels at all times.

By selecting the wireless terminal providing the best wireless quality for each data packet for transmission, the robot could switch between communication channels on the basis of dynamic monitoring of radio quality, resulting in lack of communication interruption even in an environment with obstructions. Therefore, the robot could transmit 4K-quality video and control signals without interruption caused by radio interference or base-station switching, even when moving within the facility. The robot's operator could thus successfully perform the demonstration's tasks. Even though the 4K video was compressed using the AV1 codec, end-to-end transmission and receiving took about 56 ms. This was less than 100 ms, which is considered the threshold above which latency can be perceived [1]. The demonstration also showed that an APN line can achieve sufficient communication capacity with a trivial amount of latency, even in an environment in which multiple cameras and robot sensors intermingle.

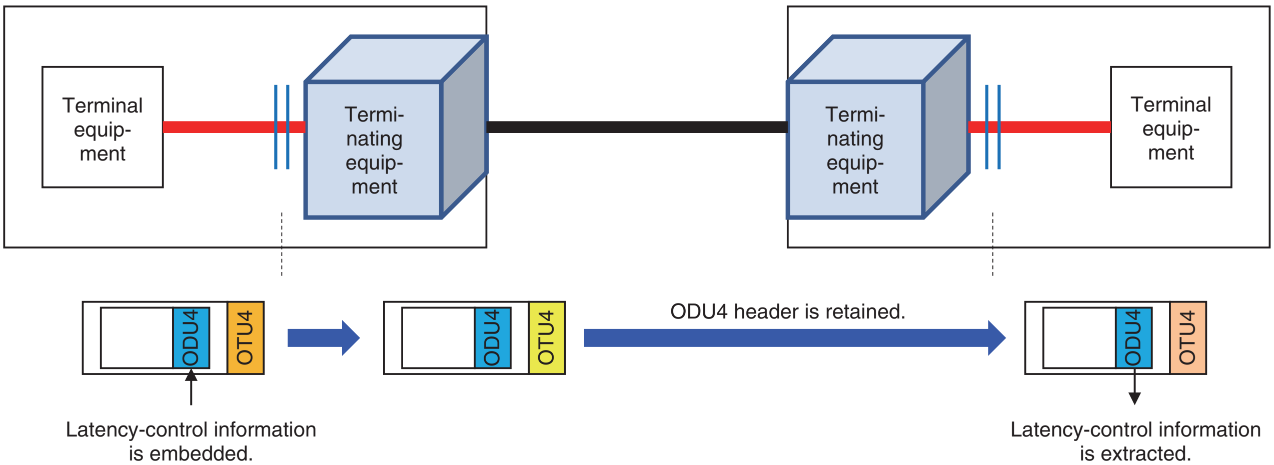

Fig. 3. Optical network service.

4. Launch of APN IOWN1.0 service

NTT is providing the commercial APN IOWN1.0 service with a network service (high-speed broadband access service powered by IOWN) and terminal equipment ("OTN Anywhere" powered by IOWN).

4.1 Network service

APN IOWN1.0's network service achieves low latency and zero signal fluctuations by eliminating data queuing and signal conversion. By using the optical transport unit 4 (OTU4) interface, a network that transparently transports Ethernet signals equivalent to 100 Gbit/s can be achieved (**Fig. 3**).

APN IOWN1.0's network uses the optical transport network (OTN) entirely for segments between user–network interfaces. The OTN provides an encapsulated optical path and transmits and receives data in units with maintenance overhead and error-correction codes assigned for each client signal. By supporting the OTN in all network-service segments, monitoring and control signals for path monitoring and performance monitoring can be propagated end-to-end.

4.2 Terminal equipment

For APN IOWN1.0, OTN Anywhere [2] is used as the terminal device equipped with latency visualization and adjustment functions. A distinctive function of OTN Anywhere is its assignment of latency-adjustment-related control signals to the maintenance-overhead domain, thus achieving end-to-end latency adjustment without network-communication interruption.

5. Creating use cases with partners through social implementation

As the first use case of NTT's commercial APN service (APN IOWN1.0) in western Japan, NTT WEST and Yoshimoto Kogyo carried out a remote entertainment event titled "Mirai no Owaraibu" (Future Comedy Live) on March 20, 2023 by connecting three locations in Osaka City—in Kyobashi (QUINTBRIDGE), Umeda (LINKSPARK), and Namba (Yoshimoto Manzai Theater) (**Fig. 4**).

By connecting the venues using APN IOWN1.0, not only was low-latency video transmission achieved, but the use of large, life-size video displays at two locations, QUINTBRIDGE and the Yoshimoto Manzai Theater, were made possible for this event. Audiences at the two locations could watch real performers at each location and virtual performers from the remote locations via the low-latency life-size video displays as if the performers were all in the same space at the same time.

Thanks to the technological achievements of APN IOWN1.0 in providing a realistic experience of remote performances, 97.3% of the audience at QUINTBRIDGE and the Yoshimoto Manzai Theatre said they "did not feel any latency at all," and 94.5% said they were "satisfied with the event." Through this effort, NTT WEST and Yoshimoto Kogyo succeeded in presenting a new form of entertainment.

6. Summary

We introduced NTT WEST's efforts in carrying out

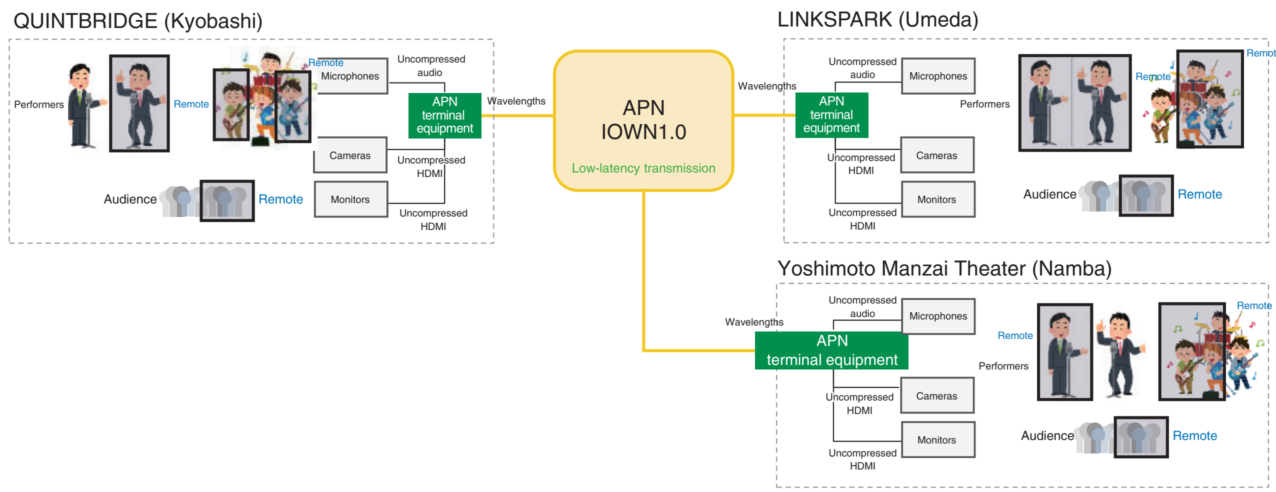

Fig. 4. First use case of commercial APN (APN IOWN1.0) in western Japan.

a remote live event and remote robot control as cases of using the APN to connect IOWN's innovative technologies to solutions for various social challenges. We also presented a summary of the APN service that NTT launched in March 2023 as the first offering of IOWN services along with examples of co-creation with partners using the APN service.

Beginning with the launch of this commercial service, we are also seeking to stimulate the creation of use cases with a variety of partners and apply IOWN to a variety of fields. For example, we expect the APN service to be applied to mobile fronthaul, which is planned as a social infrastructure in a wider range of fields, and to inter-datacenter connectivity. We are engaged in the development of services and technologies with the near-future goal of enabling visitors to the World Expo Osaka, Kansai, Japan to be held in 2025 to experience the value of IOWN through joint ventures with more customers and partners.

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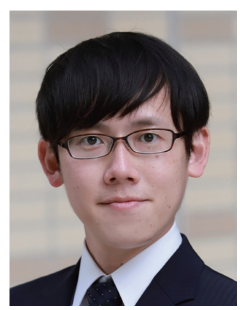

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Delay Managed Network for APN IOWN1.0

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Abstract

This article introduces the concept of the Delay Managed Network to control communication latency and the optical transport network (OTN) equipment, called OTN Anywhere, which has delay-measurement and delay-adjustment functionalities. NTT operating companies, NTT EAST and NTT WEST, released the first-version service of the All-Photonics Network (APN) of the Innovative Optical and Wireless Network (IOWN), APN IOWN1.0, in March 2023 that is based on OTN Anywhere. In addition to the benefit of low latency approaching the physical limit, this service provides end-to-end layer-1 paths without latency fluctuation and offers delay measurement and delay adjustment of each end-to-end layer-1 path. The Delay Managed Network can enhance user experience of various remote activities.

Keywords: IOWN, All-Photonics Network (APN), Delay Managed Network

1. Importance of low-latency communication

With the rapid advances in communication technologies, the number of remote activities based on sophisticated communication services is increasing. This trend has been accelerated due to the drastic lifestyle change caused by the COVID-19 pandemic. Such remote activities include conventional video streaming based on one-way communication as well as interactive video and voice streaming based on bidirectional communication.

Figure 1 shows a nation-wide remote e-sports competition across multiple cities as an example of such remote activities. Communication latency is extremely important because instantaneous response is a critical component of players' user experience (UX) while playing games. Communication latency differs depending on players' location and can fluctuate due to network congestion. This unfair communication environment is a critical problem in supporting remote e-sports competitions across multiple cities, especially professional e-sports games. Therefore, very low latency and fair communication environments are critical for use cases such as e-sports.

A next-generation communication service with low latency and latency manageability will play a key role in e-sports as well as live-entertainment, remote collaboration, and up-and-coming XR (cross reality) and the metaverse. Given this situation, we have investigated networking technologies that can enable the flexible control of communication latency.

2. Concept of Delay Managed Network

We have created a new networking concept, the Delay Managed Network, to drive the UX revolution on the basis of advanced layer-1 networking technologies. It has the following three major features (also illustrated in **Fig. 2**).

(1) Providing end-to-end layer-1 paths

The Internet is an indispensable part of daily life, and its importance will continue to increase. However, its best-effort nature sometimes causes undesirable situations, for example, sudden increases in communication latency, capacity loss, and possible loss of packets due to network congestion. These

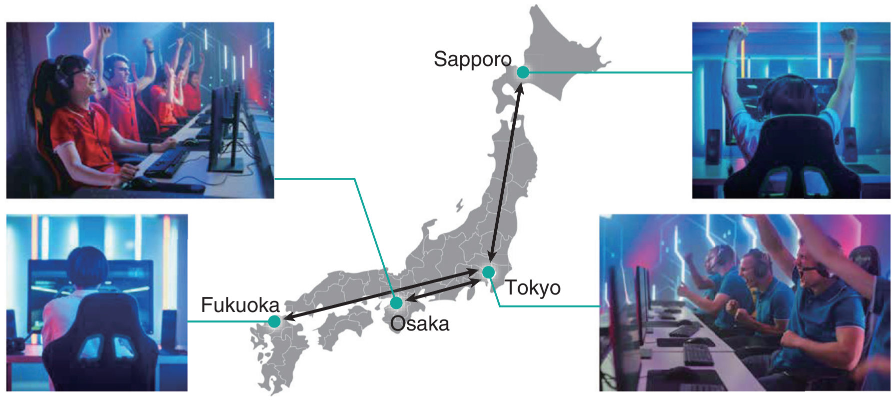


Fig. 1. Nation-wide remote e-sports competition (example of a remote activity).

problems significantly degrade UX in many use cases. Given these considerations, we want to make it possible to provide communication services that do not have such a limitation. In other words, we want to offer end-to-end layer-1 paths, which feature low absolute latency, zero-latency fluctuation, and predetermined capacity, even in the face of network congestion.

(2) Measuring and adjusting communication latency

Given the increased importance of low-latency communication, we want to create paths that offer latency that is as low as possible as well as delay-measurement and delay-adjustment functionalities to provide unprecedented UX. From the viewpoint of end users, delay measurements of only the links the communication path uses might be meaningless, so we have to provide the means to measure and adjust end-to-end latency along the path. If we use a communication protocol that inherently has latency fluctuation, delay measurements will be ineffective because latency constantly changes. Given this consideration, it is important to use a communication protocol that has no latency fluctuation.

(3) Accommodating various client signals

The Delay Managed Network has to accommodate various client signals from end users to support various use cases. In addition to Ethernet, which is widely used, the Delay Managed Network should support various client signals such as video and voice.

3. Enabling technologies for IOWN1.0

We developed an optical transport network (OTN) equipment called OTN Anywhere to enable the features of the Delay Managed Network (**Fig. 3**).

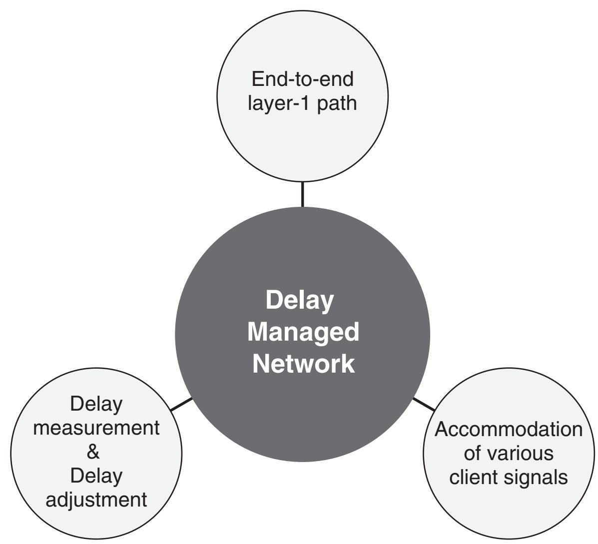


Fig. 2. Concept of Delay Managed Network.

OTN Anywhere is basically connected to the edge of the All-Photonics Network (APN) and used in combination with metro/long-haul transport equipment such as dense wavelength division multiplexing (DWDM) transmission systems. OTN Anywhere can be connected to various transmission systems worldwide via the standard interface of the optical transport unit 4 (OTU4), which is specified in the OTN (Optical Transport Network) standards of International Telecommunication Union - Telecommunication Standardization Sector (ITU-T). A layer-1 communication path, called the optical data unit (ODU) path,

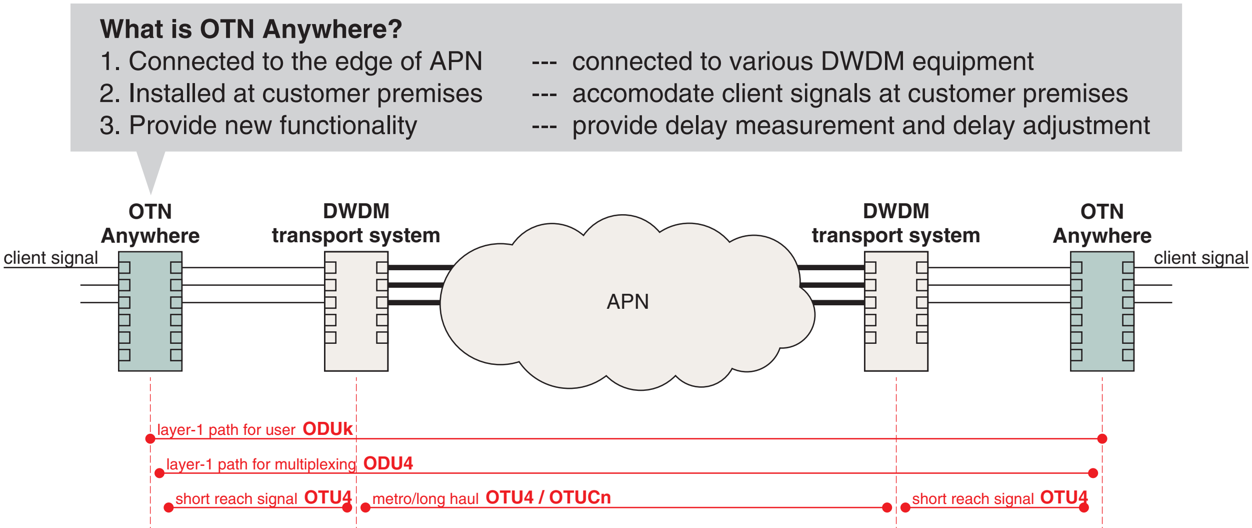


Fig. 3. Features of OTN Anywhere and network configuration.

Table 1. Outline specifications of OTN Anywhere.

		Specification
Network interface		OTU4
Client interface		10GbE 100GbE
ODU delay measurement	ODU	ODU4
	Accuracy	1.2 µs
ODU delay adjustment	ODU	ODU4
	Maximum	20 ms

Fig. 4. Appearance of OTN Anywhere.

between OTN Anywhere is transparently transported by DWDM transmission systems, so OTN Anywhere can be implemented regardless of the type of DWDM transmission system used. OTN Anywhere can be installed at customer premises and directly transfer user signals into the OTN. OTN Anywhere also has our newly developed delay-measurement and delay-adjustment functionalities. **Table 1** lists the specifications, and **Figure 4** shows the appearance of OTN Anywhere.

OTN Anywhere has the following technologies in regard to the three features described in Section 2.

(1) Providing end-to-end layer-1 paths

We use the OTN protocol for OTN Anywhere. The OTN is widely used as a backbone infrastructure in metro/long-haul networks worldwide. The OTN protocol offers 100% capacity guarantee, low latency approaching the physical limit, and no latency fluctuation. While end users merely see the protocol, we have developed OTN Anywhere as a one-rack-unit equipment, which can be installed at customer premises to provide genuine end-to-end layer-1 communication paths. OTN Anywhere can dedicate an end-to-end ODU path to the user, as shown in Fig. 3. ODU paths can be multiplexed into higher-rate ODUs without affecting other users' traffic. This enables the efficient use of lambda capacity when one user does not use the full capacity of a wavelength.

(2) Measuring and adjusting communication latency

OTN Anywhere provides delay-measurement and delay-adjustment functionalities for end-to-end ODU paths.

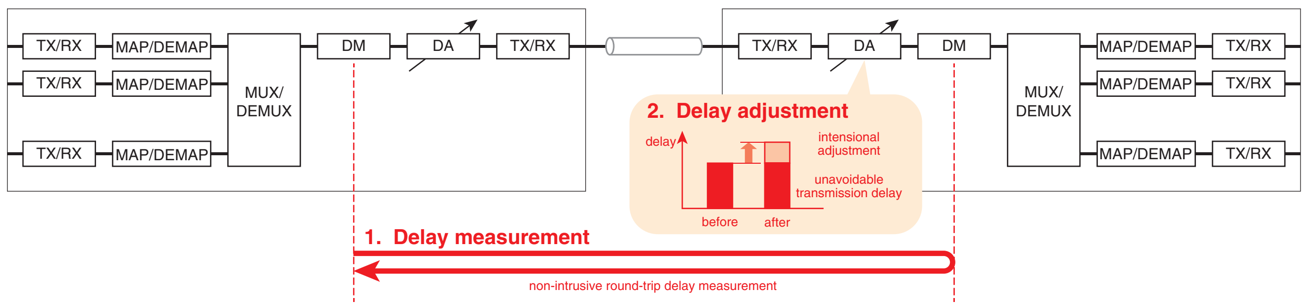


Fig. 5. Function block of OTN Anywhere with delay functionalities.

The delay-measurement function is for measuring round-trip delay in micro-second accuracy. At one end of the ODU path, OTN Anywhere adds delay-measurement bits, which then traverse the ODU path, to be loop-backed at the other end of the ODU path and reach the original end point (**Fig. 5**). This function is compliant with the delay measurement specified in ITU-T Recommendation G.709. It is still difficult to measure end-to-end round-trip delay from the viewpoint of the end user because the OTN protocol is used only in the backbone network, not end-to-end. As OTN Anywhere measures the round-trip delay, it enables end-to-end measurement.

In addition to delay measurement, OTN Anywhere can offer delay adjustment if needed (Fig. 5). The delay-adjustment function has two operation modes: instantaneous delay adjustment and hitless delay adjustment. The instantaneous-delay-adjustment mode adjusts the delay of the ODU path via short-hit, which means that bit errors are observed during adjustment. This mode is useful, for example, for drastic delay adjustment before ODU-path activation. The hitless-delay-adjustment mode adjusts the delay of the ODU path without short-hit, which means that no bit errors are observed during adjustment. This function is useful for fine-tuning delay under the in-service condition.

These two functionalities, delay measurement and delay adjustment, enable the flexible control of communication latency. They are implemented in layer 1 and independent from upper-layer protocols, so they support many use cases.

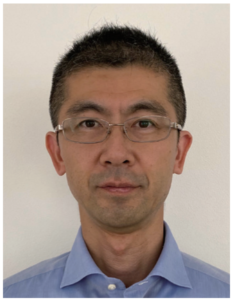
(3) Accommodating various client signals

OTN Anywhere currently supports one of the most major client signals, Ethernet (10GbE/100GbE). This means that it is possible to transport Ethernet as well as various video and voice signals by combining off-the-shelf products. These video and voice signals are mapped into the OTN via Ethernet, but as there is no Ethernet switch along the ODU path, no significant latency increase or fluctuation increase occurs.

OTN Anywhere can measure and adjust the latency of the ODU path. Measured latency values can be passed, for example, to other systems, servers, or operators. These measured delay values support real-time processing, server processing, or latency-sensitive operation. In remote e-sports competition among multiple cities, the communication latency of each venue is first measured, then the delay of each venue is set to be the same to create fair competition.

4. Perspectives on OTN Anywhere evolution

We have just taken the first step of APN IOWN1.0 by developing OTN Anywhere. We plan to evolve the APN by continuously creating new functionalities and technical innovations. The direction of OTN Anywhere evolution includes supporting various consumer and legacy signals, adding new functionalities such as path protection, and providing economical connections to the APN. We are making efforts to create innovations on the basis of potential customer needs and plan to offer unprecedented UX to each customer in the near future.



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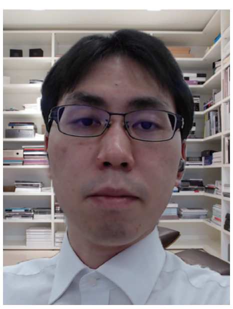

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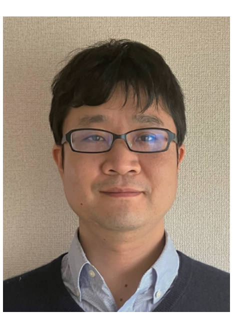

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NTT as a Creator of New Value and Accelerator of a Global Sustainable Society

Katsuhiko Kawazoe

Abstract

The first commercial service of the Innovative Optical and Wireless Network (IOWN), IOWN1.0, was launched in March 2023. This article introduces its accomplishments as well as the future that will be possible with its successors IOWN2.0, 3.0, and beyond. This article is based on the keynote speech given by Katsuhiko Kawazoe, NTT senior executive vice president, at Tsukuba Forum 2023, held on May 17 and 18, 2023.

Keywords: IOWN, photonics-electronics convergence, APN

1. New medium-term management strategy: IOWN-driven creation of new value (from concept to reality)

The Innovative Optical and Wireless Network (IOWN)* has gained recognition since it was announced four years ago in May 2019. It is now the centerpiece of NTT's new medium-term management strategy.

"Innovating a Sustainable Future for People and Planet" is the fundamental principle of this strategy. One of its key points is being conscious of our planet. The NTT Group is not just concerned about itself; we must develop sustainable business together with everyone on Earth. When IOWN was announced, we had planned to begin service in 2030. However, after Osaka was chosen as the host city of Expo 2025, we decided to move up the schedule by five years. Nevertheless, there were still some who considered this launch as being too late, so we decided to start the IOWN commercial service this March.

2. Seeking to change the game

In the past, Japan played a major role on the world stage when the "logic of quality" was central to business success. Quality was a key factor in creating things that provided value in the real world.

The era of the "logic of numbers" then arose. This paradigm is exemplified by the Internet. Voluminous data are collected and converted to marketing data, which leads to even larger markets and spurs more collection of data. This is the world we live in, a world in which the logic of numbers is dominant.

I believe what will follow next from the logic of numbers is the "logic of value." I think it will be a time when we look back to how we as humans lived happily by mutually recognizing our diverse values and views of happiness around the world and truly respecting them. We should make it an era that is not just about numbers but our well-being. Whenever we consider what is needed technologically to achieve this, we see that photonics is its technological foundation.

What we need to do is forget for the time being that all approaches are created intentionally by us humans, such as the Internet, and return once again to the basics. This is precisely the role of IOWN. We are using IOWN to achieve the next generation of communications from the fifth generation (5G) to 6G

* IOWN: A new communication infrastructure that can provide high-speed broadband communications and enormous computing resources by using innovative technologies including optical technologies.

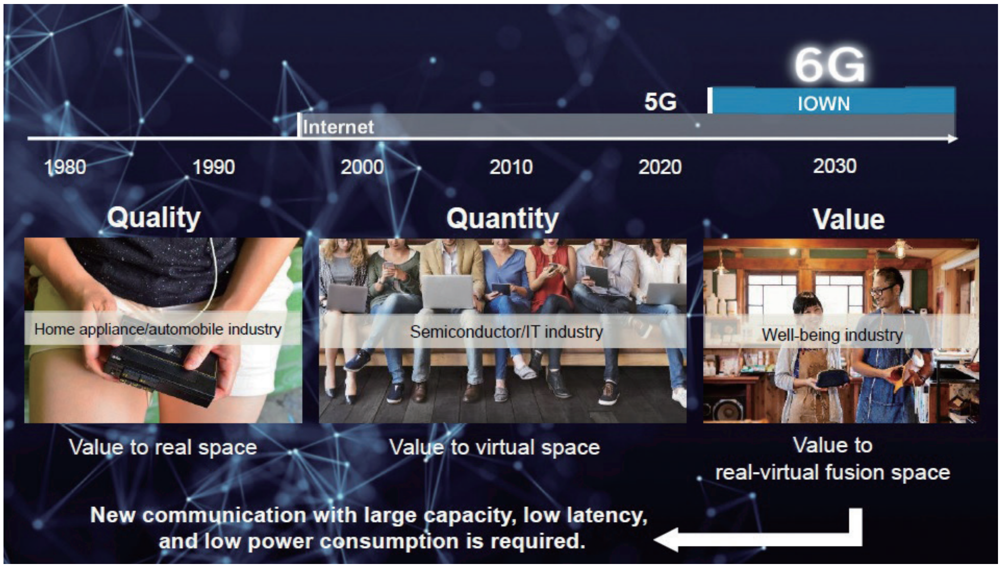

Fig. 1. Seeking a game-change.

(**Fig. 1**).

3. From digitization for efficiency to digitization to create value

It is often said that digitization is important. However, there are two types of digitization, digitization to improve efficiency and to create new value. Innovation that solves the problems we face and breaks through limits is difficult to achieve with digitization to improve efficiency alone. Therefore, we must also aim to achieve digitization that creates new value.

The datacenter business is a critical area for the NTT Group. Data volume and power consumption are growing exponentially. The rise of general-purpose artificial intelligence (AI) and generative AI, as exemplified by ChatGPT, will accelerate these trends. Generative AI technologies such as ChatGPT have shown that they can deal with both general and specialized queries with extremely high accuracy. This is something we seriously need to be aware of because data will increase explosively (**Fig. 2**).

NTT has been studying optical technology and the potential of photonics for a long time. When comparing electricity and photonics, we see that they differ in the energy it takes to transmit information. When the distance from point A to point B increases, electricity naturally requires more energy than photonics to transmit information. With electricity, more energy is consumed as the operating frequency increases. However, with photonics devices there is almost no increase in power consumption. We can save energy by applying optical technology to information transmission. The Tsukuba R&D Center has become a hub for the spread of this technology around the world, and Japan leads the world in the penetration of fiber optics. NTT's research labs have focused on the use of fiber optics in data transmission since the 1960s. Another of our goals is to also use optical technology in data processing. NTT was the first in the world to create optical transistors. The possibility of using light in data processing led to the announcement of the IOWN concept.

4. Benefits of IOWN

By reducing power consumption to 1/100 and increasing transmission capacity 125-fold compared with conventional networks, IOWN promises to make possibilities dreamt of a reality. We thus changed our policy of offering a technology after its development is complete to an approach of offering iterations each time they mature. The All-Photonics Network (APN) IOWN1.0 service was launched on March 16 this year on the basis of this new paradigm (**Fig. 3**).

5. Start of APN IOWN1.0 service

The APN is a network connected end-to-end with

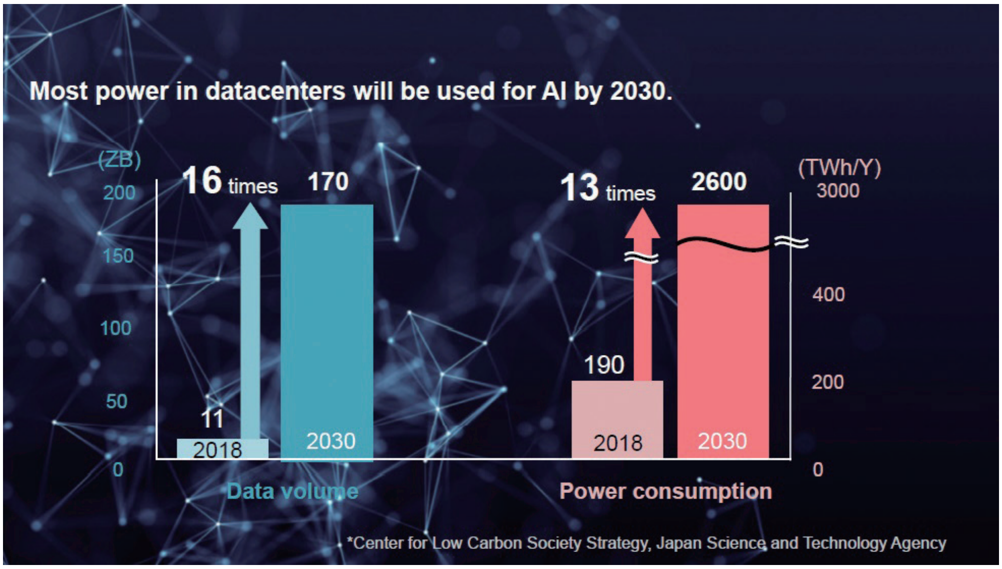

Fig. 2. Worldwide data volume and power consumption of datacenters.

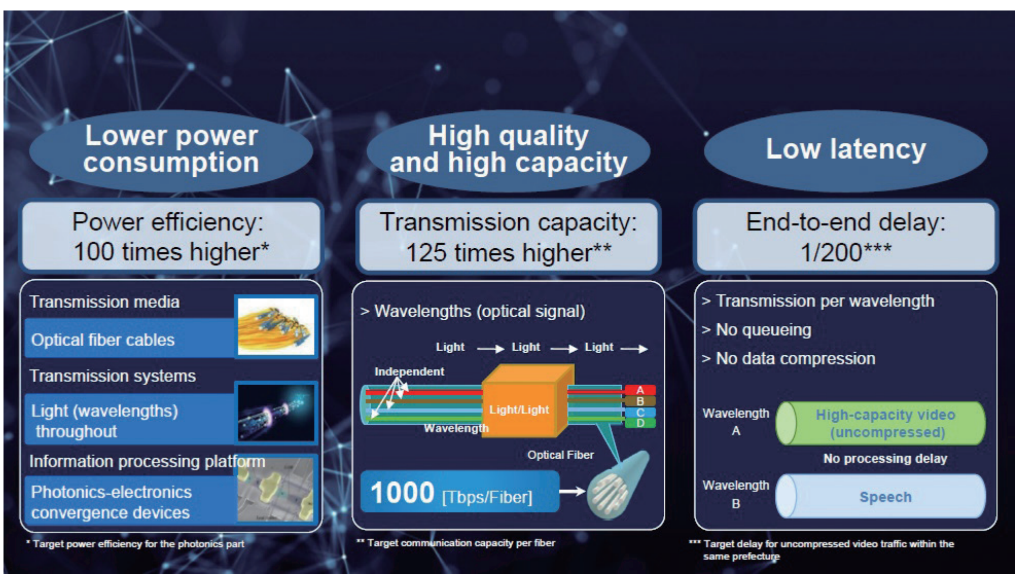

Fig. 3. Advantages of IOWN.

fiber optics. Because the network is composed entirely of optical connections, not only is low latency achieved but so is "OTN (optical transport network) Anywhere" capability, which allows latency time to be controlled by terminal equipment and the latency level to be fixed (**Fig. 4**).

Ahead of providing this APN service, NTT conducted several field demonstrations. Events such as musical concerts, e-sports tournaments, and live comedy shows were held to enable many users to experience the benefits of IOWN in offering entertainment services in the future. Many use cases of IOWN in the field of entertainment were introduced. The "Mirai no Ongakukai" event ("Music Concert of the Future"), held in February, demonstrated how the APN could provide low-latency content. Musicians

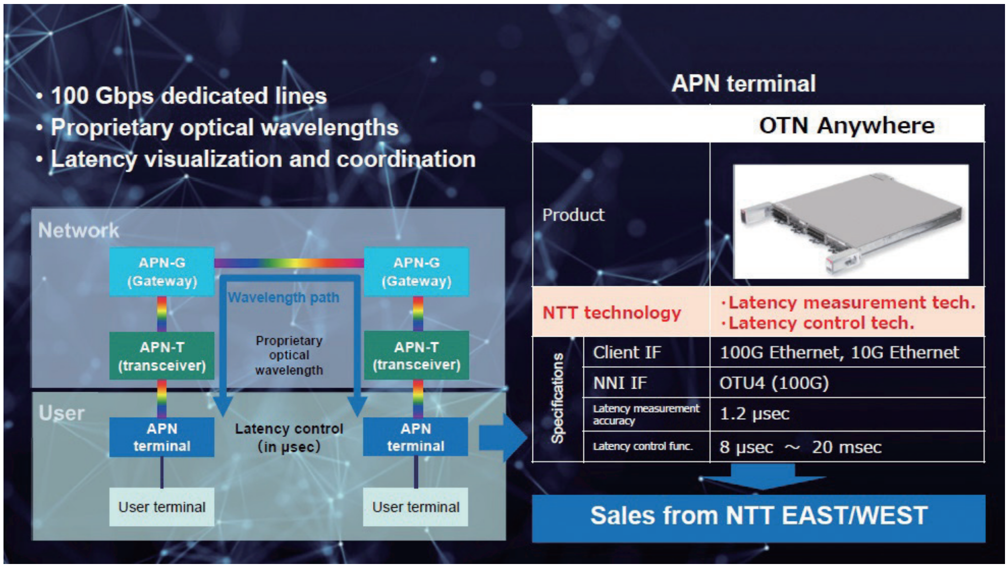

Fig. 4. IOWN1.0 APN.

Fig. 5. Co-creation with partners in diverse fields.

in Tokyo and Osaka, separated by a physical distance of 700 km but connected by fiber optics, performed a live classical concert together. The latency experienced by the musicians was the same they would experience if their instruments were 3 m apart on the same stage. This experiment demonstrated that latency could be controlled using the IOWN APN, as explained above. Users of an IOWN concert application could receive the performance almost instantaneously as there is no need to buffer the content.

Figure 5 illustrates the companies and organizations that are using the APN IOWN1.0 service to pioneer new businesses with NTT.

In the datacenter sector, the NTT Group currently holds the third largest market share globally. To further develop this business, we will continue our

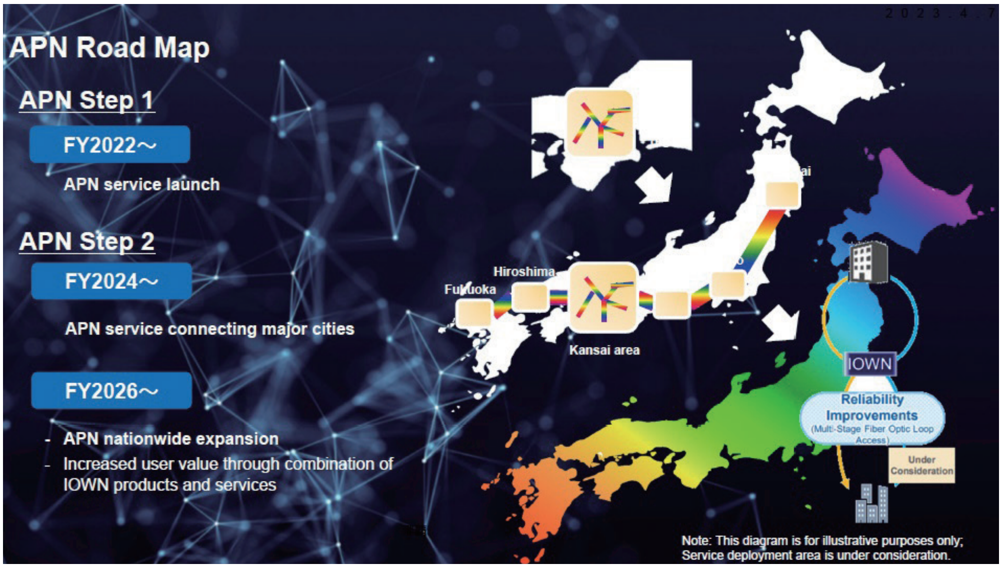

Fig. 6. Expansion of APN with services.

efforts to achieve carbon neutrality by 2030 using the IOWN technology. At the same time, we will continue with our efforts to reduce the energy consumed by datacenters.

6. Towards IOWN2.0 and beyond

IOWN2.0 involves two areas: networks and computers.

6.1 Networks

Step 2 after the launch of the APN IOWN1.0 service is to improve power efficiency 13-fold, including for inter-prefecture communications. In Step 3, we will increase power efficiency 100-fold (**Fig. 6**).

From 2024, we plan to connect major cities, and from 2026, we plan to provide this connectivity as a business service to customers who need it anywhere in Japan. In combination with this service, we seek to implement "optical access network design based on concatenated loop topology" currently being developed by the Tsukuba R&D Center in the expansion of the APN.

6.2 Computers

In June 2023, NTT will launch [launched] NTT Innovative Devices Corporation, responsible for the development, manufacture, and distribution of photonics-electronics convergence devices. This company will provide the following photonics-electronics convergence technologies that can be used not only in NTT's own networks but also in general computers.

- (IOWN2.0) Photonics-electronics convergence devices for board-to-board connections: IOWN2.0 will reduce equipment's power consumption and improve its performance through optical board-to-board connections.
- (IOWN3.0) Photonics-electronics convergence devices for chip-to-chip connections: In IOWN3.0, further reduction in power consumption will be possible with the introduction of photonics-electronics convergence devices for chip-to-chip connections.
- (IOWN4.0) Photonics-electronics convergence devices for intra-chip (die-to-die) connections: IOWN4.0 is expected to reduce power consumption to 1/100 that of current consumption by connecting waveguides in a chip optically.

IOWN photonics-electronics convergence technology will change computing architecture. Computing architecture will first experience a major shift to disaggregated computing then to a memory-centric architecture. Such an architecture will become the critical foundation on which AI and robots operate. NTT plans to invest 3 trillion yen annually over the next five years to develop not only technologies that serve as the foundation of IOWN but also services, applications, and platforms that leverage IOWN (**Fig. 7**).

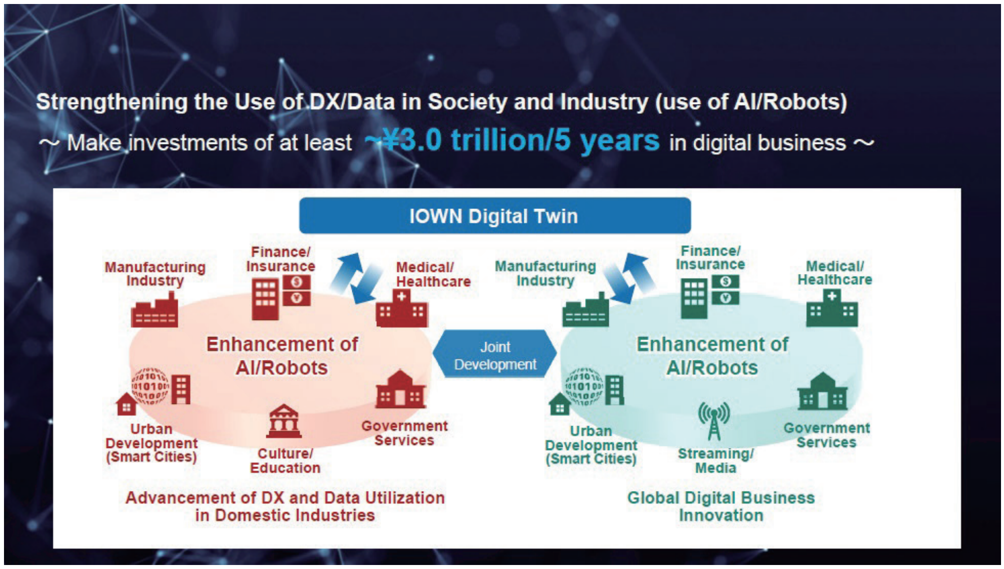

Fig. 7. New value creation with data-driven applications (Smart World).

7. IOWN Global Forum

The IOWN Global Form was launched in January 2020. It currently has 120 member companies and organizations. We aim to make IOWN not just a go-to solution for datacenters but also a household name that customers can trust. We hope that IOWN will lead to a new form of economic security where Japan will once again become a major contributor on the world stage. We wish to share a grand vision in which, instead of relying on the technology of a specific country, companies around the world cooperate without the need for competition or disputes and play necessary mutual roles to establish an ecosystem together.

Katsuhiko Kawazoe

Senior Executive Vice President, NTT Corporation.

He joined NTT in 1987 and served as senior research engineer of the Cyberspace Laboratories and the Cyber Solutions Laboratories of the Cyber Communications Laboratory Group from 2003 to 2007. He became vice president of the Research and Development Planning in 2008, head of the Service Innovation Laboratory Group, Service Evolution Research Laboratory in 2014, head of the Service Innovation Laboratory Group in 2016, senior vice president, head of Research and Development Planning, member of the Board in 2018, and executive vice president, head of Research and Development Planning in 2020. He has served as senior executive vice president, representative member of the Board since 2022.

Past and Future Prospects for Advanced Operation of Access Network Facilities

Takashi Ebine

Abstract

NTT is responsible for building and maintaining access network facilities, providing a variety of services ranging from fixed-line telephones using metal cables to data communications using optical fibers. In this context, we at NTT Access Network Service Systems Laboratories are researching and developing smart-engineering (design and construction) and smart-maintenance (maintenance and operation) technologies with the aim of operational innovation through digital transformation of such access network services. We are also taking on the challenge of creating new value in areas other than telecommunications by using assets at our communication facilities.

Keywords: operational innovation, advanced operation, access network facilities

1. Operational innovation in access network services

NTT is responsible for building and maintaining access network facilities and providing a variety of services ranging from fixed-line telephones using metal cables to data communications using optical fibers. Against this backdrop, especially in the fiber-to-the-home (FTTH) sector, which underwent a major transformation from metal to light, operational innovation has advanced significantly. As we move toward the coming Innovative Optical and Wireless Network (IOWN) era, we expect to see a significant transformation in services, along with a transformation in operational innovation.

In the early days of FTTH, Nippon Telegraph and Telephone Public Corporation was privatized against the backdrop of the deregulation of telecommunications in 1985, and in the 1990s, the construction of access network facilities underwent a major transformation due to the increase in the number of new telecommunications carriers and discussion on opening up NTT's optical-fiber network facilities to other telecommunications service providers. With the advent of competing services, such as asymmetric digital subscriber line, it was difficult to predict optical demand, and additional construction could occur, so it was a time when trial and error was repeated in the construction and maintenance of access network facilities. In such an era, the study of aerial-optical-drop fiber-cable-bundling technology, which started mainly from external factors, is an example of how operational sophistication could be achieved through the thorough use of existing facilities and space.

Although there were various challenges in the beginning toward implementing this technology, we verified and evaluated the reliability of the installation equipment and communications in response to long-term environmental changes. It is now the basic construction method for laying optical cables throughout Japan.

As we approach the IOWN era, NTT is preparing for technology accumulation and field deployment through research and development to address public demand for telecommunications infrastructure. We at NTT Access Network Service Systems Laboratories are advancing the operational sophistication of access network facilities from the perspective of operational innovation. This article presents two initiatives that have been or will be deployed in the field.

2. Upgrading facilities by digitizing the real world

One of the operational innovation initiatives that is being rolled out is the "Upgrading facilities by digitizing the real world" by using vehicles called mobile mapping systems (MMSs).

Digital Twin Computing, which digitizes and simulates the real world, is one of the components of IOWN. Outside facilities, such as utility poles, that support communication services will continue to require constant maintenance and operation. The inspection of outside facilities is carried out visually and with human experience and expertise, but further efficiency is required due to the shrinking workforce. We have been engaged in research and development of technology to automatically extract information on communication facilities from point-cloud data acquired from an MMS and quantify facility conditions such as deflection and thereby developed a structural-deterioration determination system that contributes to increasing the efficiency of inspection work.

The more flexible the pole, the more likely it is to have lateral cracks and be unsafe. By running an MMS to automatically extract utility poles with large deflections and visually inspect only those poles, it is possible to greatly reduce inspection work. Deflection can be calculated automatically by simply inputting point-cloud data into the system, which can also contribute to skill-lessness. To achieve remote and automated construction work, such as construction of columns, we are currently advancing technology for automatically recognizing facilities, heavy machinery, and the surrounding environment in real time from point-cloud data and pursuing the ultimate in accuracy to quantify the structural conditions of ultrathin objects such as cables (**Fig. 1**).

Point-cloud data has been used in various industries such as automated driving and surveying, and the accuracy of measurement equipment has been improved and their cost has decreased. However, the MMS used by each NTT Group company has different specifications, so processing and analysis software must be changed in accordance with the data acquired, which makes aggregation and deployment inefficient. In addition to automatic-recognition technology and facility-condition-quantification technology, facility requirements for acquiring point-cloud data inexpensively and with high precision from all communication facilities and the unification of MMS specifications of the NTT Group will be studied.

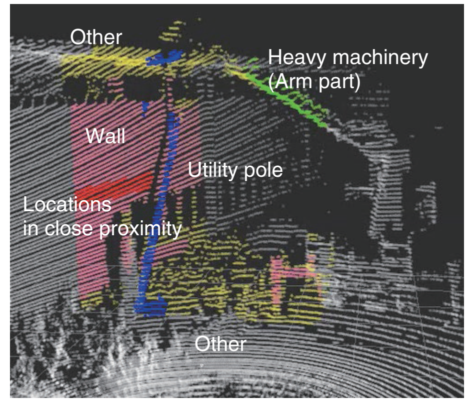

Fig. 1. Example results of real-time automatic recognition.

3. Research and development of concatenated loop topology for IOWN optical access networks

This section introduces two major activities for operational innovation. The first is the activity related to concatenated loop topology for optical access networks.

The star-type topology for the optical access network supporting FTTH services, which was designed to be economical, has been used. However, business demand from various service operators is expected to increase, including mobile-carrier demand such as Beyond fifth-generation mobile communications system (5G)/6G. Unlike FTTH, which has been used to address certain consumer demand by replacing metal cables with optical fiber cables, such business demand is uncertain in terms of the quantity and location, so problems such as inefficiency and inability to respond to highly reliable and flexible services are expected.

On the basis of this background, we established a concatenated loop topology for optical access networks that combines multiple cable loops in multiple stages and proposed a wiring method that optimizes higher reliability and high capability to accommodate optical demand with uncertainties for locations and quantity (**Fig. 2**). Loop topology has been considered a reliable and flexible wiring topology since the early days of FTTH, but this concatenated loop topology can improve reliability and flexibility not only near central offices but also in areas far from the central offices by using this multi-stage configuration. It can also select optical paths with a high degree of freedom. For optical access networks in the IOWN era, we are considering overlaying the current FTTH

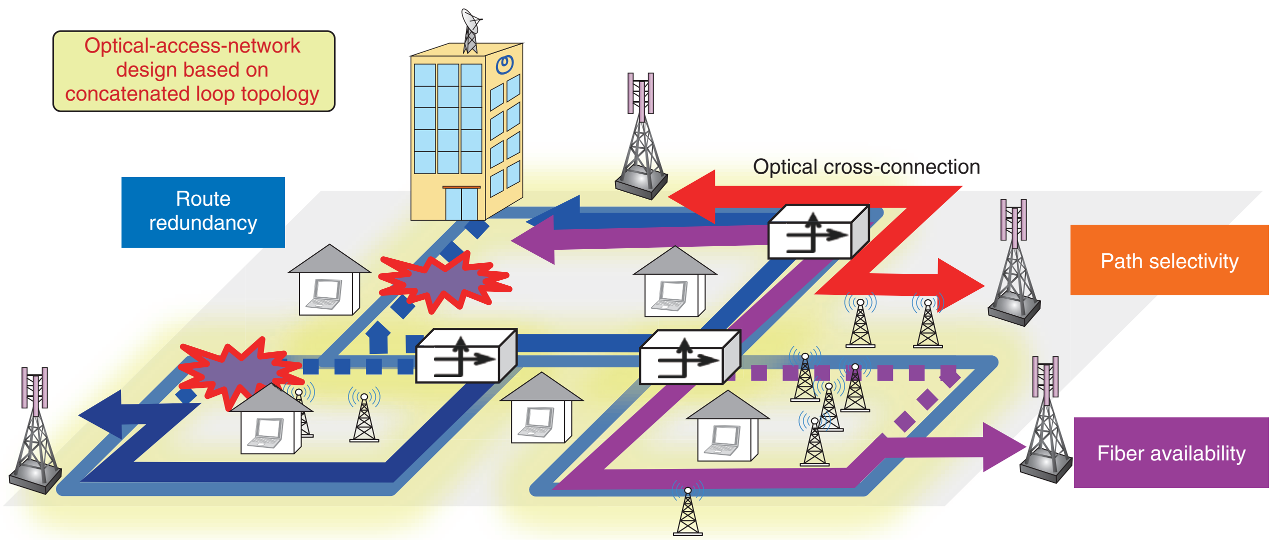

Fig. 2. Optical-access-network design based on concatenated loop topology.

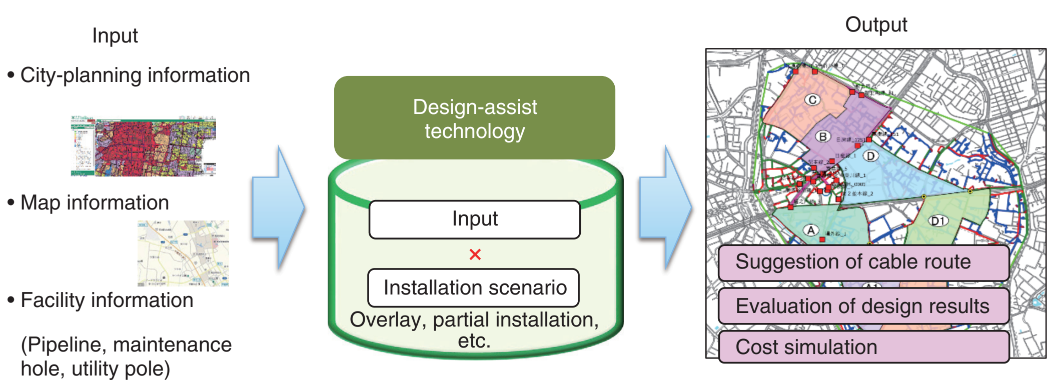

Fig. 3. Overview of design-assist technology.

network with a new layer of this concatenated loop topology.

However, to introduce new wiring methods, it is essential to estimate future demand and conduct simulations of capital investment and construction volume. This should enable the design of an optical access network on the basis of current equipment (i.e., availability of pipelines, utility poles, pull-up points, and optical cables). Manually carrying out such design requires an enormous amount of work, and the design quality varies depending on the designers' skills. Therefore, we are advancing research and development on design-assist technology for automatically generating appropriate cable-route proposals and assisting designers by inputting necessary information (**Fig. 3**). This technology is expected to make it easier to verify various deployment patterns in accordance with demand forecasts and area characteristics because it can significantly reduce the time for designing (about one to two days), which normally takes two weeks to one month by hand per area in a central office.

We will investigate the introduction of concatenated loop topology to green fields, such as smart cities, while aiming to deploy it in actual optical access networks. Operations and other aspects of this wiring method will be developed in parallel, and research and development will be promoted to implement

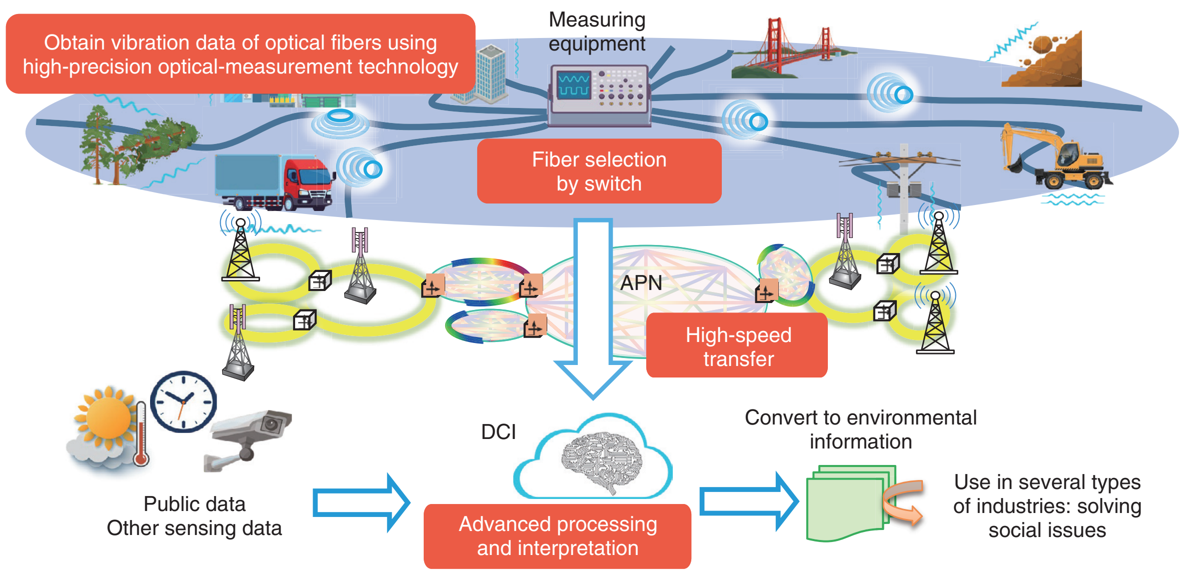

Fig. 4. Optical-fiber environmental monitoring.

IOWN along with related technology development.

4. Optical-fiber environmental monitoring using current communication cables and advanced optical-fiber sensing technology

The other operational innovation initiative that is expected to be developed is optical-fiber environmental monitoring.

By using current optical fiber cables for communications, which are the largest assets owned by the NTT Group, as sensors, we are advancing research and development on optical-fiber environmental monitoring with which vibrations generated by various events occurring around optical fiber cables are observed with our proprietary high-precision distributed acoustic sensing (DAS), and the resulting vibration data are analyzed and interpreted to identify events occurring around the cables (**Fig. 4**).

The technological requirements to achieve this include the ability to measure the distribution of vibration applied to an optical fiber with high precision, ability to process a large amount of measured data in real time to visualize the state of vibration, and ability to analyze and interpret the data to identify events. To improve the accuracy of vibration measurement, NTT's DAS is based on phase optical time-domain reflectometry (phase-OTDR) with frequency-division multiplexing (FDM) pulses. FDM phase-OTDR is used to observe more accurate phases of backscattered light and generate vibration waveforms with less noise than before by using FDM pulses and our unique noise-reduction algorithm. Although the processing of a large amount of data is a major issue, real-time data processing is possible due to the development of calculation algorithms and the use of field-programmable gate arrays. **Figure 5** shows example measurement results of vehicle traffic by FDM phase-OTDR using a communication optical fiber cable laid in an underground pipeline installed along an actual roadway. The horizontal axis shows the distance from the measuring device, and the vertical axis shows the elapsed time. The red and blue bars represent the measured amount of phase rotation of the optical signal and correspond to the amplitude of the vibration applied to the optical fiber. Therefore, a pair of red and blue lines indicates how one vehicle is traveling on the road. The number of pairs represents the number of vehicles. The slope of the line means the speed of the vehicle. This measurement can also be conducted in real time. The area around A in the figure, where the slope of the line increases, indicates that the traffic signal has turned red and vehicles have slowed down and stopped. This is expected to be applied to traffic-flow monitoring in smart cities and other areas. Vibration information obtained with such high precision is expected to be used to understand the surrounding conditions of optical fiber cables, and its use is progressing.

Optical-fiber environmental monitoring is also

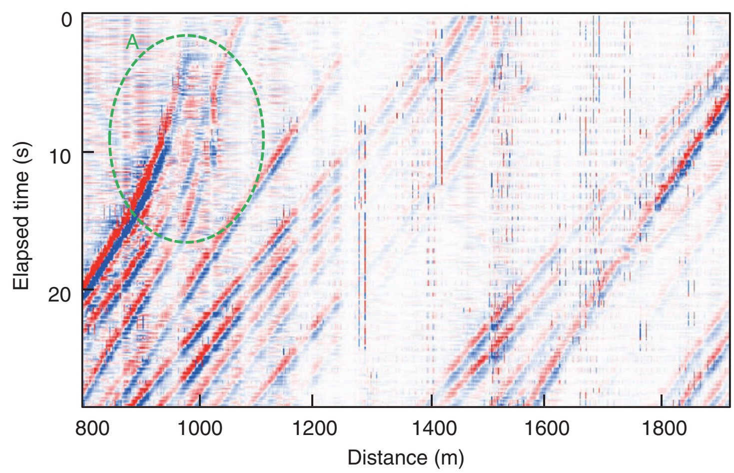

Fig. 5. Vehicle-traffic-measurement results with optical fiber cables laid in field.

aimed at achieving more advanced sensing by combining it with IOWN. We are considering the use of the fiber-path switching function of the All-Photonics Network (APN) to enable planar measurements by freely selecting the optical fibers to be sensed and the transfer of large amounts of measurement data by the high-speed transmission function of the APN. By using the abundant computing resources of the data-centric infrastructure (DCI) to analyze and interpret measurement data at high speeds, we expect to immediately generate environmental information. Discussions are currently focused on the configuration of the connection between the sensing device and switching function of the APN.

Optical-fiber environmental monitoring can provide new value to optical-fiber-cable networks as a sensing infrastructure. With the aim of expanding the application area, we will work on developing a method for measuring vibration with higher precision and over a wide area, accumulate knowledge and experiences to implement the method as a device, and develop systematization and use cases.

5. Direction of future initiatives

In the United States, companies, including Google, are focused on the road shoulder as a business opportunity and are competing for the rights to smart cities and autonomous driving. Innovation using current assets and technologies is occurring at the same time, and NTT believes that it is important to use space such as using the aerial-optical-drop fiber-cable-bundling technology, and effectively use current assets such as in optical-fiber environmental monitoring for innovation. With regard to the vast amount of assets held by NTT, such as utility poles and cables, we will continue to take on the challenge of creating new value, not only through the effective use of such assets but also in areas other than telecommunications, drawing on past good practices.

Takashi Ebine

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He joined NTT in 1997 and has been engaged in the developmental research of access network facilities. He served in this position from July 2020 to June 2023 and is currently vice president, head of NTT Access Network Service Systems Laboratories.

Low-latency and Energy Efficient Technologies for New Optical Access Networks

Tomoaki Yoshida

Abstract

NTT laboratories are engaged in the research and development of technologies to overcome increasing data volume, power consumption, and network delay. This article introduces the technologies that contribute to low latency and power saving of optical access networks being researched and developed by the Optical Access System Project at NTT Access Network Service Systems Laboratories.

Keywords: optical access systems, low-latency FDN, APN

1. High expectations for low-latency optical access networks

The concept of the Innovative Optical and Wireless Network (IOWN) envisions a network and information processing infrastructure to provide high-speed, high-capacity communications and enormous computational resources using innovative technologies that are based on photonics and optics, and the IOWN Global Forum (IOWN GF), which brings together various companies for discussions, is taking the lead in implementing IOWN. IOWN GF aims to naturally provide capabilities beyond human cognition that enable extremely high-definition video, perceptual displays, and large-volume transmission. It also discusses use cases and technologies for computing resources and devices. IOWN GF exemplifies use cases that enhance immersion and extend human cognition, such as cyber-physical systems that collect data from a large number of cameras and sensors in real time to predict the future and perform autonomous control as well as remote-control and extended-reality navigation.

Low-latency and robust networks are key for these use cases. For example, low latency and stability of the communication environment are required in the guidelines for remote surgery formulated by the Japanese Surgical Society [1]. To cope with the decrease in the working-age population, improving productivity and reducing dangerous work are urgent issues, so a low-latency and stable network to enable precise remote control is necessary.

2. Network technology for low latency

The All-Photonics Network (APN), which is a component of IOWN, is expected to provide stable low-latency communication that takes advantage of the characteristics of optical fiber. However, to achieve precise remote operation, it is necessary not only to control the delay in transmission but also reduce the time required for the input, processing, and output of information, which is part of the delay of the entire communication, and to have a mechanism that enables smooth remote operation to continue even if a failure occurs at various points.

We at the Optical Access System Project in NTT Access Network Service Systems Laboratories are developing a network technology called low-latency functional dedicated network (FDN) to enable quick response to changes in network and services and rapidly allocate and swap computing resources for edge processing (**Fig. 1**). This makes it possible to provide a stable low-latency and low-jitter network for the entire remote-control system, including optical and edge processing sections. For the practical and

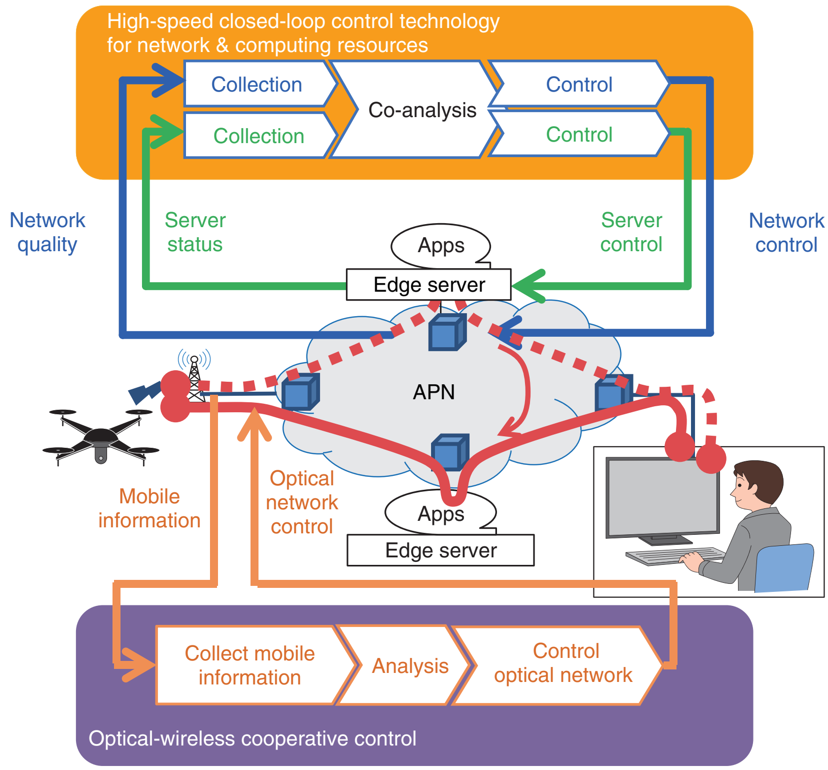

Fig. 1. Low-latency FDN.

widespread use of remote-control services, we are advancing "high-speed closed-loop control technology for network & computing resources," which takes advantage of cloud technology, especially edge computing, to enhance the reliability of image processing and artificial-intelligence processing (**Fig. 2**). This technology monitors connection quality by collecting information on the status of both the network and edge server, ensuring stability by switching the route and server simultaneously when quality becomes degraded. At the Tsukuba Forum 2023, we demonstrated an application that uses this high-speed closed-loop control technology for network & computing resources to operate a remote robot-arm through a screen and maintain high stability to continue operations even if remote-control delay is caused by the increasing background traffic on the edge server.

We are also researching and developing another low-latency technology that can be used to stably control multiple robots in a factory. It leverages time-aware shaper (TAS) technology [2] for mission-critical data transfer between multi-access edge computing (MEC) and a large number of terminals located near the user. TAS technology was originally developed as a traffic-control technology for mediating and multiplexing communications with very strict delay requirements, but it is applicable to a mechanism that executes cooperative control among multiple switches, i.e., the entire network. We demonstrated how this technology can ensure low latency for each control message between any terminal in a factory and MEC, enabling the simultaneous control of multiple delicate robotic arms.

3. Optical-power-supplied optical network unit

A promising use case for Internet of Things (IoT) is data collection in rural areas and unmanned environments, such as for observations in mountainous areas and the sea, and for monitoring facilities such as dams. In such areas, however, it is sometimes difficult to supply power through power lines. IoT devices using solar cells, energy-harvesting technology, and low power wide areas (LPWAs) have been proposed, but there are still many issues with stable power supply and the limitation of radio propagation distance. For example, in these severe climate environments,

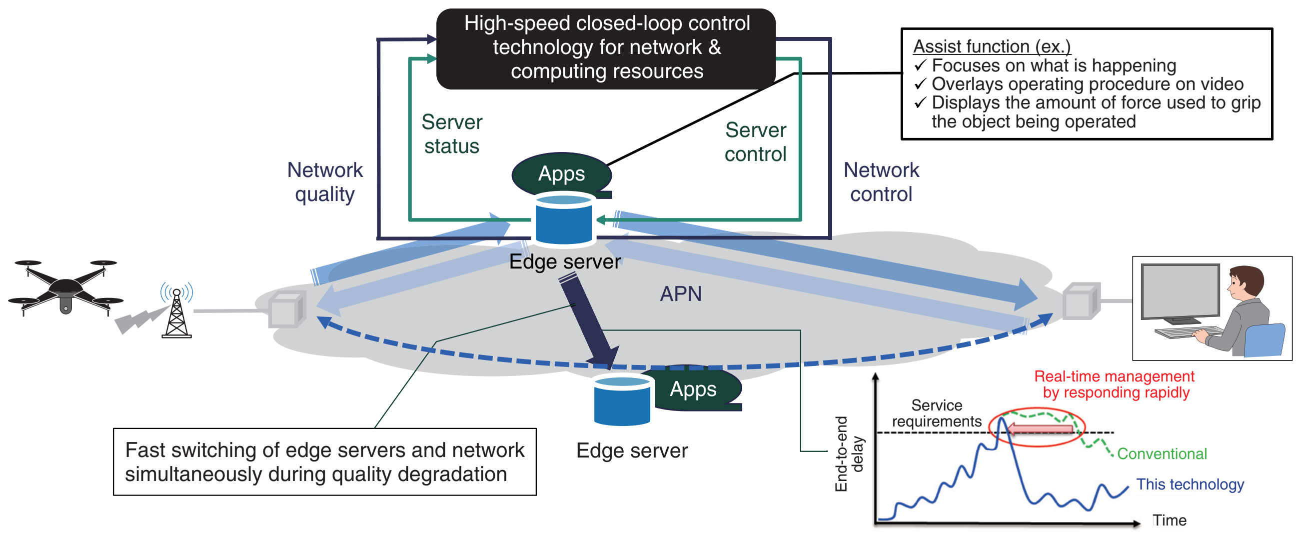

Fig. 2. High-speed closed-loop control technology for network & computing resources.

solar cells and energy-harvesting technologies are not stable power sources due to topography, weather, vegetation, and other conditions, and LPWAs are also limited in their propagation distance. Therefore, NTT Access Network Service Systems Laboratories is researching and developing an optical-power-supplied optical network unit (ONU) that enables IoT communication by using optical energy supplied through optical fibers [3].

We developed a prototype optical transceiver that operates with low power consumption and demonstrated it by installing a mechanism in which the ONU is put to sleep when communication is not needed to thoroughly suppress average power consumption while being charged by optical power received by the photoelectric conversion unit (**Fig. 3**). We demonstrated this optical-power-supplied ONU at the Tsukuba Forum 2023.

4. Research and development trends of Photonic Gateway

NTT Access Network Service Systems Laboratories conducted research and development on the Photonic Gateway (Ph-GW), which provides the functions required for user accommodation in the APN through full-mesh optical paths by end-to-end connecting terminals and using as little electrical processing as possible. The Ph-GW consists of (1) remote wavelength control, (2) multiplexing/demultiplexing, (3) pass/block, (4) turn back, and (5) add/drop using optical technology and provides end-to-end main signal opening and stopping without the user being aware of the communication protocol. NTT Access Network Service Systems Laboratories has demonstrated that these five functions are feasible [4, 5]. These functional block groups constituting the Ph-GW were proposed in IOWN GF and consented to be described as APN-G [6]. Functions (2), (3), and (5) are possible by extending the functions of a reconfigurable optical add/drop multiplexer (ROADM), which is an optical transmission device, and the Open ROADM Multi-Source Agreement has started to discuss them. Other goals, such as remote monitoring control, miniaturization of APN terminals, and cost reduction, are being investigated; thus, we will continue researching and developing the Ph-GW. We believe that users should experience the APN with available technology so that they will become aware of its advantages. Therefore, we would like to expand functions through continued research and development.

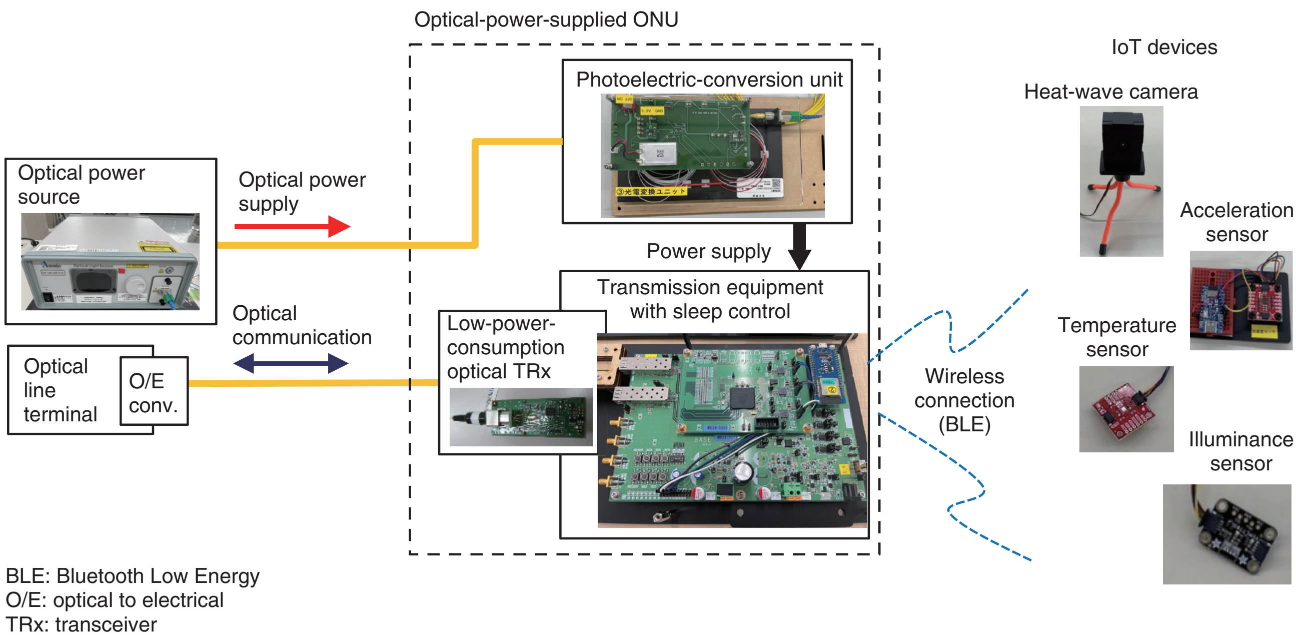

Fig. 3. Optical-power-supplied ONU demonstration.

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Wireless Technologies for Accelerating High-capacity Transmission, Low Energy, and Application-area Expansion

Takeshi Onizawa

Abstract

This article describes recent research and development of wireless technologies for the sixth-generation mobile communications system (6G) and the Innovative Optical and Wireless Network (IOWN) at NTT Access Network Service Systems Laboratories. We at NTT Access Network Service Systems Laboratories believe that IOWN and 6G have the same targets for future networks. Therefore, to actualize 6G/IOWN, we are investigating wireless technologies focusing on high-capacity transmission by combining them with optical technologies, coverage extension for the sky including satellite-communication systems, application-area expansion, and low energy as the common wireless technological issues. This article introduces these wireless technologies and their future prospects.

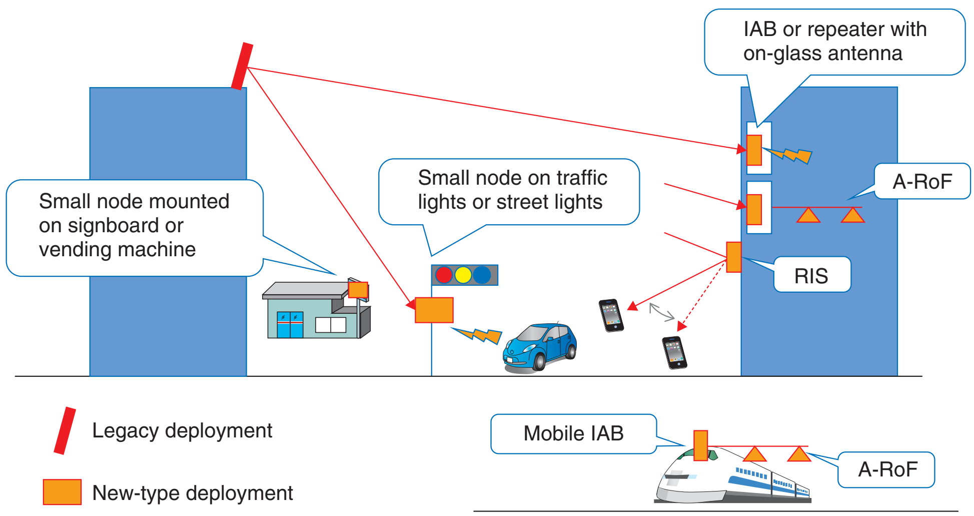
Keywords: 6G, IOWN, high capacity

1. Introduction

NTT proposed the Innovative Optical and Wireless Network (IOWN) [1] in May 2019 to construct future optical and wireless networks for the 2030s. IOWN will provide innovative optical technologies, high transmission capacity, and huge computer resources compared with conventional networks. However, the sixth-generation mobile communications system (6G) has been announced worldwide and focuses on extreme high data rate/capacity, coverage extension, and low energy [2], which have been published in white papers of many research institutes [3]. In Japan, NTT DOCOMO first published a white paper related to 6G wireless technologies in January 2020 and has updated its content for the 5th edition in Nov. 2022 [2].

We at NTT Access Network Service Systems Laboratories believe that IOWN and 6G have the same targets for future networks. Therefore, we are investigating wireless technologies combined with optical technologies for actualizing 6G/IOWN. However, we need to obtain worldwide agreement for the future of 6G. Therefore, NTT and NTT DOCOMO are expanding 6G collaboration with world-leading vendors [4] in Japan and overseas.

Regarding the wireless technologies for 6G, it is effective to use the millimeter-wave and sub-terahertz bands to increase transmission capacity. However, we need to use a large amount of wireless equipment to transmit wireless signals. This is because radio-propagation loss increases in higher frequency bands such as millimeter-wave and sub-terahertz bands. Therefore, we also need a more flexible wireless-area design compared with conventional cellular network design. We have been investigating a new radio (NR) network topology in the space domain, as shown in **Fig. 1**. To achieve this topology, we use many remote radio units (RRUs), which consist of wireless equipment and antennas, to transmit wireless signals. Therefore, distributed multiple-input multiple-output (MIMO) is effective in transmitting



Source: NTT DOCOMO, "White Paper 5G Evolution and 6G (Version 5)," Jan. 2023.

IAB: integrated access and backhaul
RIS: reconfigurable intelligent surface

Fig. 1. Example solution of NR network topology [2].

wireless signals from different RRUs. We connect a central station (CS) to RRUs by using optical fiber because of low optical transmission loss. To use the advantages described above, we proposed a distributed MIMO system connected by analog radio over fiber (A-RoF) in higher frequency bands.

Because we construct a flexible network topology by using this NR network topology, this topology is also suitable for coverage extension involving satellites and high altitude platform stations (HAPSs) and application-area expansion.

This article introduces wireless technologies focusing on high-capacity transmission, coverage extension, application-area expansion, and low energy, which are common issues with 6G/IOWN and their future prospects [5].

2. High-capacity transmission

We now describe the distributed MIMO systems in higher frequency bands, as shown in **Fig. 2**. We use A-RoF, which connects a CS to RRUs.

2.1 A-RoF

As shown in Fig. 2, a star topology is the basic topology for A-RoF transmission. However, a cascade topology is considered from the viewpoint of network flexibility. A cascade topology uses optical power splitters and an optical multiplexer/demultiplexer. Therefore, optical transmission loss passing through these optical devices increases. Consequently, there is the problem of a limited number of connecting RRUs using a conventional cascade topology.

To solve this problem, we proposed a cascade-topology approach that involves using an optical thin-film filter. This filter enables the selected wavelength with low optical transmission loss to pass through and reflect other wavelengths, which makes it possible to increase the number of connected RRUs.

By aggregating RRUs' signal processing, which requires high energy, at a CS, A-RoF enables simple and low-power-consumption RRUs. We also investigated a remote beamforming scheme [6] and conducted an experiment of 5G-NR signal transmission, which is based on the physical specification of 5G NR developed by the 3rd Generation Partnership Project (3GPP), using the remote beamforming scheme with beam table. This experiment successfully demonstrated simultaneous 4K-video transmission in both uplink and downlink directions.

We also measured the error vector magnitude (EVM) of 5G-NR signals by using 20-km single mode fiber from a CS to RRUs. The measured EVM

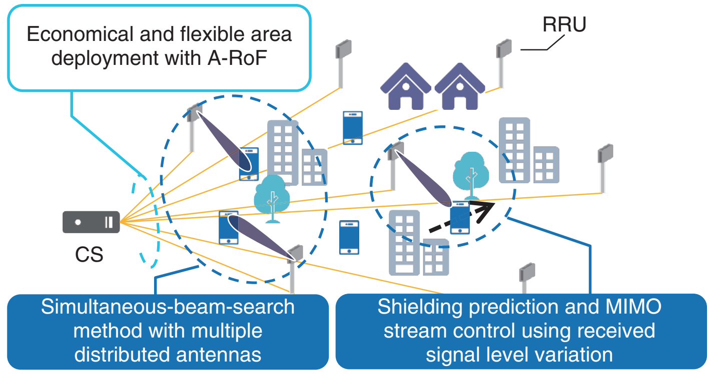
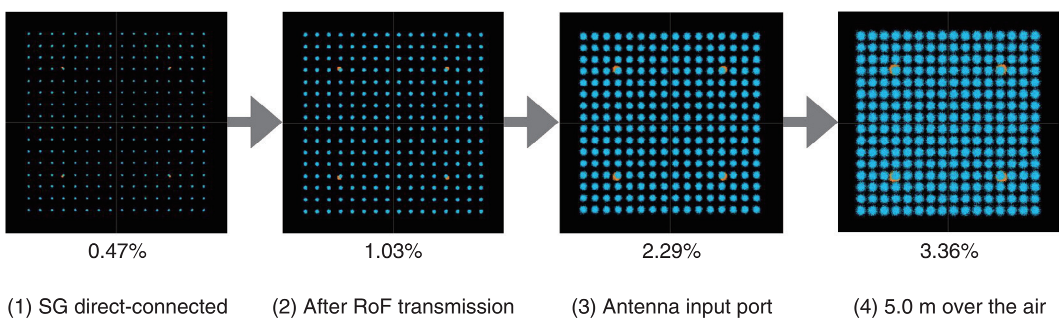


Fig. 2. Distributed MIMO systems in higher frequency bands.



SG: signal generator

Fig. 3. Measured EVM and signal constellation.

and signal constellation on each measured point of the experimental system are shown in **Fig. 3**. On the basis of the measured EVM of 5 m over the air, we confirmed about 3.36% EVM performance, which satisfies the 3.5% requirement by the 3GPP physical layer specification for 256 quadrature amplitude modulation [5].

2.2 Distributed MIMO technology

There are several issues, described in a previous study [2], that need to be addressed for developing a distributed MIMO system in higher frequency bands. To construct MIMO propagation paths, we use multiple distributed antennas as the transmitting points. This subsection introduces technologies for controlling distributed propagation paths.

To operate many RRUs effectively, high-density deployment of RRUs is required. Therefore, we also need to carry out a large amount of beam-search processing. To solve this problem, we proposed a simultaneous-beam-search method with multiple distributed antennas in RRUs that use the same frequency bands and search timing. We found that this method experimentally achieves better performance compared with the conventional method. The search time with our method is not proportional to the number of RRUs and terminals [5]. It should be noted that this method does not increase beam-search overhead resources in the time domain.

NTT, NTT DOCOMO, and NEC demonstrated a distributed MIMO system, which enables continuous wireless connections in the 28-GHz band by eliminating shielding issues [7]. This system adaptively selects connected RRUs' antennas on the basis of the environmental information of radio propagation and terminal location with the distributed-control approach. An overview of the experimental area and system is shown in **Fig. 4**. We compared A-RoF transmission with coaxial cable transmissions in terms of throughput performance. This system

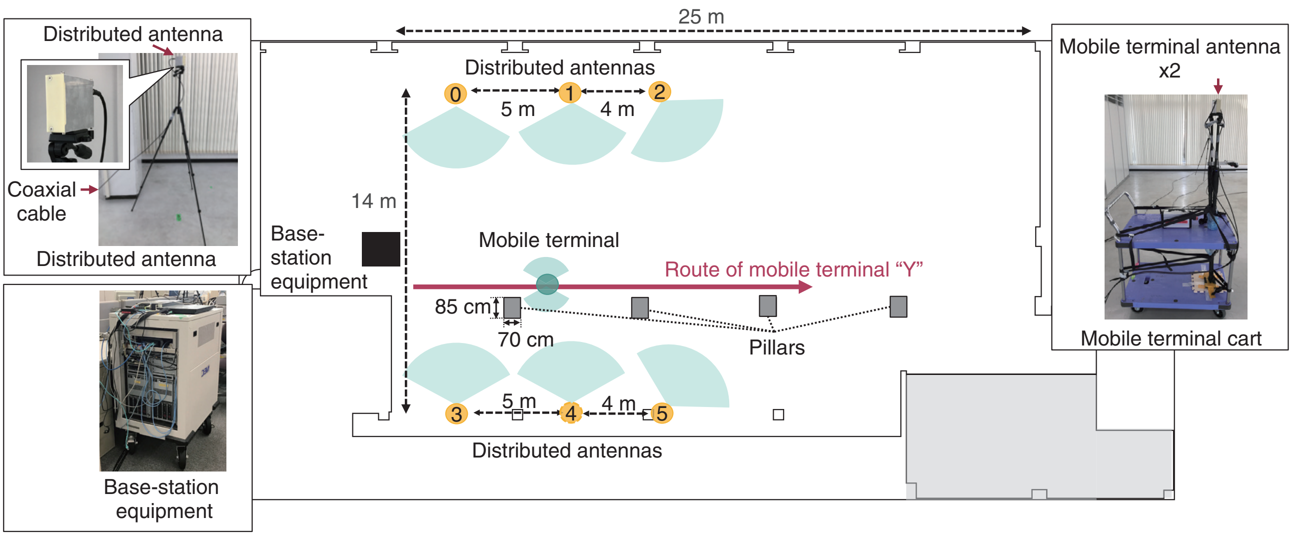


Fig. 4. Overview of the experimental area and system.

consists of distributed MIMO with A-RoF transmission, which connects a CS to two RRUs. We experimentally confirmed wireless transmission with bidirectionally time-division duplex operation in distributed MIMO using A-RoF transmission for the 28-GHz band. A-RoF transmission achieved almost the same throughput performance as coaxial cable transmissions.

3. Coverage extension

NTT is pursuing the Space Integrated Computing Network, which achieves 100% coverage area including terrestrial and non-terrestrial, by using the multi-layered non-terrestrial network (NTN) system [8]. As shown in **Fig. 5**, the multi-layered NTN system consists of geostationary orbit (GEO) satellites, low-Earth orbit (LEO) satellites, and HAPSs. Therefore, we can select the optimum wireless transmission route by taking into account the effect of radio propagation loss and channel capacity. For example, because the wireless-transmission route has increased path loss due to rain attenuation, we can control the wireless-transmission route by selecting the clear-weather route without rain attenuation. Therefore, we proposed a route-control technique to increase the channel capacity of the multi-layered NTN system [5, 8].

Satellite communication requires a high-capacity feeder-link from the satellite to earth station. This is because the satellite must transmit a huge amount of data from many terminals on Earth through the service-link. From this point of view, we studied satellite MIMO transmission of the feeder-link and developed prototype satellite MIMO equipment, which will be used in the experimental evaluation in LEO [8]. NTT has been cooperating with the Japan Aerospace Exploration Agency (JAXA) to demonstrate the practicality of satellite MIMO technology in LEO. NTT and JAXA will continue the experimental evaluation of this technology with the Innovative Satellite Technology Demonstration-4*, followed by an experimental evaluation with the Innovative Satellite Technology Demonstration-3 [5].

4. Application-area expansion

To increase the potential advantages of high-capacity transmission and coverage extension, we investigated the following two wireless technologies by focusing on application-area expansion.

The first is the base-station-selection-control technology that is based on localization information using wireless communication radio. A localization technology has attracted attention for 6G. The conventional base-station-selection technology uses the

* Innovative Satellite Technology Demonstration-4 and Innovative Satellite Technology Demonstration-3: Projects in JAXA's Innovative Satellite Technology Demonstration Program to provide opportunities for on-orbit testing of equipment and parts developed by private companies, universities, and research institutions by installing them on satellites.

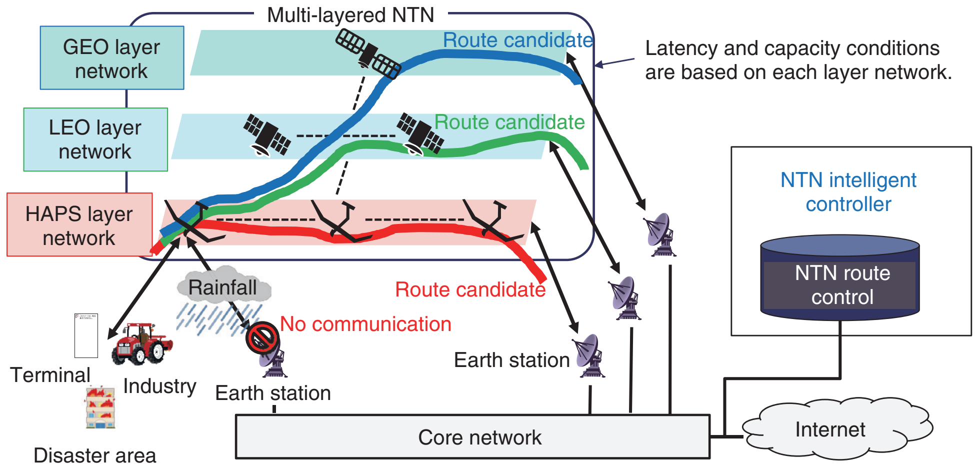


Fig. 5. Route-control technologies in the multi-layered NTN, which includes satellite and HAPS networks.

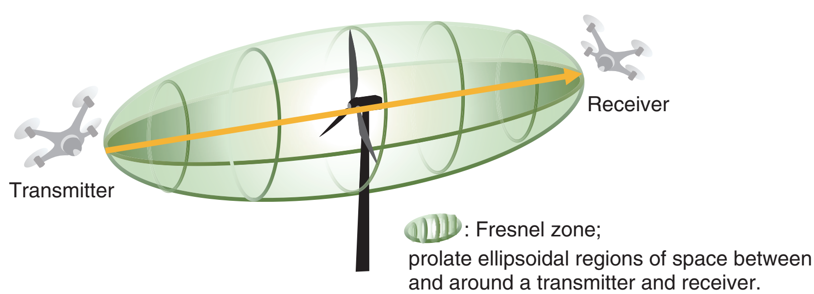


Fig. 6. Practical image of non-contact damage-inspection technology.

received-signal-power-based approach without sleep control in the base station. Our technology uses the terminal-localization information using wireless communication radio to recognize the communication area. Therefore, it enables the terminal to precisely select the base station without use of localization systems, such as the Global Positioning System. We evaluated the performance of our base-station-selection-control technology using the license-free 60-GHz band. This evaluation experiment involved using a wireless local area network system, called WiGig, located on a formula car traveling over 300 km/h as a terminal. We also conducted an experiment from the view point of low energy in base stations [9]. When the formula car approached two base stations, one base station was powered on and the other remained off. The other base station is then powered with the formula car approaching by using our localization technology. It should be noted that the formula car traveled over 260 km/h. We found that our technology decreased the active time of base stations by 60% compared with the conventional technology.

The second technology is for non-contact damage inspection of large structures [10]. We began a practical experiment on applying this technology to inspect a wind power windmill to contribute to a future carbon-neutral society. We expect good results by applying this technology to the inspection of ocean-based wind-power equipment. This technology can also be combined with the coverage-extension technologies described above.

As shown in **Fig. 6**, our non-contact inspection technology transmits a weak radio signal between two drones sandwiching the target structure (weak radio equipment can be operated without a license). Our technology detects and analyzes the variation in the received signal level at the receiver drone. Therefore, we can detect the damage on a large structure in a non-contact manner. The conventional technology requires a non-operation period because it requires on-site visual structural inspection as well as inspection from images. We plan to use our non-contact damage-inspection technology in combination with the conventional technology to shorten the non-operation period.

5. Conclusion

This article described our research and development of wireless technologies for actualizing 6G/IOWN and their future prospects. We expect to increase the performance of wireless technologies by focusing on high-capacity transmission, coverage extension, and low energy. We also expect to expand the application area of wireless technologies by achieving these targets.

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A Report on ASTAP and WTSA-24 Regional Preparatory Meeting

Hiroshi Yamamoto and Jiro Nagao

Abstract

The 35th ASTAP (Asia-Pacific Telecommunity (APT) Standardization Program) Forum was held at the Royal Orchid Sheraton Hotel and Towers in Bangkok, Thailand from April 17 to 20, 2023, and on the following day, the 1st meeting of the APT Preparatory Group for WTSA-24 (World Telecommunication Standardization Assembly 2024) was held. We report on the status of each conference and the main results of each.

Keywords: APT, ASTAP, WTSA-24

1. ASTAP overview

The Asia-Pacific Telecommunity (APT), an international organization promoting the development of information and communication technology (ICT) in the Asia-Pacific region, was established in 1979 and has 38 member countries [1].

The APT Standardization Program (ASTAP), which promotes standardization activities in the APT, was established in 1998 [2]. The main objectives are (1) to contribute to international standardization by building a cooperative and collaborative system for standardization within the APT region, (2) nurture standardization activists within the APT region and support the development of ICT skills among members within the region, especially those from developing countries, and (3) co-propose as a regional standardization organization to international standardization organizations such as the International Telecommunication Union (ITU). It is important to use ASTAP as a platform to build camaraderie in the APT region and contribute to developing countries, and as a strategic platform for Japan for international collaboration in standardization activities.

The 35th ASTAP Forum (ASTAP-35) was held at the Royal Orchid Sheraton Hotel and Towers in Bangkok, Thailand from April 17 to 20, 2023, with a total of 179 participants, which includes 123 on-site participants, 27 sponsoring members, and 7 participants from other international organizations in 24 APT member countries.

1.1 ASTAP's new management team

At the ASTAP-35, Dr. Hyoung Jun Kim (Electronic & Telecommunications Research Institute (ETRI)) of the Republic of Korea was appointed as the ASTAP chair, and Mr. Xiaoyu You (China Academy of Information and Communications Technology (CAICT)) of China and Dr. Hideyuki Iwata (Telecommunication Technology Committee (TTC)) of Japan were appointed as vice chairs for the second term. Among the executives of the Working Groups (WGs) and Expert Groups (EGs) under the WGs, the replacement regarding Japan of Mr. Noriyuki Araki (NTT) with Dr. Hideo Imanaka (National Institute of Information and Communications Technology (NICT)) as the chair of EG DRMRS (Disaster Risk Management and Relief System) and the replacement of Ms. Miho Naganuma (NEC) with Mr. Hiroshi Takechi (NEC) as the chair of EG IS (Security) were approved. **Table 1** shows the new management team.

1.2 Industry Workshop

On the first day of the ASTAP-35, an Industry Workshop was held under the theme "AI (artificial intelligence), Metaverse, Open Source." From Japan, Mr. Leon Wong from Rakuten Mobile, Dr. Hideo Imanaka from NICT, and Dr. Masahisa Kawashima

Table 1. ASTAP management team. (the chairs/vice chairs elected from Japan are indicated in bold)

Group	Chairs	Vice Chairs
Plenary	Dr. Hyoung Jun Kim (Korea)	**Dr. Hideyuki Iwata (TTC, Japan)** Mr. Xiaoyu You (China)
WG Policy and Strategic Co-ordination (WG PSC)	Mr. Dao Ngoc Tuyen (Viet Nam)	**Mr. Kaoru Kenyoshi (NICT, Japan)** Mr. Tong Wu (China)
Expert Group Bridging the Standardization Gap (EG BSG)	Mr. Dao Ngoc Tuyen (Viet Nam)	Mr. Ki-Hun Kim (Korea) **Mr. Masatoshi Mano (TTC, Japan)**
Expert Group Green ICT and EMF Exposure (EG GICT&EMF)	Dr. Sam Young Chung (Korea)	Mr. Min Prasad Aryal (Nepal) Mr. Nur Akbar Said (Indonesia) Mr. Uttachai Mannontri (Thailand)
Expert Group ITU-T Issues (EG ITU-T)	**Mr. Kaoru Kenyoshi (NICT, Japan)**	Mr. Quoc Binh Tran (Viet Nam)
Expert Group Policies, Regulatory and Strategies (EG PRS)	No candidate	
WG Network and System (WG NS)	Dr. Joon-Won Lee (Korea)	**Dr. Hiroyo Ogawa (NICT, Japan)**
Expert Group Future Network and Next Generation Networks (EG FN&NGN)	Dr. Joon-Won Lee (Korea)	**Mr. Kazunori Tanikawa (NICT, Japan)**
Expert Group Seamless Access Communication Systems (EG SACS)	**Dr. Hiroyo Ogawa (NICT, Japan)**	
Expert Group Disaster Risk Management and Relief System (EG DRMRS)	**Dr. Hideo Imanaka (NICT, Japan)**	
WG Service and Application (WG SA)	**Ms. Miho Naganuma (NEC, Japan)**	Dr. Jee-In Kim (Korea)
Expert Group Internet of Things Application/Services (EG IOT)	**Dr. Toru Yamada (NEC, Japan)**	Dr. Seung-yun Lee (Korea) Ms. Li Haihua (China)
Expert Group Security (EG IS)	**Mr. Hiroshi Takechi (NEC, Japan)**	Dr. Heuisu Ryu (Korea)
Expert Group Multimedia Application (EG MA)	**Dr. Hideki Yamamoto (OKI, Japan)**	Dr. Dong il Seo (Korea)
Expert Group Accessibility and Usability (EG AU)	Dr. Jee-In Kim (Korea)	Ms. Wantanee Phantachat (Thailand)

from NTT spoke at the AI session, Metaverse session, and Open Source session, respectively. **Table 2** lists the workshop topics.

1.3 Outcome document

At the plenary meeting, final approval was given to 17 deliverables that had been discussed by the EGs and subsequently agreed by the WGs.

2. APT WTSA-24 Preparatory Group

Following the ASTAP-35, the 1st meeting of the APT Preparatory Group for World Telecommunication Standardization Assembly 2024 (WTSA-24) was held on April 21, 2023, with a total of 127 participants, including 86 from 19 national administrations, 12 supporting members, and 18 from 3 international organizations.

The APT WTSA-24 Preparatory Group is positioned as the preparatory meeting for WTSA-24 (to be held in New Delhi, India, in October 2024) among the APT member states (38 countries), and the 1st meeting discussed management systems. From Japan, Dr. Hideyuki Iwata of the TTC was appointed as vice chair, Mr. Hiroshi Yamamoto of NTT (one of authors) as the chair of WG1 (ITU-T Working Methods), Ms. Miho Naganuma of NEC as vice chair of WG2 (ITU-T Work Organization), and Ms. Eriko Hondo of KDDI as vice chair of WG3 (Regulatory/Policy and Standardization Related Issues). **Table 3** shows the management team of the APT WTSA-24 Preparatory Group.

3. Future plans

In preparation for WTSA-24, the APT is planning a total of 5 regional preparatory meetings, with the second preparatory meeting scheduled to be held online in late January 2024.

Table 2. Industry Workshop topics. (the speakers from Japan are underlined)

Program of ASTAP Industry Workshop
Introductory Remarks by Mr. Xiaoyu You ASTAP Vice Chair/Industry Workshop Committee Member
Session 1: AI technology and standardization Chair: Ms. Miho Naganuma, NEC Corporation, Japan • AI Standard Development and Potential Collaboration by Dr. Kangchan Lee, Director, ETRI, Rep. of Korea • Ethically Aligned Design of AI for Human Well-being by Dr. Kishik Park, President, Policy Research Institute for Human Dignity, Rep. of Korea • ITU AI/ML 5G Challenge: Open platform for Datasets, Problem Statements and Pre-standards research by Mr. Vishnu Ram Ov, Vice Chair of ITU-T FG AN, ITU • Chat GPT: Pinnacle of Conversational AI and its Impact on Modern Industries by Ms. Zhang Weimin, Senior Engineer, CAICT, PR China • <u>ITU-T Focus Group on Autonomous Network by Mr. Leon Wong, Research Engineering Lead, Rakuten Mobile, Inc., Japan</u> • Development of AI Technology and Market in China by Dr. Yuntao Wang, Deputy Chief Engineer, CAICT, PR China
Session 2: Metaverse Chair: Dr. Toru Yamada, NEC Corporation, Japan • <u>Standardization of Metaverse (ITU-T FG-MV) by Dr. Hideo Imanaka, Managing Expert, NICT, Japan</u> • Embracing the Metaverse – What challenges to cope with and how? by Ms. Yuan Zhang, Director of AI Research Center, China Telecom, PR China • Metaverse Trends and Standard Requirements by Dr. Younghwan Choi, Senior Research Staff, ETRI, Rep. of Korea
Session 3: Open-Source Chair: Dr. Seungyun Lee, ETRI, Rep. of Korea • New kind of License issue with Open-Source Software by Mr. Yong Joon Joe*, Director, LSware Inc., Rep. of Korea • <u>Open Infrastructure Consortia and Open-Source Software by Dr. Masahisa Kawashima, IOWN Technology Director, NTT, Japan</u> • Driving AI Innovation via Open-Source Practices by Ms. Liya Yuan, Senior Engineer, ZTE, PR China
Conclusion of Industry Workshop by Mr. Xiaoyu You, ASTAP Vice Chair/Industry Workshop Committee Member

Table 3. APT WTSA-24 Preparatory Group management team. (the chairs/vice chairs elected from Japan are indicated in bold)

APT WTSA-24	Chairs	Vice Chairs
Plenary	Dr. Hyoung Jun Kim (Korea)	**Dr. Hideyuki Iwata (TTC, Japan)** Mr. Sushil Kumar (India) Mr. Xu Heyuan (China) Mr. Behzad Ahmadi (Iran)
Working Group	WG Chairs	WG Vice Chairs
WG1: ITU-T Working Methods	**Mr. Hiroshi Yamamoto (NTT, Japan)**	Ms. Minah Lee (Korea) Mr. Wu Tong (China) Mr. Abhay Shanker Verma (India) Ts. Norzailah Mohd Yusoff (Malaysia)
WG2: ITU-T Work Organization	Dr. Kangchan Lee (Korea)	**Ms. Miho Naganuma (NEC, Japan)** Mr. Arun Agarwal (India) Mr. Qu Zhicheng (China) Mr. Do Xuan Binh (Viet Nam)
WG3: Regulatory/Policy and Standardization Related Issues	Mr. Li Cheng (China)	**Ms. Eriko Hondo (KDDI, Japan)** Mr. Kihun Kim (Korea) Mr. Avinash Agarwal (India) Mr. Dao Ngoc Tuyen (Viet Nam)

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Hiroshi Yamamoto
Director, Standardization Office, Research and Development Planning Department, 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 NTT Group's standardization activities.

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

He received a Ph.D. in information science from Nagoya University, Aichi, in 2007 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 2019, he has contributed to the international standardization efforts on immersive live experience (ILE) of ITU-T Study Group 16. He served as an editor of ITU-T H.430.4 (ex H.ILE-MMT) and H.430.5 (ex H.ILE-PE) from 2019 to 2020. He received the ITU Association of Japan Encouragement Award in 2021. He is currently an associate rapporteur of ITU-T Study Group 16 Question 8 (Immersive Live Experience, since 2022) and the leader of ILE Sub Working Group of the Telecommunication Technology Committee (since 2020). He is a member of the Institute of Electrical and Electronics Engineers (IEEE), Institute of Electronics, Information and Communication Engineers (IEICE), and the Japanese Society of Medical Imaging Technology (JAMIT).

External Awards

IEEE SLT 2022 Best Reviewer Award
Winner: Naohiro Tawara, NTT Communication Science Laboratories
Date: January 12, 2023
Organization: 2022 IEEE Spoken Language Technology Workshop (SLT 2022)

Distinguished Paper Award
Winners: Ayaka Sano, Motohiro Makiguchi, Takahiro Matsumoto, Hisashi Matsukawa, Ryuji Yamamoto, NTT Human Informatics Laboratories
Date: May 23, 2023
Organization: Society for Information Display

For "Mirror-Transcending Aerial-imaging (MiTAi): An Optical System that Freely Crosses the Boundary between Mirrored and Real Spaces."
Published as: A. Sano, M. Makiguchi, T. Matsumoto, H. Matsukawa, and R. Yamamoto, "Mirror-Transcending Aerial-imaging (MiTAi): An Optical System that Freely Crosses the Boundary between Mirrored and Real Spaces," Journal of the Society for Information Display, Vol. 31, No. 5, pp. 220–229, 2023.

Top 3% Paper Recognition
Winners: Taishi Nakashima, Tokyo Metropolitan University; Rintaro Ikeshita, NTT Communication Science Laboratories; Nobutaka Ono, Tokyo Metropolitan University; Shoko Araki, NTT Communication Science Laboratories; Tomohiro Nakatani, NTT Communication Science Laboratories;
Date: June 4, 2023
Organization: The 2023 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP 2023)

For "Fast Online Source Steering Algorithm for Tracking Single Moving Source Using Online Independent Vector Analysis."
Published as: T. Nakashima, R. Ikeshita, N. Ono, S. Araki, and T. Nakatani, "Fast Online Source Steering Algorithm for Tracking Single Moving Source Using Online Independent Vector Analysis," Proc. of ICASSP 2023, Rhodes, Greece, June 2023.

Top 3% Paper Recognition
Winners: Takatomo Kano, NTT Communication Science Laboratories; Atsunori Ogawa, NTT Communication Science Laboratories; Marc Delcroix, NTT Communication Science Laboratories; Roshan Sharma, Carnegie Mellon University; Kohei Matsuura, NTT Human Informatics Laboratories; Shinji Watanabe, Carnegie Mellon University
Date: June 4, 2023
Organization: ICASSP 2023

For "Speech Summarization of Long Spoken Document: Improving Memory Efficiency of Speech/Text Encoders."
Published as: T. Kano, A. Ogawa, M. Delcroix, R. Sharma, K. Matsuura, and S. Watanabe, "Speech Summarization of Long Spoken Document: Improving Memory Efficiency of Speech/Text Encoders," Proc. of ICASSP 2023, Rhodes, Greece, June 2023.

Best Paper Award
Winners: Kenichi Fujita, NTT Human Informatics Laboratories; Takanori Ashihara, NTT Human Informatics Laboratories; Hiroki Kanagawa, NTT Human Informatics Laboratories; Takafumi Moriya, NTT Human Informatics Laboratories; Yusuke Ijima, NTT Human Informatics Laboratories
Date: June 10, 2023
Organization: ICASSP 2023 Workshop on Self-supervision in Audio, Speech and Beyond (SASB 2023)

For "Zero-shot Text-to-speech Synthesis Conditioned Using Self-supervised Speech Representation Model."
Published as: K. Fujita, T. Ashihara, H. Kanagawa, T. Moriya, and Y. Ijima, "Zero-shot Text-to-speech Synthesis Conditioned Using Self-supervised Speech Representation Model," Proc. of SASB 2023, Rhodes, Greece, June 2023.

IEEE Photonics Society 2023 William Streifer Scientific Achievement Award
Winner: Shinji Matsuo, NTT Device Technology Laboratories
Date: June 20, 2023
Organization: IEEE Photonics Society

For contributions to ultra-high speed, low power consumption membrane lasers and their heterogeneous integration.

Outstanding Reviewer Recognition
Winner: Atsushi Ando, NTT Human Informatics Laboratories
Date: June 21, 2023
Organization: ICASSP 2023

Best Paper Award in Industry Innovation
Winner: Jin Uchiyama, NTT Access Network Service Systems Laboratories
Date: July 4, 2023
Organization: The 28th Optoelectronics and Communications Conference (OECC 2023)

For "An Evaluation of Cost-efficiency by Extending ROADM-based Metro-access Converged Optical Networks to Cover Point-to-multipoint Connections."
Published as: J. Uchiyama, R. Koma, K. Hara, J. Kani, and T. Yoshida, "An Evaluation of Cost-efficiency by Extending ROADM-based Metro-access Converged Optical Networks to Cover Point-to-multipoint Connections," OECC 2023, Shanghai, China, July 2023.